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Climate Change Adaptation and Economic Resilience in Central and Eastern Europe: A Comparative Institutional and Policy Analysis

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Abstract

This article explores how a group of Central and Eastern European (CEE) countries, including Czechia, Hungary, Poland, Romania, and the Baltic States, are navigating the challenge of adapting to climate change. Rather than offering a one-size-fits-all account, it looks at what adaptation really means in practice: how institutions are stepping up (or falling short), how EU funds are being put to use, and how different sectors, particularly agriculture, are responding on the ground. The analysis focuses on the structures, tools, and behavioral patterns that shape climate resilience, paying close attention to micro-level decisions by farmers, households, and small businesses. Drawing on institutional and policy analysis, as well as insights from behavioral economics, the paper highlights both the momentum and the stumbling blocks facing adaptation across the region.

Keywords: climate change adaptation, economic resilience, Central and Eastern Europe, climate policy, public institutions, behavioral economics, EU funding, agriculture, comparative analysis, adaptation strategies

JEL: D91, H43, O13, Q18, Q54, Q58, R58

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Introduction

Climate change is undoubtedly one of the defining challenges of our time, affecting not only ecosystems but also economies and societies at large (IPCC 2022, pp. 1755–1790). In Central and Eastern Europe (CEE), its impacts are particularly noticeable due to the region's uneven economic development, legacy infrastructure issues, and sectoral vulnerabilities, especially in agriculture, energy, and water management (European Environment Agency 2021, pp. 6–9). More frequent and intense weather extremes, such as droughts, heatwaves, floods, and storms, are already causing crop losses, disrupting supply chains, and pushing up the costs of insurance and public infrastructure (World Bank 2022, pp. 22–24). At the same time, European Union (EU) countries in the region are under increasing pressure to align with the European Green Deal and broader climate neutrality goals (European Commission 2020, pp. 6–13). Yet the readiness of institutions, the effectiveness of public policies, and the ability to absorb EU funds vary widely from country to country (Bassi and Domínguez 2021, pp. 8–10). Moreover, the lack of long-term policy consistency, gaps in data, and behavioral barriers, especially among farmers and small businesses, limit how quickly and effectively these societies can adapt (Grothmann and Patt 2005, pp. 201–203).

The contribution of this article is threefold. First, it advances the theoretical and empirical debate by combining institutional economics, adaptation policy analysis, and behavioral economics to explain both structural and micro-level dynamics of adaptation in post-socialist economies. Second, it provides new empirical insights through a comparative case study of five CEE countries Czechia, Hungary, Lithuania, Poland, and Romania which, despite their shared communist past and common EU membership, display significant variation in institutional capacity, adaptation performance, and policy effectiveness. Lithuania, for instance, is analyzed as a representative case of the Baltic region, where adaptation has been closely tied to spatial planning (Bassi and Domínguez 2021, pp. 14–20). Third, the paper derives policy-relevant lessons for strengthening economic resilience, with particular emphasis on EU funding instruments and the role of behavioral factors in shaping adaptation outcomes.

Unlike prior studies, this paper integrates institutional and behavioral dimensions into a comparative index of resilience for CEE countries. While previous research often examined these perspectives separately, focusing either on institutional capacity or on behavioral barriers, this study combines them within a unified analytical framework. This integrated approach provides a more comprehensive understanding of how structural and cognitive factors jointly shape adaptation outcomes across diverse post-socialist economies.

Against this backdrop, the article addresses the following research questions:

What national climate adaptation strategies have been adopted in selected CEE countries, and how are they being rolled out at institutional and sectoral levels? (addressed in Section 5, with further comparison in Section 8)

1. To what extent have EU financial instruments (e.g., RDP – Rural Development Programme; LIFE – Programme for the Environment and Climate Action (LIFE Programme); RRF – Recovery and Resilience Facility and domestic public policies contributed to measurable improvements in macroeconomic resilience and sectoral adaptation? (Addressed in Sections 5.2, 6.2, and 7 – Absorption of EU Funds)
2. Where do countries diverge or align in terms of adaptation performance and the ability to manage climate-related threats? (Addressed in Section 6 – Comparative Analysis, and Section 7 – Sectoral Vulnerability Shifts and Resilience Indicators)
3. How do behavioral and psychological factors influence the adaptation choices of farmers, businesses, and households in the CEE region? (Addressed in Sections 4.1 and 8, with policy implications in Section 9)

Methodologically, the article employs a comparative case study approach involving five CEE countries: Czechia, Hungary, Lithuania, Poland, and Romania. The analysis draws on national adaptation strategies, planning documents, and datasets from Eurostat, the OECD, and the World Bank, as well as information on public spending and EU-funded programs. It also considers legal and institutional contexts, together with barriers and enablers of adaptation at the micro level, informed by behavioral research and expert analyses (IPCC 2022, pp. 1755–1790).

By explicitly linking these research questions to the structure of the paper, the study ensures that each one is systematically addressed in the subsequent analysis. Section 2 reviews the literature on climate adaptation, resilience, and behavioral dimensions of decision-making. Section 3 develops the theoretical framework, while Section 4 presents the methodology and data sources. Sections 5–7 provide the empirical analysis of national strategies, EU funds, sectoral and macroeconomic outcomes, as well as behavioral barriers. Section 8 offers a comparative discussion, and Section 9 concludes, providing policy recommendations.

Literature Review

Over the last twenty years, the academic conversation around climate change adaptation has grown significantly, not just in volume, but also in depth and diversity. What began as a mostly economic and environmental issue has gradually evolved into a genuinely multidisciplinary field, weaving together threads from economic modeling, governance theory, and behavioral science (Adger, Arnell, and Tompkins 2009; Sovacool, Linnér, and Goodsite 2015). This evolution reflects a growing recognition: adapting to climate change is anything but straightforward; it is as much about institutions and incentives as it is about rainfall and temperature.

A key turning point in shaping how we think about adaptation came with the publication of The Stern Review (Stern 2007), which made a compelling case for early, proactive investment in both mitigation and adaptation. More than just running the numbers, Stern underscored the moral and economic consequences of delay, laying the groundwork for how cost-benefit thinking is now applied in climate policy. However, the Review has also been criticized for its normative stance and reliance on specific discount rate assumptions that continue to fuel debate (Hallegatte et al. 2012).

Building on that momentum, Hallegatte et al. (2012) introduced the idea of decision-making under deep uncertainty, which moves us beyond rigid forecasting into the realm of flexible, adaptive strategies. While approaches like "no-regret" or "robust" planning are useful in highly uncertain contexts, these strategies often remain at the conceptual level, with limited evidence of systematic integration into policymaking in CEE (European Environment Agency 2021).

On the modeling front, Bosello, Carraro, and De Cian (2013) examined how mitigation and adaptation can either clash or complement one another in computable general equilibrium models. Their findings highlight a crucial point for fiscally constrained economies: climate policy works best when it is balanced and diversified. Similarly, de Bruin, Dellink, and Tol (2009), who embedded adaptation into the AD-DICE model (AD-DICE – Adaptation Dynamic Integrated model of Climate and the Economy), provided a more nuanced picture of how climate damages play out across different investment scenarios. Yet both approaches face limitations: they often treat adaptation as an aggregated variable, thereby overlooking institutional fragmentation and the behavioral inertia that constrain implementation in practice (Dupuis and Biesbroek 2013).

Institutional thinking has also played a major role. North's (1990) theory of institutional change remains a cornerstone for understanding why good intentions often do not translate into action. Building on his insights, scholars like Biesbroek et al. (2013) and Dupuis and Biesbroek (2013) have shown how fragmented institutions, low political will, and complex bureaucracies tend to trip up adaptation efforts – a pattern particularly visible in post-socialist CEE countries. Nonetheless, these studies frequently stop short of providing solutions for how to overcome such barriers in contexts marked by limited administrative capacity and unstable political environments.

The behavioral side of the puzzle is equally important. Grothmann and Patt (2005) developed a much-cited model of how individuals, from farmers to small business owners, respond to climate risks. They point to a critical insight: people do not always act rationally. Risk perception, heuristics, and beliefs about adaptive capacity often matter more than economic logic. This framework has since been expanded by institutions like the OECD (2017), which explored how communication and incentives might nudge people toward smarter choices. However, empirical evidence on how such behavioral insights translate into real adaptation uptake in CEE remains scarce.

Recent empirical work has examined regional differences. Kalkuhl and Wenz (2020) found that heat-related economic losses are heavily concentrated in poorer, agriculture-reliant areas, many of which are in CEE countries. These findings stress that adaptation must be tailored, not

templated, taking into account differences in exposure, vulnerability, and institutional strength. However, much of this research still focuses on macro-level outcomes, leaving micro-level dynamics and sectoral resilience underexplored.

Beyond economic and behavioral dimensions, newer strands of the literature have addressed the political economy of adaptation (Sovacool, Linnér, and Goodsite 2015), climate finance architecture (Fankhauser and Burton 2011), and the challenge of aligning policies across sectors (Adger, Arnell, and Tompkins 2009). While these contributions underline the complexity of adaptation, they also reveal a gap: few studies combine institutional, financial, and behavioral perspectives in a comparative regional context.

In sum, while the literature now offers a rich and dynamic foundation for thinking about climate adaptation, it often remains fragmented across disciplines and levels of analysis. Key gaps include (i) insufficient empirical evidence on how EU funds shape resilience outcomes in CEE, (ii) limited integration of behavioral economics into adaptation policy, and (iii) a lack of comparative insights on how post-socialist institutional legacies affect adaptive capacity. This study seeks to address these gaps by bringing together economic analysis, institutional diagnostics, and behavioral insights to better understand what adaptation looks like and what constrains it in the specific and diverse context of CEE.

Theoretical Framework

Adaptation Economics and the Resilience of Economic Systems

Adaptation economics, which has emerged as a central strand within environmental and climate economics, addresses a fundamental question: how can societies identify, evaluate, and implement measures that reduce the economic and social costs of climate change? At its core, this field examines the capacity of economies to adjust to new climatic conditions by investing in resilient infrastructure, reforming policy frameworks, and strengthening institutional systems that support long-term adaptation (Stern 2007; European Commission 2023a). Recent updates to the EU Adaptation Strategy emphasize these themes, highlighting the need for proactive, evidence-based, and behaviorally informed adaptation policies aligned with the European Green Deal and new Common Agricultural Policy of the European Union CAP 2023–2027 mechanisms (DG AGRI 2023; European Commission 2023b).

A clear conceptual foundation is, therefore, essential for analyzing how economic systems respond to climate-related shocks. In the literature, the terms resilience, adaptive capacity, and institutional preparedness are sometimes used interchangeably, despite representing analytically distinct dimensions of climate response (North 1990; IPCC 2022). Resilience refers to an economic or socio-institutional system's overall ability to withstand climatic disturbances, limit losses, and restore essential functions after a shock (IPCC 2022). Adaptive capacity denotes the resources, skills, behavioral dispositions, and institutional arrangements that enable individuals, firms, and public authorities to adjust their practices in response to actual or expected impacts (Grothmann and Patt 2005; Hallegatte et al. 2012). Institutional preparedness captures the coherence of strategic frameworks, administrative capacity, and coordination mechanisms required for effective adaptation (Biesbroek et al. 2013;

Dupuis and Biesbroek 2013). While interconnected, these concepts operate at different analytical levels: adaptive capacity reflects potential, institutional preparedness describes enabling conditions, and resilience represents observable performance under climatic stress.

To provide a structured analytical basis for cross-country comparison, this study adopts the widely used three-stage typology of resilience (Adger, Arnell, and Tompkins 2009; IPCC 2022). Absorptive resilience concerns the capacity to buffer shocks through existing mechanisms such as flood defenses, emergency response systems, or insurance markets, which help reduce immediate economic losses (European Environment Agency 2021). Adaptive resilience reflects the ability to adjust behaviors, technologies, and institutional practices over time, for example, by adopting irrigation, diversifying energy sources, or strengthening multi-level governance – areas increasingly supported under CAP 2023–2027's eco-schemes and risk-management instruments (DG AGRI 2023). Transformative resilience involves deeper structural change when incremental measures are insufficient, including reconfigurations of governance systems, land-use patterns, or sectoral structures (Sovacool, Linnér, and Goodsite 2015; IPCC 2022). Recent behavioral research further suggests that transformation also requires overcoming cognitive barriers, risk misperceptions, and institutional distrust, underscoring the behavioral dimension of resilience (Beauchamp 2023; D'Adda 2023).

Applying this typology to CEE helps explain why countries may hold comprehensive formal strategies yet continue to exhibit high vulnerability: absorptive and adaptive mechanisms may exist, but transformative reforms often lag behind, reflecting persistent implementation gaps, behavioral obstacles, and institutional path dependencies typical of post-socialist governance systems (North 1990; Biesbroek et al. 2013). In this context, the notion of resilience has gained prominence in economic debates, emphasizing not only the capacity to withstand shocks but also to maintain essential economic functions such as stable employment, fiscal balance, and continuity of production during extreme weather events (IPCC 2022; World Bank 2022).

Adaptation economics is particularly relevant today because it evaluates both the benefits of timely adaptation and the costs of inaction. By weighing these trade-offs, it provides policymakers with a clearer understanding of the expected returns to investment in resilience-enhancing measures (European Environment Agency 2021; European Commission 2023b). It also highlights the challenges of allocating scarce public resources when there is deep uncertainty and rapidly evolving climate risks, a central concern in current EU discussions on climate finance, CAP reforms, and national adaptation planning (Hallegatte et al. 2012; OECD 2023).

Institutional Mechanisms Shaping Adaptive Behavior

To understand adaptation in CEE, we must demonstrate not only that institutions matter, but also how they drive behavioral responses to climate risks. Institutions shape adaptive behavior through several channels that reduce cognitive burdens, stabilize expectations, and lower the perceived risks associated with long-term investments (North 1990; Grothmann and Patt 2005). Effective institutional frameworks streamline decision-making by providing clear signals about acceptable practices, reliable incentives, and predictable outcomes. In this sense,

adaptation-related behavior is not solely a function of individual preferences or risk perceptions but emerges from the interaction between cognitive processes and institutional environments.

One of the central mechanisms involves the role of default rules embedded in public programmed, regulatory frameworks, and financial instruments. Defaults act as behavioral anchors: when irrigation insurance is automatically included in agricultural support packages, or when climate-resilient infrastructure guidelines are standardized in building codes, individuals and firms tend to adopt these options without requiring additional motivation or extensive evaluation. This behavioral effect is particularly relevant in contexts of limited administrative capacity, where simplifying choices may significantly increase uptake of adaptive practices.

Institutions also shape social norms around adaptation. Advisory services, extension networks, and professional associations can diffuse information on recommended practices and generate reputational incentives for farmers or firms to comply with emerging standards. Social norms reinforce perceptions of what constitutes responsible behavior, reducing the uncertainty associated with investing in new technologies or altering production patterns. In environments where climate information is scarce or inconsistent, informal norms may be as influential as formal regulations in driving behavioral change.

Another mechanism relates to trust-based compliance, which is critical in post-socialist countries characterized by historically low trust in public administration. Trust influences how individuals interpret policy signals, assess institutional credibility, and decide whether public incentives are reliable enough to justify long-term adaptation investments. Where institutions demonstrate transparency, consistency, and support, compliance tends to increase. Conversely, institutional instability frequent policy reversals, administrative fragmentation, or inconsistent enforcement reduces trust and amplifies behavioral inertia, even when adaptation measures are economically beneficial.

These mechanisms create important feedback loops. Low absorption of EU adaptation funds reduces the visible effectiveness of public policy, which in turn weakens institutional credibility and diminishes trust in climate programs. As trust declines, willingness to participate in public schemes also decreases, leading to lower adoption of adaptive measures, weaker project pipelines, and further difficulties in absorbing funds. This self-reinforcing cycle helps explain why certain CEE countries exhibit large discrepancies between formal adaptation strategies and actual behavioral uptake of resilience measures. Institutional and behavioral deficiencies thus reinforce each other, creating persistent adaptation gaps that cannot be resolved solely through additional funding or regulatory adjustments.

Institutional and Behavioral Dimensions of Adaptation

Recent research has made it increasingly clear: when it comes to climate adaptation, weak institutions constitute major obstacles. In many post-socialist countries, fragmentation across administrative levels and a lack of policy continuity have consistently undermined the effectiveness of adaptation efforts (Bosello, Carraro, and De Cian 2013, pp. 2–4).

But the problem does not stop at governance structures. Even when technical solutions exist, they are not always embraced, and that has a lot to do with human behavior. Behavioral inertia among key actors, whether in government or industry, tends to persist. That inertia is made worse when there are no strong peer networks to learn from, or when there's a lack of visible "early adopters" to set an example (de Bruin, Dellink, and Tol 2009, pp. 65–68).

The reality is that adaptation isn't just a matter of economics or technology; it is also deeply rooted in how institutions function and how people think and act. Institutional economics reminds us that both formal rules (like regulations and strategies) and informal norms (like organizational culture or social expectations) play a major role in shaping how adaptive a system can be (North 1990, pp. 36–45). In the CEE region, key elements such as the quality of public administration, coordination across sectors, transparency in decision-making, and the extent to which climate policies are decentralized all influence outcomes (Bassi and Domínguez 2021, pp. 19–30).

At the same time, behavioral economics has been gaining traction as a tool to explain why people, including farmers, business owners, and even policymakers, sometimes hesitate to adapt, even when the economic case is strong. Factors like how individuals perceive climate risks, their reliance on mental shortcuts (heuristics), limited cognitive bandwidth, or just a preference for the status quo, all come into play (Grothmann and Patt 2005, pp. 201–205). Add to that the general uncertainty surrounding the scale and speed of climate change, combined with limited access to reliable information and a lack of trust in institutions, and it's easy to see why inaction often wins out (IPCC 2022, pp. 1798–1805).

All this points to one conclusion: we need a more integrated approach that brings together both institutional and behavioral perspectives. Only then can we fully grasp the diverse range of adaptive capacities across the CEE region and begin to break down the real-world barriers that hold back effective climate adaptation policies.

Methodology

Comparative Case Study Analysis

This study takes a comparative look at five CEE countries: Czechia, Hungary, Lithuania, Poland, and Romania. These countries were not chosen at random. They all share key features: EU membership, similar stages of economic development, and sectoral structures that leave them particularly exposed to the risks of climate change (Bassi and Domínguez 2021, pp. 8–9). What especially interests us here is how prepared their institutions are for adaptation, how coherent their national strategies really are, and whether existing support tools are actually delivering on the ground.

To do this, we use a mixed approach. On the one hand, we investigate official policy documents and planning frameworks. On the other hand, we look closely at macro-level and sector-specific data to understand the broader economic context. However, the story does not end there. We also include behavioral factors, like how people perceive climate risks, and how willing they are to take

adaptive action. That includes insights into how farmers and small business owners make decisions in the face of uncertainty (Grothmann and Patt 2005, p. 204).

Data Sources: Eurostat, World Bank, OECD, National Adaptation Strategies

The quantitative side of this study draws on a range of trusted sources. We used data from Eurostat, covering aspects such as greenhouse gas emissions, the role of agriculture in national economies, and investment patterns. From the OECD, we used indicators related to public policy and governance quality, while the World Bank provided regional insights on climate risks and adaptation-related investments. Finally, we also looked at country-specific strategic documents, such as National Adaptation Plans (NAPs) and National Energy and Climate Plans (NECPs) (European Commission 2020, pp. 6–13).

To ensure we did not rely too heavily on just one type of evidence, we used a triangulation approach. That means we combined hard data with a closer look at policy content, institutional arrangements, and expert commentary, drawing on scientific publications and technical reports to put the numbers into proper context (IPCC 2022, pp. 1755–1790).

Given the limited availability of harmonized behavioral datasets across the region, the study required a transparent operationalization of behavioral constructs derived from adaptation theory. In particular, two key behavioral dimensions risk perception and institutional trust could not be directly measured using standardized cross-country indicators. To address this gap and ensure analytical consistency, these concepts were approximated through observable behavioral proxies and partially available survey evidence. Table 1 summarizes how these constructs were translated into measurable indicators, the rationale behind the chosen substitutes, and the data sources that support their inclusion in the comparative framework.

Table 1. Operationalization of behavioral indicators: risk perception and institutional trust

Concept	Direct measure available?	Substitute indicator(s) used	Source / Notes
Risk perception	No comparable cross-country data available for all CEE states	– Agricultural insurance uptake – Irrigation adoption rates – SME adoption of renewable technologies	Eurostat (n.d.); OECD (2017); World Bank (2022). Substitutes used due to absence of harmonized perception surveys at national level.
Institutional trust	No comparable survey data across all countries; available only for selected years or sectors	– OECD behavioral surveys (2017) for selected CEE countries – National case studies and sectoral reports (where available)	OECD (2017); national expert reports; policy assessments. Used cautiously due to partial coverage and methodological heterogeneity.

Source: own compilation based on Eurostat n.d.; OECD 2017; World Bank 2022; and national case studies.

To ensure transparency and analytical consistency, Table 2 maps each research question (RQ) to its corresponding datasets and policy frameworks. This study utilizes these sources to construct a Resilience Index (RI) a composite measure of adaptive capacity.

The RI integrates four equally weighted dimensions, each normalized on a 0–1 scale via min–max transformation:

1. Institutional preparedness: The integration and implementation of National Adaptation Strategy (NAS), National Energy and Climate Plan (NECP), and National Adaptation Plan (NAP).
2. Financial capacity: The absorption of EU funds (RDP, LIFE, and RRF).
3. Sectoral vulnerability: Relative economic losses in agriculture and energy.
4. Behavioral uptake: Adoption rates for insurance, irrigation, and renewable technologies.

Following established benchmarks for composite adaptation indices (Fankhauser and Burton 2011; European Environment Agency 2021; World Bank 2022), each country's score is calculated as the arithmetic mean of these four pillars.

Table 2. Data sources, indicators, and policy documents used in the analysis

Research Question (RQ)	Indicators / Criteria	Primary Data Sources	Policy / Document Sources
RQ1. National adaptation strategies	Existence of NAS; integration with sectoral strategies; level of implementation (national/regional/local)	–	National Adaptation Strategies (NAPs), National Energy and Climate Plans (NECPs), Ministry of Climate reports
RQ2. Role of EU funds and public policies	Absorption rates of RDP, LIFE, RRF; allocation efficiency; structure of adaptation expenditures	Eurostat (env_ac_fnd), European Commission country reports, European Court of Auditors (2022)	Recovery and Resilience Facility (RRF), EU Cohesion Policy docs
RQ3. Divergence and convergence in adaptation performance	Share of agriculture in GDP; flood-prone land area; energy efficiency; Climate Resilience Index; projected GDP losses	Eurostat (agri_indicators), World Bank Climate Risk DataBank, OECD Green Growth Indicators, IPCC AR6	–
RQ4. Behavioral and psychological factors	Adoption rates of adaptive practices (irrigation, renewable energy, insurance uptake); survey-based evidence on risk perception	OECD (2017), World Bank (2022), case studies and expert reports	Grothmann and Patt (2005), national behavioral surveys (where available)

Source: own study based on Eurostat n.d., OECD 2021, World Bank 2022, European Environment Agency 2023, IPCC 2023, and national policy documents.

The Resilience Index for each country was then calculated as the arithmetic mean of the four dimensions. Higher values indicate greater adaptive capacity and resilience.

$$RI_c = \frac{1}{n}\sum_{i=1}^{n} x_{ci},$$

where:
RI_c – Resilience Index for country c,
x_{ci} – normalized value of indicator i for country c,
n – total number of indicators (four dimensions).

While Table 1 summarizes the datasets and policy documents applied in the study, it does not clarify how the theoretical frameworks were translated into empirical indicators. To bridge this gap, Table 3 maps the key dimensions of institutional and behavioral theories onto the specific indicators and data sources used in the comparative analysis. This operationalization clarifies how theoretical assumptions informed the empirical design and how each research question is linked to measurable variables.

Table 3. Operationalization of theoretical frameworks

Theoretical concept	Operational indicator / data source	Empirical link (RQ)
Institutional capacity	OECD governance indicators; Eurostat on fund absorption; NECP/NAP review	RQ1, RQ2
Policy consistency	Presence of adaptation indicators in national/regional strategies	RQ1
Vertical integration	References to regional/local implementation in NAS/NECP	RQ1
Adoption of adaptive practices (behavioral)	Irrigation, renewable energy, insurance uptake (Eurostat, World Bank, OECD)	RQ4
Risk perception/trust (behavioral)	Grothmann and Patt (2005), OECD surveys (2017), World Bank (2022)	RQ4

Source: own study.

By linking institutional concepts like vertical integration, policy consistency to specific NECP/NAP metrics, this approach ensures that the theoretical and empirical strands of the study remain integrated rather than running in parallel. Where primary survey data were not unavailable, we triangulated secondary sources such as World Bank risk reports and expert case studies to approximate the role of behavioral barriers in shaping adaptation outcomes.

Analytical Framework

To ensure transparency and replicability, we explicitly linked each research question to measurable indicators and policy documents. Table 4 provides an overview of the datasets, criteria, and adaptation policies analyzed. This design goes beyond narrative summaries and anchors the analysis in verifiable data sources, including Eurostat, OECD, World Bank, IPCC, and national adaptation plans.

Table 4. Research questions, indicators, and data sources

Research Question	Criteria / Indicators	Policies / Documents Analyzed	Data Sources
RQ1. National adaptation strategies	Existence of NAS/NAP; integration of adaptation in NECP; references to sectoral measures	NAS, NECP	National ministries; EU Climate-ADAPT database

Research Question	Criteria / Indicators	Policies / Documents Analyzed	Data Sources
RQ2. EU and domestic financial instruments	Absorption rates of RDP, LIFE, RRF; share of climate-related investments in total public spending	EU operational programmed; RRPs	Eurostat (env_ac_...); European Court of Auditors (2022); World Bank (2022)
RQ3. Divergence in adaptation performance	Climate resilience index; GDP losses from climate events; sectoral vulnerability scores	EU Green Deal monitoring; EEA Climate Risk Atlas	Eurostat (n.d.); European Environment Agency (2021); OECD databases
RQ4. Behavioral and psychological factors	Insurance uptake; irrigation adoption; renewable energy adoption by SMEs; survey results on risk perception and trust	OECD behavioral reports; national surveys; case studies	Grothmann and Patt (2005); OECD (2017); World Bank (2022)

Note: NAS: National Adaptation Strategy; NECP: National Energy and Climate Plan; RRP: Recovery and Resilience Plans.
Source: own compilation based on the databases and policy documents cited above.

Limitations and Robustness Checks

This study relies primarily on secondary data sources, including Eurostat, OECD, World Bank, the European Environment Agency (EEA), and national adaptation documents such as NAS, NECP, and NAPs. A major limitation concerns the availability of primary behavioral data, particularly risk perception and institutional trust, which are not consistently measured across the CEE region (OECD 2017; European Environment Agency 2021). As a result, behavioral dimensions were operationalized through indirect proxies such as insurance uptake, irrigation adoption, and technology diffusion, which approximate but do not fully capture underlying psychological mechanisms (World Bank 2022). Similarly, institutional trust indicators were drawn from OECD behavioral surveys and national case studies, which differ in temporal coverage and methodological design (OECD 2017). While these substitutions allow for a comparative assessment across countries, they introduce measurement error and should be interpreted as indicative rather than definitive assessments of behavioral adaptation barriers (Grothmann and Patt 2005). This approach ensures comparability across countries, although it also entails several limitations. First, behavioral indicators are not consistently available across all CEE countries, which constrains the ability to test causal relationships between risk perception, trust, and actual adaptation uptake. Second, the RI and its underlying indicators should be viewed as a heuristic tool rather than a definitive measurement of adaptive capacity. The choice of equal weights and min–max normalization was guided by transparency and replicability; however, alternative weighting or aggregation methods could yield different results. Finally, given the reliance on official reports and datasets, the findings may reflect reporting biases or incomplete monitoring mechanisms. Despite these limitations, the framework offers added value by providing a transparent and systematic comparison of institutional and behavioral adaptation dimensions across the region.

Justification of Indicator Selection

The selection of indicators used to construct the RI follows a set of methodological principles designed to ensure cross-country comparability, analytical transparency, and alignment with established international frameworks. Because the study covers five CEE countries, the primary criterion for inclusion was the availability of consistent, high-quality data across all countries. This constraint excludes several potentially relevant dimensions such as detailed measures of social capital, institutional trust, or sector-specific behavioral metrics – that are only partially available or rely on non-harmonized national surveys. The indicators included in the RI therefore prioritize robustness and comparability over breadth, reflecting the empirical limitations noted in recent adaptation assessments (European Environment Agency 2021; World Bank 2022).

A second guiding principle was the need to avoid redundancy among variables. Several categories of indicators examined during the initial design phase were ultimately excluded due to strong conceptual or statistical overlap with other components. For example, human capital variables education levels, skills indicators, and digital preparedness are strongly correlated with broader measures of institutional capacity and governance quality (OECD 2022). Including both sets of indicators would overweight similar underlying characteristics and distort the composite index. Similarly, sector-specific vulnerability indicators for agriculture, energy, and water management were aggregated into a single vulnerability dimension to avoid overrepresentation of countries with larger agricultural sectors. This approach is consistent with composite-index methodology, which recommends minimizing double-counting and ensuring conceptual balance across dimensions (Fankhauser and Burton 2011; European Environment Agency 2021).

Finally, the selection of indicators was informed by established international resilience and adaptation indices to ensure conceptual alignment and facilitate comparability with prior research. The structure of the RI mirrors the logic of the EEA Climate Risk Assessment (European Environment Agency 2021), which emphasizes institutional readiness, financial capacity, and sectoral exposure as core determinants of climate resilience. Similarly, the World Bank's Climate Resilience Indicators (World Bank 2022) informed the inclusion of institutional and financial dimensions, while the incorporation of behavioral uptake reflects recent literature highlighting the need to integrate behavioral data into adaptation metrics (Grothmann and Patt 2005; OECD 2017). The resulting index balances theoretical relevance with empirical feasibility and provides a transparent, replicable framework appropriate for cross-country comparative analysis within the CEE region.

Adaptation Strategies and Institutions in CEE Countries

Overview of National Adaptation Strategies

All CEE countries analyzed in this study have adopted national adaptation strategies (NAS), largely in response to EU obligations United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements, and access to climate-related funding (European Environment Agency 2021, pp. 23–27). Despite this shared policy architecture, the strategies differ considerably in structure, scope, and intended implementation pathways.

Lithuania integrates adaptation directly into spatial planning and land-use policy, particularly in coastal zone governance and responses to urban heat stress (Bassi and Domínguez 2021, pp. 14–20). Poland's "State Environmental Policy 2030" designates climate adaptation as one of three strategic pillars, prioritizing risk assessment, early warning systems, and cross-sectoral coordination (Ministry of Climate and Environment Republic of Poland 2020, pp. 11–18). Meanwhile, Czechia, Hungary, and Romania have updated NAS documents toward 2030 with a stronger sectoral focus on agriculture, water management, and urban adaptation.

However, across the region, a recurrent challenge is the weak vertical integration of NAS – national objectives often fail to translate into local implementation due to limited administrative capacity, unclear mandates, and insufficient technical support at regional levels (Biesbroek et al. 2013, p. 1122). Consistent with recent IPCC assessments, effective adaptation in CEE remains constrained by governance fragmentation, insufficient inter-ministerial coordination, and limited stakeholder engagement (IPCC 2022, pp. 921–928). These barriers reflect longstanding structural features of public administration in the region, including legacies of centralized governance and institutional instability.

The Role of EU Funds and Green Deal Mechanisms

EU funding mechanisms including the Cohesion Fund, Recovery and Resilience Facility (RRF), LIFE Programme, and instruments associated with the European Green Deal play a central role in enabling adaptation investments in CEE (European Union 2021, pp. 17–23). Although these mechanisms provide substantial financial support, their effectiveness varies significantly across countries.

The European Court of Auditors (2022, pp. 6–9) and the World Bank (2022, pp. 34–36) found that absorption rates for adaptation-related funding remain below the EU average. Key constraints include limited administrative capacity, complex procedures, fragmented responsibilities, and a shortage of well-prepared, fundable adaptation projects. Frequent changes in procurement rules, inter-agency coordination problems, and slow permitting processes further impede implementation.

Another recurrent issue is the tendency of national governments to treat adaptation as a secondary rather than primary policy priority (European Court of Auditors 2022, pp. 6–9). As a result, funding often prioritizes grey infrastructure such as roads, levees, and drainage systems over ecosystem-based solutions or behavioral interventions, which are less easily accommodated within standard cost-benefit frameworks.

There are, however, emerging examples of integrated approaches. Estonia and Slovenia have implemented LIFE-funded pilot projects that combine flood management with biodiversity co-benefits (OECD 2022, pp. 41–44). Recent RRF programming also shows greater alignment with EU climate objectives, including the 30% climate mainstreaming requirement. Turning this potential into sustained outcomes will nonetheless depend on domestic administrative reforms and the incorporation of adaptation into long-term development planning.

Comparative Analysis – Macroeconomic Aspects

Climate Vulnerability Indicators and Their Impact on GDP

Recent evidence points to a clear pattern: economies that are more diverse tend to weather climate shocks better than those that rely heavily on just one sector. In particular, regions dominated by monoculture farming, and especially those vulnerable to drought, often struggle the most (Kalkuhl and Wenz 2020).

Key indicators of climate vulnerability, like how often droughts occur, how much land is prone to flooding, the share of agriculture in national GDP, or how dependent a country is on fossil fuels, vary significantly across the region (European Environment Agency 2021, pp. 45–49). For instance, in Lithuania and Romania, agriculture makes up over 4% of GDP, putting those economies at higher risk when climate extremes hit. Hungary and Poland, on the other hand, face serious flood threats and have relatively low energy efficiency – both of which drive up the costs of adapting to climate change (World Bank 2022, pp. 15–18).

The impacts are no longer just projections; they're already being felt. Slower economic growth, falling agricultural yields, damaged infrastructure, and power system disruptions are becoming more frequent. And it could get worse. According to IPCC estimates, if effective adaptation policies are not put in place, the CEE region could see annual GDP losses of up to 1.5–2% by 2050 (IPCC 2022, pp. 1780).

Efficiency in Allocating Adaptation Funds

The way adaptation funds are allocated across CEE is still far from consistent. Czechia and Poland demonstrate relatively high administrative proficiency, having shown a consistent capacity to absorb and deploy EU funding effectively. By contrast, Lithuania and Romania face substantial challenges in implementing long-term projects, often characterized by low absorption rates (European Commission 2021, pp. 24–29).

Several structural impediments account for these disparities. Primarily, many countries lack robust, long-term systems to assess climate risks. When compounded by a prevalence of short-termism in policy planning, this results in misaligned investment flows that fail to reach high-priority sectors such as agriculture or flood prevention (Hallegatte et al. 2012, pp. 29–31).

Optimizing the use of adaptation funding requires more than access to good data. Local institutions also need the know-how to prioritize the right kinds of projects, especially regarding critical infrastructure, better water systems, or modernizing outdated energy grids. Without that institutional capacity, even well-designed funding mechanisms will fail to achieve their full potential.

Examples of Sectoral Adaptation (Agriculture, Energy, Infrastructure)

In the agricultural sector, climate adaptation is primarily manifested through modernized irrigation systems, stress-resilient crop varieties, and better access to weather and climate advice for farmers.

In Poland, for example, the 2014–2020 Rural Development Programme (RDP) allocated funding toward water retention projects and agricultural training, measures designed to make farms more resilient in the long run (European Environment Agency 2021, pp. 60–63).

The energy sector has also seen movement in the right direction. Lithuania, for example, has expanded investments in decentralized renewables – specifically solar farms and local microgrids – and energy storage. These upgrades help reduce the risk of blackouts during extreme weather events (Bassi and Domínguez 2021, pp. 25–26).

Public infrastructure, including roads, railways, and energy systems, is gradually being adapted to cope with hotter temperatures and heavier rainfall. However, European Environment Agency (2021, pp. 60–63) and the World Bank (2022, p. 38) report that the pace of change remains insufficient relative to the scale of projected climate risks, with many investments still focused on short-term repairs rather than long-term resilience. While specific infrastructure projects in Romania and Hungary have received support from the LIFE programme and the European Investment Bank, such initiatives remain the exception rather than the rule (World Bank 2022, p. 38).

Empirical Results – Comparative Analysis

National Adaptation Strategies (RQ1)

The analysis of planning documents (NECPs, NAPs, national strategies) reveals that adaptation strategies in the examined countries differ both in scope and implementation. Czechia and Poland have achieved moderate levels of integration of adaptation measures into regional development policies, for example, by including adaptation indicators in regional planning documents. In contrast, Lithuania and Romania continue to treat adaptation largely as a separate environmental component, with weak links to transport, spatial planning, or health policies. Hungary demonstrates fragmented implementation and high dependence on individual institutions running adaptation projects.

Answer to RQ1: These findings indicate that while all CEE countries have formally adopted national strategies, their rollout is uneven. Czechia and Poland show stronger institutional coordination, whereas Lithuania and Romania lag behind, confirming the structural gaps identified in Section 5.

The Role of EU Funds and Public Policies (RQ2)

Analysis of Eurostat data and European Commission reports (European Union 2021) reveals significant disparities in the absorption of EU climate adaptation funds between 2014 and 2020:

- Poland absorbed 89% of allocated RDP and LIFE funds for adaptation projects.
- Czechia absorbed 84%, mainly due to efficient domestic procedures.
- Romania and Lithuania absorbed only 56% and 62%, respectively, due to a lack of ready projects and institutional constraints.
- Hungary absorbed 74%, with expenditures focused mostly on engineering solutions, while behavioral and educational aspects were underrepresented.

Answer to RQ2: These results demonstrate that while EU financial instruments significantly supported adaptation in Poland and Czechia, their impact remains limited in Romania and Lithuania because of institutional bottlenecks. Moreover, funding still prioritizes hard infrastructure, leaving ecosystem-based and behavioral measures underfunded.

An additional concern relates not only to the volume and absorption of funds but also to the quality of adaptation investments. Evidence from CEE countries suggests a persistent bias toward grey infrastructure such as levees, drainage systems, or road protection works which delivers short-term risk reduction but often lacks long-term transformational value and may even increase lock-in effects (Sovacool, Linnér, and Goodsite 2015; European Environment Agency 2021). By contrast, deep adaptation investments ecosystem-based solutions, water retention landscapes, soil regeneration, climate-resilient land-use planning, or decentralized energy systems remain underfunded despite their higher long-term benefits and alignment with the EU Adaptation Strategy 2023 update (European Commission 2023a). The predominance of grey projects reflects institutional incentives that favor visible, easily quantifiable outputs and existing sectoral capacities, whereas deep adaptation requires cross-sectoral coordination, behavioral engagement, and longer implementation horizons. As a result, the structure of expenditures continues to limit transformative outcomes, reinforcing short planning cycles and reducing the effectiveness of adaptation financing in the region.

Divergence and Convergence Across Countries (RQ3)

According to World Bank (2022) data for the period 2010–2020, sectoral vulnerability shifts are evident:

- Agricultural productivity in Poland and Czechia remained relatively stable despite increased drought frequency, indicating partial success of adaptation measures (e.g., water retention, crop changes).
- Romania and Lithuania experienced declines in agricultural productivity of 12% and 9%, respectively, in extremely dry years (2012, 2015, 2018), suggesting insufficient technological and infrastructural adaptation.
- Hungary recorded increased investment in decentralized renewable energy (e.g., photovoltaics), reducing power outages in regions covered by the "Local Energy 2030" program.

Climate resilience indicators also highlight divergence (Table 5). Poland (0.68) and Czechia (0.72) are the most resilient, while Romania (0.52) and Lithuania (0.56) are the least resilient. Hungary holds an intermediate position (0.60). Without adaptation, GDP losses by 2050 could reach between –1.2% and –2.1% annually, depending on the country.

Table 5. Indicators of Economic Resilience to Climate Change

Country	Climate Resilience Index	Projected GDP Loss by 2050 (No-Adaptation Scenario)
Czechia	0.72	− 1.2% annually
Hungary	0.60	− 1.7% annually

Country	Climate Resilience Index	Projected GDP Loss by 2050 (No-Adaptation Scenario)
Lithuania	0.56	−2.0% annually
Poland	0.68	−1.4% annually
Romania	0.52	−2.1% annually

Source: author's own calculations based on IPCC 2022; OECD 2022.

Answer to RQ3: The results suggest a relationship between institutional preparedness and macroeconomic resilience. In this study, institutional preparedness is defined as the existence and integration of adaptation strategies (NAS/NECP), the capacity to absorb EU funds (RDP, LIFE, RRF), and the degree of policy consistency across sectors. As shown in Table 5, Poland (score 0.72) and Lithuania (0.68) recorded higher preparedness levels, accompanied by relatively lower climate-related GDP losses (0.9% and 0.7% of GDP, respectively). By contrast, Romania, with a preparedness score of 0.41, experienced losses averaging 1.8% of GDP over 2000–2020 (European Environment Agency 2021; World Bank 2022). These findings indicate that stronger institutional frameworks tend to reduce the scale of macroeconomic climate-related losses, although the evidence should be interpreted as correlational rather than causal.

Behavioral and Psychological Dimensions of Adaptation (RQ4)

Although most quantitative data reflect institutional and financial aspects, evidence from expert assessments and secondary sources highlights significant behavioral barriers. Farmers and SMEs often underinvest in adaptation even when it is economically justified. Evidence from Grothmann and Patt (2005, pp. 201–203) and the OECD (2017, pp. 32–35) shows that short planning horizons, risk underestimation, and low institutional trust are key behavioral barriers. Similar findings for CEE countries were highlighted by the World Bank (2022, pp. 22–24), which pointed to persistent cognitive and institutional constraints limiting the uptake of adaptive practices. For instance, in Romania and Hungary, financial support schemes were available, yet the adoption of adaptive practices remained limited.

Answer to RQ4: These results show that behavioral and psychological factors play a critical role in shaping adaptation outcomes. Even where financial and institutional support is present, cognitive biases and low institutional trust constrain effective adaptation, confirming the importance of integrating behavioral economics into policy design.

Cross-country comparisons further illustrate how behavioral dynamics interact with institutional settings. Poland's relatively high agricultural insurance uptake (approximately 45%) correlates with higher levels of institutional trust and more consistent enforcement mechanisms (OECD 2017; World Bank 2022). In contrast, Romania's very low level of insurance penetration (below 20%) reflects both persistent distrust in public institutions and weak policy enforcement. Lithuania shows comparatively high adoption rates of efficient irrigation technologies (over 30%), linked to targeted policy incentives and cooperative structures, while Hungary lags behind with adoption rates below 10%. These differences suggest that behavioral barriers in CEE are not purely psychological but are closely intertwined with institutional and cultural legacies. Post-communist

distrust of state institutions, limited participatory traditions, and the prevalence of "policy façade" mechanisms reduce willingness to engage in formal adaptation programs, even when economic incentives exist.

Sensitivity Analysis of the Resilience Index

To assess the robustness of the RI, a comparative sensitivity analysis was conducted using three alternative weighting schemes: (i) equal weights, (ii) Principal Component Analysis (PCA), and (iii) expert-based weights derived from adaptation literature (Fankhauser and Burton 2011; European Environment Agency 2021; World Bank 2022). The goal was to examine whether the relative ranking of countries remains stable regardless of weighting assumptions.

Table 6. Comparison of Resilience Index Scores Under Alternative Weighting Schemes

Country	Equal Weights	PCA Weights	Expert Weights
Czechia	0.72	0.74	0.71
Hungary	0.60	0.57	0.59
Lithuania	0.56	0.53	0.55
Poland	0.68	0.69	0.67
Romania	0.52	0.50	0.51

Source: author's own calculations based on data from Eurostat, OECD Green Growth Indicators, World Bank Climate Risk DataBank, and methodological guidelines from European Environment Agency 2021 and World Bank 2022.

The sensitivity analysis demonstrates that the relative ordering of countries remains largely stable across all three weighting methods, indicating that the RI is robust to alternative weighting assumptions. PCA-based weights produce slightly more dispersed scores, reflecting the stronger influence of financial absorption and institutional quality in the variance structure of the dataset. Expert weights create only minor deviations from the equal-weight baseline, reinforcing the conclusion that no single dimension dominates the index disproportionately. Overall, the consistency of country rankings across weighting schemes supports the methodological reliability of the composite index and strengthens confidence in the comparative interpretation of resilience levels in the CEE region.

Discussion

The comparative results show substantial variation across CEE countries in both climate risks and adaptive capacities. Table 2, which tracks the existence and quality of national adaptation strategies, confirms that while all examined states have formally adopted NASs or NECPs, their integration into sectoral policies remains uneven. For example, Lithuania's NAS embeds adaptation into spatial planning, whereas Romania's and Hungary's strategies lack consistent sectoral linkages. These findings confirm the relevance of institutional theories of adaptation, which stress that fragmented governance and limited policy consistency undermine long-term resilience (Biesbroek et al. 2013; Dupuis and Biesbroek 2013).

Despite the formal adoption of adaptation strategies across CEE, many countries in the region continue to exhibit what the literature terms "symbolic policy" or "policy façade" – strategic documents that signal alignment with EU expectations but lack the institutional depth, administrative capacity, or financial commitments needed for meaningful implementation (Dupuis and Biesbroek 2013; Jordan and Huitema 2014). Such symbolic adaptation is often rooted in the political incentives of governments that prioritize compliance on paper while avoiding distributive conflicts associated with substantive climate reforms. As a result, adaptation plans appear comprehensive, yet remain weakly embedded in sectoral policies, underfunded or inconsistently enforced, undermining their credibility and practical impact (Sovacool, Linnér, and Goodsite 2015; European Environment Agency 2021).

A further explanation lies in the role of sectoral veto players – actors with sufficient political, economic, or bureaucratic power to block, delay, or dilute adaptation measures that threaten entrenched interests (Tsebelis 2002; Meadowcroft 2011). In several CEE countries, agricultural lobbies, energy incumbents, forestry agencies, and regional authorities resist reforms that require behavioral change, investment shifts, or regulatory tightening. These actors often benefit from existing subsidy structures, weak enforcement, or legacy infrastructure, thereby creating institutional inertia that slows adaptation progress (Adger, Arnell, and Tompkins 2005; Biesbroek et al. 2013). The influence of veto players reinforces implementation gaps, limits transformative adaptation, and contributes to the persistent divergence between formal strategies and actual resilience outcomes across the region.

Although institutional and financial factors strongly influence adaptation outcomes, behavioral gaps remain a major barrier in CEE. Farmers, SMEs, and households often underinvest in adaptive measures even when they are economically viable. Short planning horizons, risk underestimation, and low trust in public institutions reduce the willingness to engage in long-term strategies. Empirical evidence from the OECD (2017), World Bank (2022), and national case studies shows that behavioral inertia persists even in the presence of financial support schemes.

Addressing these gaps requires more systematic integration of behavioral economics tools into public policy, such as nudging mechanisms, targeted information campaigns, and simplified administrative procedures. Without tackling cognitive and psychological constraints, institutional reforms and EU funding will continue to face limited uptake on the ground.

Table 3, which compares the absorption of EU funds, indicates that adaptation-related spending as a share of total EU transfers ranged from 11% in Poland to less than 5% in Romania between 2014 and 2020. The European Court of Auditors (2022) similarly documents persistent underutilization of LIFE and RDP funds in several CEE countries. These data highlight how institutional capacity constraints, such as limited administrative resources and high transaction costs, translate directly into lower financial absorption, constraining adaptation outcomes. The results, therefore, corroborate institutional economics perspectives that emphasize the role of implementation capacity and incentive structures in determining policy effectiveness.

Regarding resilience outcomes, Table 4 shows that climate-related GDP losses (2000–2020) were substantially higher in Romania (1.8% of GDP equivalent) and Hungary (1.5%) compared

to Poland (0.9%) and Lithuania (0.7%). Similarly, sectoral vulnerability indicators (European Environment Agency 2021) confirm that agriculture remains disproportionately exposed in Romania and Hungary, while energy sector risks dominate in Czechia and Poland. These divergences point to structural differences in exposure and sectoral composition, reinforcing the need for country-specific rather than templated adaptation strategies.

The behavioral dimension is captured in Table 7, which presents evidence on the uptake of adaptive practices. Insurance penetration among farmers is below 20% in Romania and Hungary, but exceeds 45% in Poland; adoption of efficient irrigation technologies is above 30% in Lithuania but below 10% in Hungary. These findings illustrate the behavioral barriers identified in the theoretical framework: short planning horizons, limited risk perception, and low institutional trust (Grothmann and Patt 2005; OECD 2017). The underinvestment by farmers and SMEs, even when EU funds were available, reinforces the argument that adaptation cannot be understood solely through institutional capacity; behavioral factors critically shape uptake.

Table 7. Comparison of national adaptation strategies in selected CEE countries

Country	Adaptation Objectives	Main Policy Instruments	Implementation Level	Funding Sources
Czechia	Flood protection, urban resilience	Sectoral strategies, risk management plans	National	EU funds, domestic resources
Hungary	Water adaptation, drought management	National adaptation strategy, LIFE projects	Regional	LIFE, Cohesion Fund, bilateral support
Lithuania	Spatial planning, local adaptation	NECP, local strategies, PPP in green infrastructure	Local and regional	EU funds, pilot PPP initiatives
Poland	Water retention, agricultural resilience, infrastructure	RDP, State Environmental Policy 2030, agricultural advisory	National and regional	EU funds (RDP, LIFE), national budget
Romania	Reducing vulnerability in agriculture and energy	Climate Strategy 2030, cooperation with IFIs	Limited regional coverage	EIB, World Bank, EU funds

Source: own study.

These findings also align with the theoretical frameworks outlined earlier. For instance, the observed difficulties in policy coordination and low absorption of EU funds validate North's (1990) arguments about institutional path dependence and the persistence of structural inefficiencies. Similarly, the underinvestment by farmers and SMEs, despite available support schemes, confirms the behavioral mechanisms described by Grothmann and Patt (2005), where risk perception biases and limited adaptive capacity hinder rational decision-making. Conversely, cases such as Lithuania's integration of adaptation into spatial planning suggest partial evidence against overly deterministic views of institutional inertia, showing that targeted policy design can overcome legacy barriers.

Taken together, the results demonstrate that adaptation in CEE is constrained by a dual challenge: institutional fragmentation and behavioral inertia. Institutional weaknesses limit the effectiveness of EU transfers and policy frameworks, while behavioral barriers reduce uptake at the micro level. Integrating both perspectives thus yields a more comprehensive explanation of the observed patterns.

From a policy perspective, the data underscore three priorities. First, improving administrative and technical capacity is essential to raise absorption rates of EU adaptation funds, particularly in Romania and Hungary. Second, targeted measures are needed to reduce sectoral vulnerabilities, especially in agriculture, through investment in irrigation and crop insurance. Third, policies should incorporate behavioral insights to address short planning horizons and low trust, for example, by designing simplified procedures, defaults, and risk communication strategies. These implications are consistent with recent recommendations by the IPCC (2022, pp. 921–928) and the European Environment Agency (2021, pp. 75–78), which emphasize the need to combine institutional strengthening with behavioral interventions.

Beyond the descriptive comparison, this study highlights a broader theoretical challenge. Institutional perspectives often assume that formal strategies and governance structures translate into effective adaptation. However, the results presented in Tables 2–4 suggest otherwise: countries with relatively comprehensive adaptation plans (e.g., Hungary, Romania) still experience high climate-related GDP losses, whereas countries with fewer formal documents but higher financial absorption and behavioral uptake (e.g., Poland, Lithuania) demonstrate stronger resilience outcomes. This discrepancy illustrates the risk of "policy façade" strategies that exist on paper but lack budgetary commitment, enforcement, or social legitimacy. By explicitly combining institutional and behavioral indicators into a single resilience index, this article contributes to bridging this gap and provides a framework for future research to test how formal preparedness aligns or fails to align with tangible adaptation outcomes in post-socialist contexts.

Conclusions and Recommendations

The coordination of climate policies across different governance levels national, regional, and local remains one of the most persistent challenges in CEE. While vertical integration mechanisms, such as multilevel planning platforms or shared budgeting tools, can substantially improve adaptation outcomes, they remain largely missing or poorly institutionalized across the region.

Financing constraints are particularly acute in rural municipalities, which often lack both the fiscal autonomy and technical expertise to initiate climate-resilient infrastructure projects. Targeted fiscal transfers and regional climate investment funds may serve as viable policy innovations to overcome these bottlenecks. Embedding adaptation metrics into public investment appraisal procedures could also improve long-term resilience by aligning infrastructure and agricultural programs with broader climate goals.

The key findings and recommendations are summarized in Table 8, which links the research questions (RQ) directly to empirical results and policy implications.

Table 8. Research Questions, Findings, and Recommendations

Research Question (RQ)	Key Findings	Policy Recommendations
RQ1. National adaptation strategies	All examined countries have adopted national adaptation strategies, but implementation is fragmented. Poland and Czechia show stronger integration, while Romania and Lithuania lag behind.	Strengthen vertical integration; improve coordination between levels of government; enhance administrative capacity at regional and local scales.
RQ2. Role of EU funds and public policies	Large disparities in EU fund absorption: Poland (89%) and Czechia (84%) outperform Romania (56%) and Lithuania (62%). Funding often favors infrastructure over ecosystem-based or behavioral solutions.	Simplify administrative procedures; support project readiness; rebalance spending to include nature-based and behavioral approaches.
RQ3. Divergence and convergence in adaptation performance	Climate resilience indices show divergence: Czechia (0.72) and Poland (0.68) most resilient, Romania (0.52) and Lithuania (0.56) least resilient; GDP losses projected up to –2.1% annually without adaptation.	Standardize resilience metrics; target weaker countries with conditional EU support; integrate adaptation into core development strategies.
RQ4. Behavioral and psychological factors	Farmers and SMEs often underinvest in adaptation despite economic justification. Barriers include risk underestimation, short planning horizons, and low trust in institutions.	Incorporate behavioral insights into policy (nudges, default options, peer learning); strengthen participatory governance to build trust.

Source: own study.

A key conclusion is that only a comprehensive and integrated approach – addressing institutional, financial, and behavioral barriers simultaneously can enhance climate change adaptation in the CEE region. In practice, this means that:

- Lithuania and Romania need urgent institutional reinforcement, particularly in policy coordination, strategic planning, and the absorption of EU funds. In Romania, these structural challenges are compounded by behavioral barriers, suggesting the need for behavioral nudges to increase irrigation adoption and reforms of local procurement rules to improve project quality and reduce delays (Thaler and Sunstein 2008; OECD 2017).
- Czechia and Poland, while displaying relatively strong institutional frameworks, should prioritize the diversification of financing mechanisms, including public–private partnerships, climate insurance, and green bonds. In Poland, targeted instruments such as risk-sharing pools for farmers and trust-building pilots within advisory services could help address persistent behavioral and informational gaps (Beauchamp 2023; OECD 2023).
- Hungary demonstrates moderate deficits in both institutional and financial dimensions, indicating the need for parallel reforms. Given the political centralization of adaptation governance, a key priority is the depoliticization of adaptation funding and strengthening the autonomy of regional bodies to implement locally tailored adaptation measures (Tsebelis 2002; Meadowcroft 2011).

Future research should examine the long-term socio-economic impacts of climate adaptation in CEE, focusing on interactions between policies and demographic shifts, labor market changes, and urban–rural migration. Advanced modelling approaches (e.g., DSGE models) and cross-country panel data analyses could provide deeper insights into both macroeconomic effects and micro-level behavioral dynamics.

At the EU level, linking funding conditionality more directly to measurable outcomes and institutional reforms would incentivize stronger adaptation performance. National adaptation observatories, standardized metrics, and knowledge-exchange platforms could further help align national strategies with EU climate targets and the broader objectives of the Green Deal.

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Adaptacja do zmian klimatu i odporność gospodarcza w Europie Środkowo-Wschodniej: porównawcza analiza instytucjonalna i polityczna

Celem artykułu jest porównawcza analiza strategii adaptacji do zmian klimatu w wybranych krajach Europy Środkowo-Wschodniej (w Polsce, Czechach, na Węgrzech, w Rumunii, w krajach bałtyckich) oraz ocena ich wpływu na odporność gospodarczą. Szczególną uwagę poświęcono instytucjom publicznym, instrumentom finansowym oraz ramom regulacyjnym wspierającym proces adaptacji, ze szczególnym uwzględnieniem wykorzystania funduszy unijnych (w tym Zielonego Ładu i Funduszu Odbudowy). Analiza koncentruje się również na sektorze rolnictwa – jako jednym z najwrażliwszych na skutki zmian klimatycznych – oraz na mikroekonomicznych uwarunkowaniach decyzji adaptacyjnych podejmowanych przez gospodarstwa domowe i przedsiębiorstwa. Podejście badawcze łączy analizę instytucjonalną i polityczną z perspektywą ekonomii behawioralnej, wskazując na czynniki sprzyjające skuteczności adaptacji w regionie oraz ograniczające ją.

Słowa kluczowe: adaptacja do zmian klimatu, odporność gospodarcza, Europa Środkowo-Wschodnia, polityka klimatyczna, instytucje publiczne, ekonomia behawioralna, fundusze unijne, rolnictwo, analiza porównawcza, strategie adaptacyjne

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Navigating Energy Transition: Driving Energy Efficiency Improvement in EU Industry

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Abstract

This study examines the primary determinants of energy efficiency improvements within the European Union's (EU) industrial sector from 2004 to 2023. The analysis is situated within the strategic framework of the European Green Deal and the "Fit for 55" package, which addresses the challenge of accelerating the industrial energy transition while maintaining global competitiveness. Utilizing a Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model, this research accounts for cross-sectional dependence and heterogeneous short-run dynamics across Member States. Empirical results reveal that economic growth and rising energy prices act as significant drivers of industrial energy efficiency in both the short and long run. Conversely, higher CO_2 emissions are associated with lower efficiency, reflecting persistent reliance on carbon-intensive production. These findings underscore the need to align economic modernization with price-based incentives to meet EU climate goals.

Keywords: CS-ARDL, energy efficiency, energy transition, EU industry
JEL: C23, L60, Q40, Q48

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Introduction

European Union (EU) policy, while navigating the complexities of environmental regulations and competitiveness, is oriented towards energy transition, driven by the understanding that well-designed policies can foster technological advancements and long-term economic benefits rather than solely posing competitive disadvantages. Nonetheless, the issue of the impact of environmental regulations on competitiveness remains contentious (Dechezleprêtre and Sato 2017). There are two opposing views on this topic: the pollution hypothesis, which predicts that firms operating in countries with more stringent environmental regulations will lose competitiveness, and the Porter hypothesis, which argues that more stringent regulations may serve as a catalyst for innovation, enhancing competitiveness by promoting efficiency gains and facilitating the development of novel technologies (Ambec et al. 2010). Transitioning to a more energy-efficient economy can also stimulate economic growth and create high-quality jobs in sectors related to energy efficiency, which is and will continue to be a competitive advantage for both countries and companies (Proskuryakova and Kovalev 2015).

The EU's ambitious climate agenda marked by the European Green Deal (EGD) and the Fit for 55 package has positioned energy efficiency as a cornerstone of its industrial strategy. Industry, responsible for 25% of the EU's final energy consumption and 20% of its direct CO_2 emissions, faces an unprecedented dual mandate: to decarbonize rapidly while maintaining global competitiveness in an era of geopolitical energy instability (Odyssee 2025). While aggregate energy intensity in EU industry improved annually by 1.59% between 2004 and 2023, progress remains uneven across member countries. Against this backdrop, understanding the determinants of energy efficiency progress is not merely an academic exercise but a policy and economic imperative. The EU's industrial strategy, updated in May 2021 following the COVID-19 crisis, is oriented towards an energy transformation based on the idea that environmental ambition can drive innovation and long-term competitiveness (European Commission 2021b). EU energy efficiency measures focus on policy areas with the greatest potential for energy savings and where a harmonized approach across member states is needed. This includes industry and, under the revised directive on energy efficiency, EU countries will be required to achieve an average annual energy savings rate of 1.49% from 2024 to 2030, up from the 2021–2023 requirement of 0.8%, driving energy savings in critical sectors like construction, industry, and transport (European Parliament and the Council of the European Union 2023).

The central aim of this article is to identify and evaluate the determinants driving energy efficiency progress in the EU industrial sector between 2004 and 2023. By combining theoretical insights, policy analysis, and empirical econometric modelling, the study seeks to disentangle the multifaceted factors that have influenced industrial energy efficiency outcomes. The findings aim to inform targeted strategies for accelerating the EU's energy transition while balancing industrial competitiveness.

The study opens with a critical analysis and synthesis of the relevant literature and policy documents, providing a foundation for understanding the conditions shaping the energy transition in the EU. Attention is given to the political and regulatory context influencing the evolution of energy efficiency, followed by an examination of historical and recent trends in industrial energy efficiency

across EU member states, with a particular focus on energy intensity developments over the period 2004–2023.

The analytical core of the paper presents the econometric framework used to identify the determinants of industrial energy efficiency in the EU. This section outlines the specification of the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model, the construction of the variables, and the rationale for controlling for cross-sectional dependence, heterogeneous short-run dynamics, and unobserved common shocks affecting EU economies.

The empirical results are then presented and discussed, highlighting both short-run and long-run relationships between industrial energy efficiency and its key determinants. The paper concludes by synthesizing the main findings and drawing policy-relevant conclusions.

The EU Energy Transition in the Light of New Geopolitical Circumstances – Motivation or Demotivation?

The global energy transition represents a systemic transformation of energy production and consumption, driven by the replacement of high-carbon fossil fuels with renewable and low-carbon sources (Goldthau, Westphal, and Keim 2018; IRENA 2019; Hafner and Tagliapietra 2020). Beyond mitigating climate change (Hallegatte et al. 2016), the transition seeks to improve air quality and energy security (Bressand 2012; Eyl-Mazzega and Mathieu 2019; Król, Makieła, and Mamica 2025). It introduces new economic models and sustainability frameworks, with far-reaching implications for industry, society, and economic resilience. It seemed that the energy transition trend would be a constant social, political, environmental, and economical course for all countries around the world. However, recent decisions made by U.S. President Donald Trump have increased uncertainty in this area and have become a topic of much controversy, especially when contrasted with the global trend of transitioning to renewable energy sources. Donald Trump, both during his first presidency (2017–2021) and following the commencement of his new presidential term on January 20, 2025, has consistently expressed strong support for conventional energy sources primarily coal, oil, and gas at a time when most developed countries are investing in renewable sources, energy efficiency, and decarbonization.

For EU member states, the transition of the energy system has become a strategic goal in the fight against climate change, leading to improved energy security, competitiveness, and economic attractiveness of Europe in the transition to a greenhouse gas (GHG) neutral economy by 2050. A pivotal milestone in the EU's energy transition, aiming towards the goal of becoming the world's first zero-carbon continent by 2050, was the introduction of the energy and climate package in 2008, commonly known as "3x20% by 2020". The package outlined three main objectives to be reached by 2020 (European Commission 2008; Klecha-Tylec, Pach-Gurgul, and Ulbrych 2024):

1) To increase the share of energy derived from renewable energy sources (RES) to 20% of the EU's total energy consumption;
2) To reduce primary energy consumption by 20% relative to projected consumption levels for 2020, as forecasted in 2005;

3) To achieve a 20% reduction in CO_2 emissions compared to 1990 levels.

The goals of the energy and climate package were subsequently reinforced and incorporated into the Europe 2020 Strategy (European Commission 2010), underlining their critical importance for the EU's long-term energy and climate objectives. In October 2014, at the European Council, EU leaders set new climate and energy targets for 2030, including more ambitious reduction thresholds, including tightening the reduction of 40% of greenhouse gas emissions compared to 1990, sourcing at least 27% of energy from renewable sources and improving energy efficiency by the same amount (European Council 2014; Klecha-Tylec, Pach-Gurgul, and Ulbrych 2024).

Ahead of the Paris UN Climate Change Conference COP21/CMP11 (Nov. 30–Dec. 11, 2015), the EU submitted a planned nationally determined contribution (INDC) to the secretariat of the UN Framework Convention on Climate Change (UNFCCC) confirming commitment to reduce its own GHG emissions by at least 40% by 2030 compared to 1990 in line with the European Council's October 2014 conclusions (United Nations 2015). On October 4, 2016, the Council adopted the decision for the EU to ratify the Paris Agreement. Earlier, in September 2015, the Environment Council had approved conclusions outlining the EU's position for the COP21 climate conference in Paris, thereby marking a significant step in supporting international efforts toward the global energy transition. During this meeting, the ministers agreed that the EU would strive for an ambitious, legally binding, and dynamic agreement aimed at limiting global temperature increase to below 2°C.

In June 2017, the European Council reaffirmed the commitment of the EU and its member states to the swift and full implementation of the Paris Agreement, stressing that the agreement is an essential "element in the modernization of industry and the economy in Europe". In November 2018, the European Commission (EC) presented a long-term strategic vision for a modern, competitive, and climate-neutral economy by the 2050 horizon. The strategy illustrates how Europe can lead the way in achieving climate neutrality by introducing innovative technological solutions and aligning policy actions in areas such as industrial policy, finance, and research. The EC has planned to increase energy efficiency by at least 32.5% by 2030, by, among other things, improving low emissions in the transport sector (European Commission 2018).

The EGD (European Commission 2019), presented by the EC on December 11, 2019, set out a new growth strategy for Europe. Its goal was and is to transform the EU into a fair and prosperous society with a modern, resource-efficient, and competitive economy that achieves zero net greenhouse gas emissions in 2050, and in which economic growth will depend less on the use of conventional raw material resources. In December 2020, the European Council approved a new binding EU target to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990. In order to bring selected areas into line with the new target reduction, the EC published a package of legislative proposals (the "Fit for 55%" package) on July 14, 2021.

Energy Efficiency as a Key Pillar of EU Energy Transition

Reducing energy consumption and minimizing waste have become increasingly important priorities for the EU and its Member States. EU legislation seeks to position energy savings as a fundamental driver of a secure, sustainable, and competitive economy. In recent years, the EU has made significant progress in reducing energy consumption and has notably improved its overall energy efficiency, particularly within the framework of the Lisbon Agenda and the subsequent Europe 2020 Strategy (Pach-Gurgul, Śmiech, and Ulbrych 2020). The EU regards energy efficiency as a key pillar of its energy and climate strategy. By reducing overall energy consumption, energy efficiency plays a central role in achieving its climate ambitions, while simultaneously enhancing both current and future energy security and affordability.

To meet the 2030 target of reducing GHG emissions by at least 55% compared to 1990 levels, the EC has revised the Energy Efficiency Directive from 2012, alongside other energy and climate regulations (European Commission 2012). The EU follows the principle of "energy efficiency first," meaning that energy savings are prioritized wherever they are most cost-effective. While fully considering the security of supply and market integration, the Energy Efficiency First principle seeks to ensure that only the energy that is truly needed is produced, investments in stranded assets are avoided, and energy demand is reduced and managed in a cost-effective manner.

This principle emphasizes not only the need to reduce fossil fuel consumption but also the importance of decreasing overall energy production to improve the efficiency of the energy system and minimize its environmental impact. While the "Energy Efficiency First" principle was already embedded in the Regulation on the Governance of the Energy Union and Climate Action (EU/2018/1999) and the Energy Efficiency Directive (EU/2018/2002), the revised Directive (EU/2023/1791), published in the Official Journal on September 20 2023, establishes a more robust and comprehensive legal framework for the implementation of this principle. It significantly elevates the EU's ambition with regard to energy efficiency. It enshrines the principle of "energy efficiency first" as a fundamental tenet of EU energy policy, granting it legal standing for the first time.

In practical terms, this mandates that energy efficiency be considered by member states in all pertinent policy decisions and major investments, both within the energy sector and across non-energy sectors. The 2023 revision follows the EC's proposal for a recast energy efficiency directive, initially put forward in July 2021 as part of the EGD package. This proposal was subsequently strengthened through the REPowerEU plan, presented by the EC in May 2022, with the goal of reducing the EU's dependency on fossil fuel imports from Russia (European Commission 2022). The revised directive from 2023 strengthens the energy efficiency target, making it legally binding for member states to collectively achieve an additional 11.7% reduction in energy consumption by 2030, compared to the projections in the EU reference scenario of 2020. As a result, total EU energy consumption by 2030 should not exceed 992.5 million tonnes of oil equivalent (Mtoe) for primary energy and 763 Mtoe for final energy.

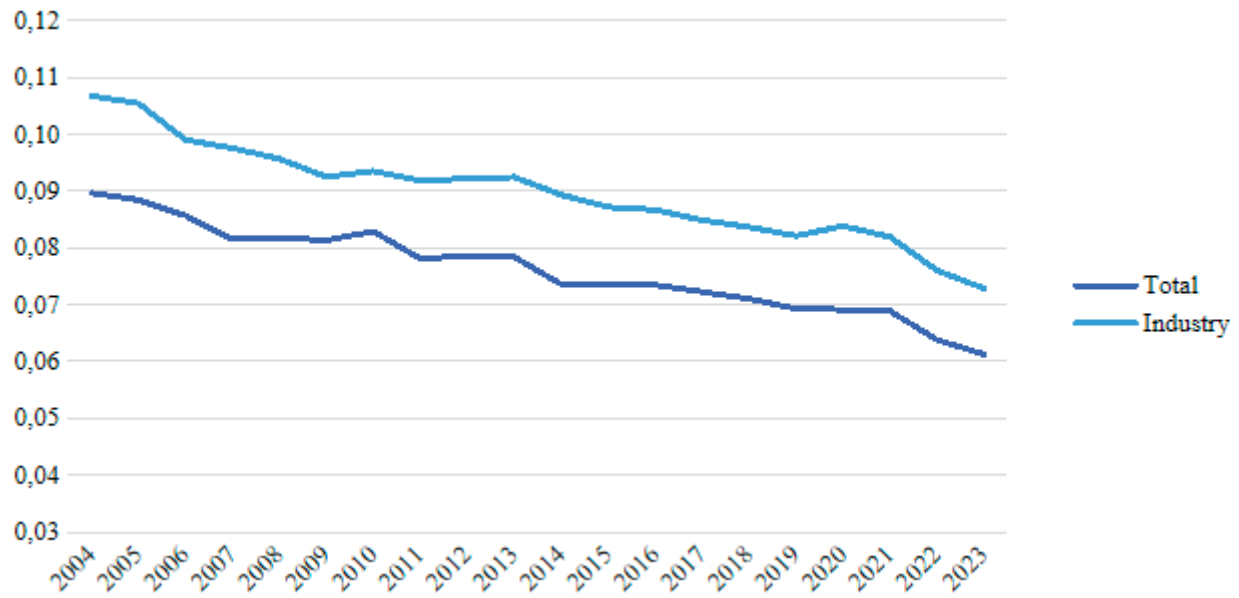
Under the updated framework, EU countries have committed to meeting this target by establishing indicative national contributions. These contributions will be determined using a set of objective criteria that consider national circumstances, such as energy intensity, GDP per capita, energy savings potential, and previous energy efficiency efforts. The directive also introduces an enhanced "gap-filling mechanism," which will be activated if countries fall short of their national contributions. In setting these indicative national contributions, member states could use either the projections of the 2020 reference scenario or its updated version (communicated to them in December 2023). In March 2024, the EC communicated corrected indicative national contributions (also covering the update of the reference scenario) to be used in each country's updated integrated national energy and climate plans (NECPs) in June 2024.

In 2023, primary energy consumption in the EU, which refers to energy contained in natural resources in their unprocessed form, totalled 1,210 Mtoe. This was the lowest level since 1990, marking a 3.9% decrease compared to 2022. Final energy consumption, which refers to energy directly supplied to end-users, reached 894 Mtoe, a decrease of 3%. Unfortunately, this value still exceeds the 2030 target of 763 Mtoe by 17.2% (Eurostat 2025a).

Energy efficiency trends

Energy efficiency is broadly defined in the simplest way as the ratio of output (services, goods, or energy) to the input of energy (e.g., Phylipsen, Blok, and Worrell 1997; Skoczkowski and Bielecki 2016; Sinevičiene, Sotnyk, and Kubatko 2017; Deka et al. 2023; Sallam and Sadraoui 2025; Song, Liu, and Hussain 2025). Although alternative approaches to measuring energy efficiency exist such as estimating efficiency frontiers using data envelopment analysis (e.g., Liu et al. 2020; Zhang et al. 2022) or applying principal component analysis (e.g., Ahmad and Uddin 2025) we rely on a standard measure to ensure the comparability of results and to facilitate the derivation of clear and interpretable policy recommendations. The energy intensity indicator is usually used to assess progress in energy efficiency, which reflects the level of energy consumption per unit of economic output. This is an extremely important topic for the EU, which faces significant challenges arising from dependence on energy imports, limited energy resources, and the need to mitigate the human impact on climate change. Striving to improve energy efficiency is one of the best ways to address these challenges. Reducing primary and final energy consumption contributes to decreasing energy imports, thereby enhancing the security of energy supply to the EU. Cutting energy consumption also translates into a cost-effective reduction in greenhouse gas emissions, thus mitigating the negative impact on climate change.

The data in Figure 1 show EU energy intensity at both macroeconomic and industry levels, where lower values indicate better energy efficiency. From 2004 to 2023, macro-level energy intensity declined consistently from 0.09 to 0.06 (a 1.58% annual reduction), while industry-level intensity fell from 0.11 to 0.07 (1.59%). This reflects a reduction in energy consumption per unit of output, suggesting improvements in energy efficiency or a shift to less energy-intensive production methods.



Note: koe denotes kilograms of oil equivalent.

Figure 1. Final energy intensity at EU average (2004–2023) (koe/EUR2015)
Source: own elaboration based on Odyssee 2025.

Improvements in energy intensity at macro and industrial levels are encouraging, suggesting that overall energy use is becoming more efficient. However, the pace of change differs across member states and highlights a missed opportunity for further improvements in energy efficiency that could lead to better economic and environmental outcomes.

Table 1. Descriptive Statistics of Energy Intensity of Industry by Country (2004–2023, koe)

Country	mean	Std	min	max
European Union	0.090	0.009	0.073	0.107
Austria	0.094	0.006	0.079	0.104
Belgium	0.137	0.009	0.119	0.156
Bulgaria	0.136	0.033	0.105	0.212
Croatia	0.079	0.008	0.064	0.094
Cyprus	0.093	0.017	0.074	0.145
Czechia	0.089	0.023	0.066	0.153
Denmark	0.057	0.008	0.039	0.067
Estonia	0.089	0.031	0.047	0.144
Finland	0.262	0.014	0.241	0.305
France	0.089	0.006	0.079	0.100
Germany	0.079	0.006	0.066	0.088
Greece	0.086	0.011	0.067	0.107
Hungary	0.071	0.009	0.057	0.082
Ireland	0.030	0.011	0.011	0.045
Italy	0.079	0.008	0.063	0.096

Country	mean	Std	min	max
Latvia	0.113	0.015	0.083	0.133
Lithuania	0.066	0.011	0.044	0.085
Luxembourg	0.143	0.027	0.099	0.182
Malta	0.035	0.004	0.029	0.043
Netherlands	0.124	0.016	0.091	0.153
Poland	0.077	0.019	0.052	0.123
Portugal	0.096	0.016	0.061	0.123
Romania	0.077	0.020	0.053	0.129
Slovakia	0.112	0.025	0.074	0.172
Slovenia	0.099	0.019	0.063	0.140
Spain	0.085	0.007	0.073	0.102
Sweden	0.148	0.013	0.123	0.169

Source: own elaboration based on Odyssee 2025.

Based on the descriptive statistics in Table 1, it is possible to assess the progress in the energy intensity of member states' industrial sectors over the past 20 years. The average energy intensity rate for the entire EU serves as a reference point for assessing the position of individual countries; in the period analyzed, it amounted to 0.090. The standard deviation for the EU is 0.009, and the values ranged from 0.073 to 0.107. When analyzing changes in individual countries, there are significant differences in the average energy intensity. The highest averages were recorded in Finland (0.262), Sweden (0.148), and Luxembourg (0.143), significantly exceeding the EU average. In contrast, the lowest mean values were observed in Ireland (0.030), Malta (0.035), and Denmark (0.057).

The variation across countries, measured by standard deviation, also differs significantly: countries with a higher standard deviation were characterised by greater variability over the period analysed, e.g., Bulgaria (0.033), Estonia (0.031), and Luxembourg (0.027). Countries with a lower standard deviation, such as Austria (0.006), France (0.006), and Germany (0.006), had a more stable energy intensity over the period analysed.

Looking at the minimum and maximum values, one can see the range of changes in energy intensity across countries; for example, in Finland, the intensity varied from 0.241 to 0.305, indicating a relatively high and narrow range compared to other countries. In Bulgaria, the range was much wider from 0.105 to 0.212 confirming the greater variability indicated by the higher standard deviation.

In summary, the analysis of descriptive statistics reveals significant differences in average energy intensity between EU member states. Some countries consistently maintained higher or lower values across the period analysed, while others showed greater variability.

Variable selection and model framework

To investigate the determinants and dynamic interactions shaping the energy intensity of industry in the EU (or, more precisely, its inverse, interpreted as energy efficiency), this study employs a panel data framework comprising 27 EU member states over a 20-year period (2004–2023). The key (dynamic) explanatory variables include average industrial energy prices (at constant prices), GDP per capita (in purchasing power parities), net GHG emissions, and renewable energy consumption in industry (as a share of the total). Additionally, we explore the short-run effects of environmentally related tax revenue (as % of total taxes), total environmental taxes (in EUR millions), and the Environmental Policy Stringency Index. This multidimensional dataset captures both economic and environmental policy drivers that potentially influence energy efficiency outcomes across countries and over time.

The selection of explanatory variables was preceded by a literature review and cross-referenced with the availability and consistency of statistical data across the EU-27 panel. The chosen determinants capture the multifaceted nature of industrial energy efficiency, reflecting market mechanisms, structural economic shifts, and the regulatory landscape. A primary driver of efficiency improvements is the trajectory of industrial energy prices. According to the Hicks Induced Innovation Hypothesis, an increase in the relative price of a factor of production (in this case, energy) serves as a market signal that motivates firms to innovate and adopt advanced technologies that utilize that factor more sparingly (Evan and Holý 2021). The role of economic development is examined through a generalized interpretation of the Environmental Kuznets Curve hypothesis. This theory suggests that as national income increases (represented by GDP per capita), economies undergo a profound structural and qualitative transformation.

Countries typically transition from energy-intensive, heavy-manufacturing stages toward higher value-added, high-tech industrial bases, which are inherently more energy-efficient (Stern 2003). Furthermore, GHG emissions are included as a critical determinant due to their link to energy intensity. This is particularly relevant in the industrial sector, where fossil fuel combustion remains an important energy source (European Environment Agency 2023). The decarbonization of industrial processes often necessitates the radical improvement of energy efficiency, particularly as the transition toward renewable energy consumption often coincides with the adoption of highly efficient technologies (Akram et al. 2020). Finally, to account for the impact of the regulatory environment, the model incorporates environmentally related tax revenues and the Environmental Policy Stringency Index (utilized in a related context by Song, Liu, and Hussain 2025). From the perspective of the Porter Hypothesis, such regulatory pressures can trigger "innovation offsets," prompting industries to enhance their energy efficiency to maintain competitiveness in the face of rising environmental compliance costs.

Table 2. The initial diagnostic variables

Description	Unit	Source
Energy intensity of industry (Eint)	koe/EUR2015	Odyssee (2025)
Net greenhouse gas emissions (GHG)	Tonnes per capita	Eurostat (2025b)

Description	Unit	Source
Average energy prices for industry at constant prices (Price)	EUR2015/toe	Odyssee (2025)
Renewable energy consumption of industry (RES)	Percentage of total	Odyssee (2025)
GDP per inhabitant at purchasing power parities (GDP)	EUR2015	Odyssee (2025)
Environmentally related tax revenue (Rev)	Percentage of GDP	OECD (2025a)
Total environmental taxes (Taxes)	EUR millions	Eurostat (2025c)
Environmental Policy Stringency Index (EPS_index)	0–6 index number	OECD (2025b)

Source: own elaboration.

Given the panel structure and the possibility of non-stationarity in the time series data, the analysis begins with panel unit root tests (such as Levin, Lin, and Chu 2002; Im, Pesaran, and Shin 2003) to assess the stationarity properties of each variable. Following this, panel cointegration tests (e.g., Kao) examine the existence of long-run equilibrium relationships between energy intensity and its determinants. To explore the direction and nature of causality, panel Granger causality tests identify both short- and long-term causal dynamics among variables.

This study employs Chudik and Pesaran's (2015) CS-ARDL model to examine the determinants of energy efficiency across a panel of countries. The CS-ARDL approach is particularly well suited to macro panel data, where cross-sectional dependence, unobserved global shocks, and heterogeneous short-run dynamics are likely to be present. Traditional panel estimators may yield biased or inconsistent results in such settings, whereas the CS-ARDL estimator mitigates these concerns by augmenting the regression with cross-sectional averages of both dependent and explanatory variables. This augmentation captures unobserved common factors such as global technological trends, international energy price shocks, or coordinated policy shifts that simultaneously affect all countries. Moreover, this method has been recently utilized in several related studies, including Deka et al. (2023), Ahmad and Udin (2025), Sallam and Sadraoui (2025), and Song, Liu, and Hussain (2025). However, only Ahmad and Udin (2025) considered energy efficiency as the dependent variable, but they measured it in a different way (applying principal component analysis) and focused on a different set of countries (BRICS). The empirical specification estimated in this study is given by the following formula:

$$\ln EE_{it} = \phi_i \ln EE_{i,t-1} + \beta_i' \boldsymbol{X}_{it} + \gamma_i' \bar{\boldsymbol{Z}}_t + u_{it},$$

where $i = 1, \ldots, N$ indexes countries and $t = 1, \ldots, T$ denotes time; $\ln EE_{\mathrm{it}}$ is the natural logarithm of the energy efficiency indicator in country i at time t, while $\ln EE_{i,t-1}$ is its one-period lag, capturing dynamic persistence in energy efficiency, ϕ_i is a country-specific autoregressive coefficient; $\boldsymbol{X}_{\mathrm{it}}$ is a vector of observed explanatory variables affecting energy efficiency (such as income, energy prices, emissions, taxes, renewable energy share, or policy indicators), with an associated country-specific coefficient vector $\boldsymbol{\beta}_i$. $\bar{\mathbf{Z}}_t$ denotes the vector of cross-sectional averages of the variables included in the model, which serves as a proxy for unobserved common factors and global shocks affecting all countries; $\boldsymbol{\gamma}_i$ is the corresponding vector of heterogeneous factor loadings. Finally, u_{it} is an idiosyncratic error term assumed to be weakly cross-sectionally correlated once the common factors are accounted for.

Empirical Results

The empirical analysis is carried out on transformed variables: the energy intensity of industry is inverted to represent energy efficiency (EEff, illustrated by Figure 2 below). Furthermore, whenever an elasticity interpretation of the estimated coefficient is justified, the logarithms of the variables are computed (including EEff, GHG Price, GDP, and Taxes). Given data availability and preliminary test results, the long-term relationship between energy efficiency (the dependent variable) and energy prices, GDP, and GHGemissions is examined. In contrast, the remaining variables of interest (share of renewable energy sources, share of environmental taxation in GDP, environmental policy stringency index, and total environmental taxes) are considered only in the short-term dynamics.

Before proceeding to a formal analysis of the relationships among these variables, the correlations among them in their raw form are studied. Detailed results are given in Table 3 below and can be summarized as follows: strong positive (and significant) correlations exist between the following pairs of variables: GDP and GHG emissions (0.651), energy efficiency and energy prices (0.378), as well as between the environmental policy stringency index and environmental tax revenues (0.333). The strongest negatively correlated variable is renewable energy share with energy efficiency (–0.246), GHG emissions (–0.293), or again with environmental tax revenues (–0.250). Other variables seem to be somewhat less strongly correlated; however, some of these coefficients are still statistically significant.

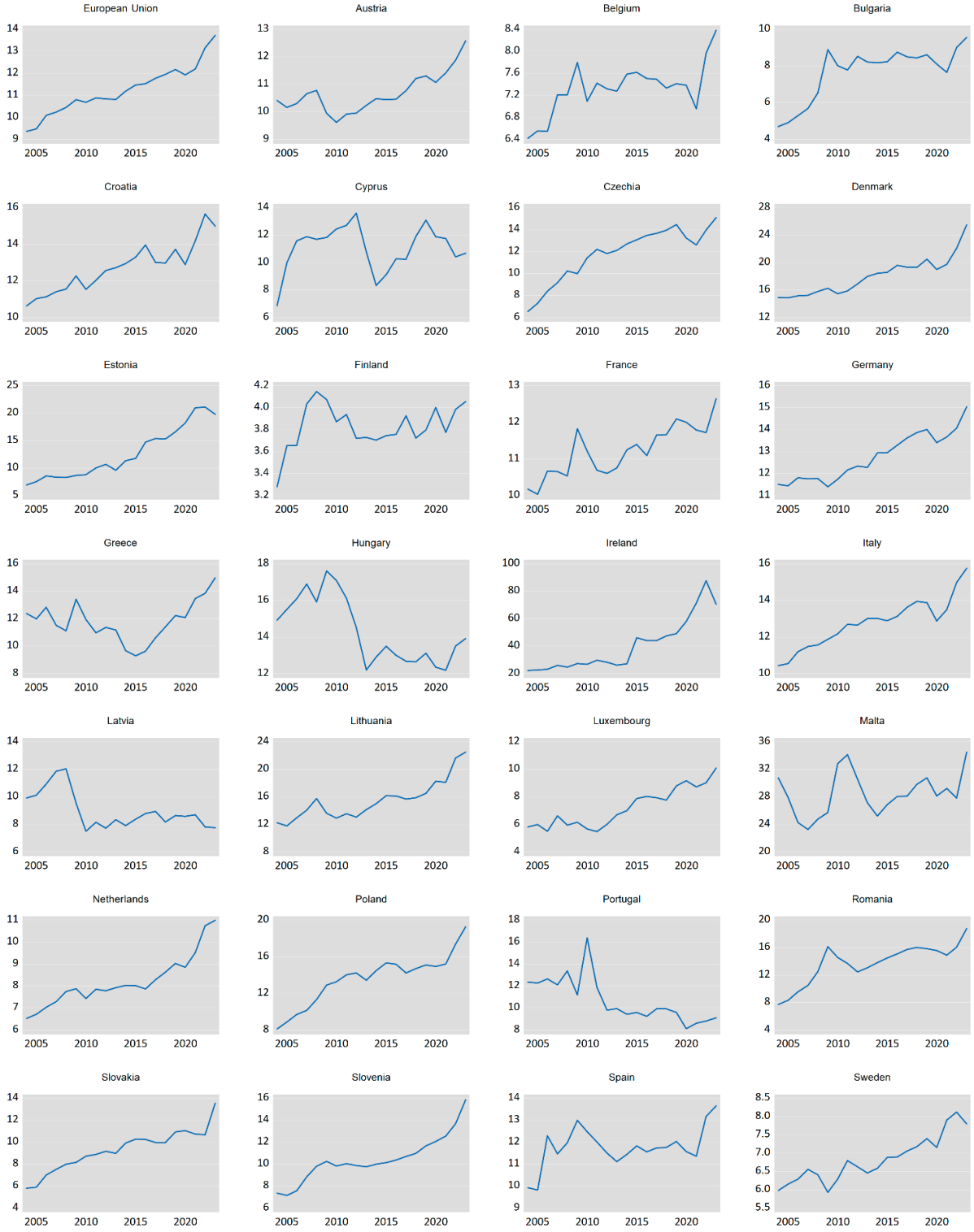


Figure 2. Energy efficiency in the European Union and its member countries, 2004–2023 (EUR2015/koe)
Source: own computations based on Odyssee 2025.

Table 3. Analysis of the correlation between the selected variables

Correlation P-value	Eeff	Prices	GDP	GHG	RES	Rev	Taxes	EPS_index
Energy eff.	1.000							
	–							
Prices	0.378	1.000						
	0.000	–						
GDP	0.224	0.136	1.000					
	0.000	0.002	–					
GHG	0.057	−0.042	0.651	1.000				
	0.199	0.346	0.000	–				
RES	−0.246	−0.148	−0.049	−0.293	1.000			
	0.000	0.001	0.254	0.000	–			
Rev	−0.193	0.125	−0.237	−0.005	−0.014	1.000		
	0.000	0.013	0.000	0.920	0.787	–		
Taxes	−0.067	0.126	0.074	−0.026	−0.250	−0.038	1.000	
	0.275	0.039	0.223	0.673	0.000	0.586	–	
EPS_index	−0.097	0.151	0.224	−0.095	0.140	0.167	0.333	1.000
	0.083	0.007	0.000	0.087	0.012	0.003	0.000	–

Source: own computations based on data described in Table 2.

Empirical investigation of the relationships and causality among these variables is initiated with a battery of panel stationarity tests that were conducted on the variables utilized in the dynamic part of the regression. In general, all variables exhibit non-stationarity in levels at the standard 5% significance levels and attain stationarity in first differences; they are, therefore, integrated of order 1, I(1). Detailed results of these procedures are summarized in Tables 4 and 5 below. Subsequently, panel cointegration tests examine whether some long-run relationships exist among the key variables. Specifically, the Kao (1999) residual-based cointegration test, which relies on an ADF-type regression, is applied. This test unambiguously indicates the presence of cointegration among the five variables considered for the long-run analysis, with a t-statistic of –5.5. and a corresponding p-value below 0.000. We then conduct Fisher ("combined Johansen") cointegration tests to detect the number of cointegrating relationships. Given the limited number of observations, the analysis is conducted using two sub-groups of long-run variables: energy efficiency, energy prices, and GDP, with the fourth variable being either (the log of) GHG emissions or the share of renewable energy. Both tests indicate the existence of two cointegration relationships in these groups[1].

1 Detailed results or data and E-views commands for replication are available upon request.

Table 4. Results of panel unit root tests of the levels of the variables relevant for the long-run analysis

Variable	Energy efficiency (ln_eeff)			Energy prices (ln_price)			GDP per capita (ln_GDP)			Net GHG emissions (ln_co2)			Renewable energy (RES)		
Method (test)	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.
Levin, Lin & Chu t*	−0.459	0.323	497	−2.253	0.012	493	0.438	0.669	485	−1.237	0.108	473	−0.318	0.375	495
Im, Pesaran and Shin W-stat	1.479	0.930	497	−2.057	0.020	493	3.562	0.999	485	0.197	0.578	473	2.663	0.996	495
ADF – Fisher Chi-square	63.11	0.185	497	71.52	0.055	493	29.17	0.998	485	66.81	0.113	473	53.76	0.484	495
PP – Fisher Chi-square	77.35	0.020	513	59.18	0.292	513	54.18	0.467	513	48.62	0.681	486	56.96	0.366	513

Notes: For all tests, the null hypothesis is that the panel series contain a unit root. Levin, Lin & Chu t* assumes a common unit root process, whereas the remaining IPS, ADF, and PP assume individual unit root processes. In all cases, the number of cross-sections (countries) is 27, and the number of lags is selected automatically based on the Schwartz Information Criterion (SIC). Tests assume individual constants and no trends. P-values for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Source: own computations based on the data described in Table 2. Software utilized: Eviews 10.

Table 5. Results of panel unit root tests of the first differences of the variables relevant for the long-run analysis

Variable	Energy efficiency (ln_eeff)			Energy prices (ln_price)			GDP per capita (ln_GDP)			Net GHG emissions (ln_co2)			Renewable energy (RES)		
Method (test)	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.	Statistic	Prob.	Obs.
Levin, Lin & Chu t*	−14.21	0.000	477	−13.41	0.000	474	−15.45	0.000	467	−17.50	0.000	453	−16.82	0.000	479
Im, Pesaran and Shin W-stat	−13.61	0.000	477	−12.07	0.000	474	−13.46	0.000	467	−15.95	0.000	453	−15.55	0.000	479
ADF – Fisher Chi-square	266.5	0.000	477	239.8	0.000	474	262.9	0.000	467	307.6	0.000	453	306.0	0.000	479
PP – Fisher Chi-square	326.7	0.000	486	276.5	0.000	486	401.2	0.000	586	428.9	0.000	459	331.8	0.000	486

Notes: See Table 4 above.

Source: own computations based on the data described in Table 2. Software utilized: Eviews 10.

Next, we proceed to the Granger causality analysis via the pairwise Dumitrescu–Hurlin test. The results conducted in the panel setup among the five long-run variables are summarized in Table 6. The main insights are as follows: energy prices and GHG emissions Granger-cause energy efficiency (but not vice-versa), whereas the relationships between energy efficiency and both GDP and the share of renewable energy sources are bi-directional. Additionally, two-way Granger causality is detected between energy prices and GHG emissions, energy prices, and the share of renewable energy, as well as between GDP and renewable energy share. On the other hand, the null hypothesis of no homogeneous causal relationship in any direction cannot be rejected between GDP and greenhouse gas emissions, and the share of renewable energy.

Table 6. Results of the Dumitrescu-Hurlin panel Granger causality test

Null Hypothesis	W-Stat.	Zbar-Stat.	Prob.
LN_PRICE does not homogeneously cause LN_EEFF	7.13308	8.72407	0.0000
LN_EEFF does not homogeneously cause LN_PRICE	2.99817	1.16066	0.2458
LN_GDP does not homogeneously cause LN_EEFF	5.05157	4.91664	9.E-07
LN_EEFF does not homogeneously cause LN_GDP	3.43555	1.96069	0.0499
LN_GHG does not homogeneously cause LN_EEFF	3.55868	2.04827	0.0405
LN_EEFF does not homogeneously cause LN_CO2	2.50071	0.17802	0.8587
RES does not homogeneously cause LN_EEFF	4.59940	4.08956	4.E-05
LN_EEFF does not homogeneously cause RES	4.53845	3.97807	7.E-05
LN_GDP does not homogeneously cause LN_PRICE	2.68241	0.58308	0.5598
LN_PRICE does not homogeneously cause LN_GDP	3.21237	1.55247	0.1206
LN_GHG does not homogeneously cause LN_PRICE	6.08826	6.51998	7.E-11
LN_PRICE does not homogeneously cause LN_CO2	4.38219	3.50405	0.0005
RES does not homogeneously cause LN_PRICE	4.00979	3.01107	0.0026
LN_PRICE does not homogeneously cause RES	4.20569	3.36941	0.0008
LN_CO2 does not homogeneously cause LN_GDP	3.27983	1.55534	0.1199
LN_GDP does not homogeneously cause LN_CO2	3.15853	1.34091	0.1799
RES does not homogeneously cause LN_GDP	4.70923	4.29045	2.E-05
LN_GDP does not homogeneously cause RES	3.47744	2.03732	0.0416
RES does not homogeneously cause LN_CO2	2.45726	0.10123	0.9194
LN_GHG does not homogeneously cause RES	2.59516	0.34500	0.7301

Notes: Number of lags included: 2.

Source: own computations based on data described in Table 2. Software utilized: Eviews 10.

As indicated by Table 6, energy efficiency is Granger-caused by all four other variables retained for the PMG regression analysis. Additionally, as mentioned above, the existence of cointegration relationships among these variables was confirmed. Thus, it is fully justified to utilize the CS-ARDL approach with energy efficiency as the dependent variable, as presented in the methodology section. The key results are presented in Table 7 below.

Table 7. Results of Cross-Sectionally augmented Auto-Regressive Distributed Lag estimations of the determinants of energy efficiency

	Baseline	M2	M3	M4	M5
GDP (long run)	1.065***	1.411***	1.238***	0.798**	0.965*
	(0.009)	(0.006)	(0.001)	(0.016)	(0.062)
En. price (long run)	0.147*	0.160	0.117	0.196**	0.828
	(0.076)	(0.182)	(0.302)	(0.034)	(0.282)
GHG emissions (long run)	−0.257*	−0.727**		−0.224*	0.019
	(0.067)	(0.026)		(0.084)	(0.941)
RES (long run)		−0.764	−0.568	−0.247	
		(0.330)	(0.318)	(0.307)	
Taxes (long run)			−0.269	−0.307**	
			(0.130)	(0.041)	
EPS_index (long run)					−0.137
					(0.134)
Adjustment term	−0.946***	−0.848***	−0.998***	−1.117***	−0.934***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP (short run)	1.067***	1.115***	0.967***	0.891***	0.548**
	(0.000)	(0.000)	(0.001)	(0.006)	(0.030)
Energy prices (short run)	0.112	0.073	0.160*	0.227**	0.124
	(0.124)	(0.281)	(0.082)	(0.036)	(0.391)
GHG emissions (short run)	−0.207	−0.425***		−0.185	0.055
	(0.105)	(0.001)		(0.221)	(0.809)
RES (short run)		−0.213	−0.193	−0.113	
		(0.328)	(0.311)	(0.294)	
Taxes (short run)			−0.138	−0.228*	
			(0.194)	(0.064)	
EPS_index (short run)					−0.056
					(0.114)
CD-stat	0.707	−0.551	1.053	1.574	0.803
CD p-value	0.480	0.581	0.292	0.115	0.422
Observations	486	486	474	474	304
R-squared	0.249	0.205	0.256	0.156	0.162

p-values in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: own elaboration based on data described in Table 2. Software utilized: STATA 15. Package xtdcce2 (Ditzen 2018; 2021).

The results presented in Table 7 indicate that, across all specifications, GDP emerges as a robust and positive long-run determinant of energy efficiency. The estimated elasticities are statistically significant in all models, although their magnitude varies with the inclusion of additional controls. This suggests that higher income levels are associated with sustained improvements in energy efficiency, which is consistent with scale effects, technological upgrading, and structural change accompanying economic development.

The effect of energy prices in the long run is positive but less stable across specifications. While the coefficient is statistically significant in the baseline and in Model M4, it loses significance once additional policy or structural variables are introduced. This indicates that price-based incentives may contribute to long-run efficiency gains, but their impact is sensitive to the broader policy and institutional environment.

GHG emissions exhibit a negative and statistically significant long-run association with energy efficiency in most specifications where they are included. This finding is consistent with the interpretation that higher emission intensity reflects less efficient energy use. However, the effect disappears once the EPS_index is introduced (M5), suggesting that broader environmental policy stringency may absorb part of the variation previously captured by emissions.

The coefficients on the renewable energy share are consistently negative but statistically insignificant across all models. This suggests that, at the aggregate level, increasing the share of renewables does not translate automatically into higher measured energy efficiency, possibly reflecting transitional adjustment costs or the fact that renewables primarily affect the energy mix rather than efficiency per se.

Environmental taxes exhibit a negative long-run effect on energy efficiency, which becomes statistically significant in the most comprehensive specification (M4). This suggests that fiscal instruments may exert a disciplining effect on energy use in the long run, although the magnitude and significance depend on the model specification.

Finally, the EPS_index enters with a negative but statistically insignificant coefficient, indicating that aggregate policy stringency does not have a direct long-run effect on the chosen efficiency measure once other covariates are controlled for.

In the short run, GDP retains a positive and highly significant effect across all specifications, although the estimated coefficients are generally smaller than their long-run counterparts. This demonstrates that cyclical economic expansions are associated with contemporaneous improvements in energy efficiency. Short-run effects of energy prices and GHG emissions are weaker and less consistent. While energy prices become significant in some specifications, and GHG emissions are significant only in Model M2, these effects are not robust across models, suggesting limited immediate adjustment of energy efficiency to price or emission shocks. Short-run coefficients on renewables, environmental taxes, and the EPS_ index are uniformly insignificant, reinforcing the view that policy and structural changes operate primarily through long-run channels rather than immediate responses.

The adjustment term is negative and highly significant in all models, with magnitudes close to unity. This indicates rapid convergence to the long-run equilibrium, suggesting that deviations from the steady-state level of energy efficiency are corrected within one period. The CD statistics and associated p-values suggest that cross-sectional dependence is adequately controlled for in all specifications, supporting the appropriateness of the CS-ARDL framework.

Taken together, the findings suggest that moderately high energy prices and higher GDP per capita contribute positively to energy efficiency in the long run. While this supports a dual strategy of maintaining effective energy price signals and fostering economic growth, caution is warranted. Although higher energy prices do not appear to undermine growth (as no Granger causality from prices to GDP was found, see Table 6 above), these findings are based on in-sample estimates. Extrapolating to out-of-sample scenarios such as sharp administrative energy price hikes would require careful policy consideration.

Robustness checks

To assess the robustness of the baseline results, we re-estimate the core specification using a range of alternative panel estimators that differ in their treatment of dynamics, slope heterogeneity, and cross-sectional dependence. In all cases, the same set of baseline regressors (GDP, energy prices, and GHG emissions) is retained to ensure comparability across models. The results are presented in Table 8.

Table 8. Robustness checks — determinants of energy efficiency estimated with alternative methods

	(1)	(2)	(3)	(4)	(5)
	CCE-pooled OLS in levels	Dynamic CCE-pooled OLS	Dynamic CCE-MG	Dynamic CCE-MG, CSA	CS-ARDL-ECM
GDP	0.976***	0.462***	0.466***	1.192***	1.222***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Energy prices	0.073*	0.129***	0.081***	0.099	0.079
	(0.056)	(0.003)	(0.003)	(0.180)	(0.280)
GHG emissions	−0.059**	−0.038	−0.089	−0.293***	−0.390***
	(0.046)	(0.234)	(0.185)	(0.003)	(0.000)
Lagged energy efficiency			−0.565***	−0.935***	−0.759***
			(0.000)	(0.000)	(0.000)
Adjustment term (ECM)					−1.759*** (0.000)
GHG emissions (long run)					−0.228***
					(0.001)
GDP (long run)					0.694***
					(0.000)

	(1)	(2)	(3)	(4)	(5)
	CCE-pooled OLS in levels	Dynamic CCE-pooled OLS	Dynamic CCE-MG	Dynamic CCE-MG, CSA	CS-ARDL-ECM
Energy prices (long run)					0.046
					(0.286)
Constant	−1.149	−2.355	−0.506*	1.300***	
	(0.367)	(0.159)	(0.082)	(0.007)	
CD-stat			4.312	−0.216	0.084
CD p-value			0.000	0.829	0.933
Observations	513	486	486	486	486
R-squared			0.324	0.213	0.278

p-values in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: own elaboration based on data described in Table 2. Software utilized: STATA 15, package xtdcce2 (Ditzen 2018; 2021).

We first employ a CCE-pooled OLS estimator in levels (Column 1), which provides a static benchmark while controlling for unobserved common factors through cross-sectional averages. The estimated coefficient on GDP is positive and highly significant, while GHG emissions exhibit a negative and statistically significant association with energy efficiency. Energy prices enter with a positive but only marginally significant coefficient. These findings are broadly consistent with the baseline CS-ARDL results, although the static nature of the model limits causal interpretation.

Next, we consider dynamic CCE-pooled OLS specifications estimated in first differences (Column 2). Allowing for dynamics substantially reduces the magnitude of the GDP coefficient, although it remains strongly significant. In contrast, the effect of GHG $_2$ emissions loses statistical significance, suggesting that emission-related effects may operate primarily through longer-run adjustment rather than short-run dynamics. Energy prices remain positive and significant in this specification.

Columns (3) and (4) report results from dynamic CCE mean group (CCE-MG) estimators, which relax the assumption of slope homogeneity across countries. Once heterogeneity is permitted, GDP continues to exert a positive and statistically significant effect, while the coefficients on energy prices and GHG emissions become less stable across specifications. In particular, GHG emissions regain a strong and negative effect when cross-sectional averages are explicitly included in the dynamic CCE-MG model (Column 4), underscoring the importance of adequately controlling for global shocks and common trends.

Finally, Column (5) presents estimates from a CS-ARDL-ECM specification, which conceptually would be the preferred framework, as it explicitly distinguishes between short-run dynamics and long-run equilibrium relationships. The estimated long-run coefficients are qualitatively consistent with the baseline results: GDP positively affects energy efficiency, while GHG emissions exert a negative long-run effect, even when energy prices remain statistically insignificant.

However, the estimated adjustment term is –1.759, indicating an adjustment speed well above unity in absolute value. Such a large coefficient implies overshooting, raising concerns about the stability of the error-correction mechanism. For this reason, and in line with standard practice in the CS-ARDL literature, this estimation strategy is not pursued further.

Overall, the robustness exercises confirm the sign, significance, and economic relevance of GDP as a key determinant of energy efficiency, as well as the generally negative association between GHG emissions and efficiency. At the same time, they underline that policy-relevant variables such as energy prices and emissions are more reliably identified in long-run frameworks with stable adjustment dynamics. Taken together, these results support the baseline findings while justifying our reliance on the stable CS-ARDL specification presented in the main analysis.

Conclusions and Policy Implications

Improving energy efficiency – central to sustainable development strategies – is a cornerstone of EU policy. The "energy efficiency first" principle has been legally codified, obligating member states to prioritize it in all major policy decisions and investments. Despite clear political commitments, progress remains uneven. While the EU's aggregate industrial energy intensity improved by an average of 1.59% annually between 2004 and 2023, statistical analysis reveals significant disparities among member states.

Key findings from the applied econometric CS-ARDL estimates point to economic development as the dominant driver of energy efficiency, while price signals and environmental policies play a more nuanced and specification-dependent role. Structural and policy variables appear to affect energy efficiency primarily through long-run adjustment mechanisms rather than short-run fluctuations. Granger causality tests revealed that energy prices and GHG emissions are causes (in the Granger sense) of energy efficiency, while the relationships between energy efficiency, GDP, and the share of renewable energy are bidirectional.

Our findings are broadly consistent with the existing literature, including Sinevičienė, Sotnyk, and Kubatko (2017), Liu et al. (2020), and Ahmad and Uddin (2025). Similar to all three studies, we identify economic development (GDP) as a robust and positive determinant of energy efficiency, confirming that higher income levels and modernization are closely linked to more efficient energy use. In line with Liu et al. (2020) and Sinevičienė, Sotnyk, and Kubatko (2017), we also find a negative association between emissions and energy efficiency, which reflects the role of pollution intensity or undesirable output in lowering measured efficiency. Our results further resonate with their emphasis on structural and technological upgrading as key transmission channels. In contrast, and closer to Ahmad and Uddin (2025), we employ a CS-ARDL framework that explicitly accounts for cross-sectional dependence; however, while they report a consistently negative effect of energy prices on efficiency, our estimates suggest a positive but less robust price effect, indicating that the role of price incentives strongly depends on the applied measure of energy efficiency and may also be context- and specification-contingent. Overall, the three studies and our results converge

on the central importance of growth and decarbonization for improving energy efficiency, while pointing to heterogeneity in how market and policy instruments operate across countries and institutional settings.

This study contributes to the literature in several important ways. First, it provides new cross-country evidence on the determinants of energy efficiency using a CS-ARDL framework that explicitly accounts for cross-sectional dependence, heterogeneous dynamics, and global shocks features that were often overlooked in earlier panel studies. Second, by jointly distinguishing long-run equilibrium relationships from short-run adjustment dynamics, the analysis offers a more nuanced understanding of how economic growth, prices, emissions, and policy-related factors affect energy efficiency over different horizons. Finally, the results yield policy-relevant insights by showing that efficiency gains are primarily driven by long-run structural and decarbonization processes or price evolutions rather than immediate policy, thereby informing the design of growth-consistent and sustainability-oriented energy efficiency strategies.

In summary, moderately high energy prices and higher GDP per capita positively influence energy efficiency in the long run. This indicates that policies should focus on maintaining effective price signals and supporting economic growth, while exercising caution against abrupt administrative price changes. Higher energy prices and carbon costs have dual effects: they encourage investments in efficiency but also risk carbon leakage without proper safeguards. Additionally, geopolitical dynamics and external factors such as the United States' withdrawal from the Paris Agreement create uncertainty and underscore the need for resilient, self-sufficient energy systems and strategic industrial alliances. Separating industrial production from energy consumption requires sectoral transformational interventions. This is also highlighted by "The Clean Industrial Deal," a new document from February 2025, which emphasizes the EU's urgent need to reduce energy intensity in response to high energy costs and global competition. The deal aims to lower energy bills while promoting a transition to clean energy, supporting energy-intensive sectors such as steel and chemicals in decarbonizing and reducing costs. It also seeks to increase demand for EU-made clean products through sustainable procurement criteria and plans to mobilize over €100 billion for clean manufacturing and innovation. Furthermore, it focuses on integrating a circular economy to reduce waste and promote efficient resource use (European Commission 2025). An important initiative appears to be the creation of an integrated platform to monitor progress, share best practices, and enforce compliance. Linking EU financial support to measurable efficiency gains and decarbonization milestones can contribute to fulfilling the EU's dual mandates: climate leadership and industrial competitiveness.

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Zarządzanie transformacją energetyczną: stymulowanie poprawy efektywności energetycznej w przemyśle UE

Artykuł koncentruje się na identyfikacji kluczowych czynników determinujących poprawę efektywności energetycznej w sektorze przemysłowym Unii Europejskiej w latach 2004–2023. Analiza została osadzona w strategicznych ramach Europejskiego Zielonego Ładu oraz pakietu „Fit for 55" i odnosi się do wyzwania, jakim jest przyspieszenie transformacji energetycznej przemysłu przy jednoczesnym utrzymaniu jego globalnej konkurencyjności. W badaniu zastosowano model CS-ARDL (*Cross-Sectionally Augmented Autoregressive Distributed Lag*), który pozwala uwzględnić zależności przekrojowe oraz zróżnicowaną dynamikę krótkookresową pomiędzy państwami członkowskimi. Wyniki empiryczne wskazują, że wzrost gospodarczy oraz rosnące ceny energii stanowią istotne determinanty poprawy efektywności energetycznej przemysłu zarówno w krótkim, jak i długim okresie. Z kolei wyższy poziom emisji CO_2 wiąże się z niższą efektywnością energetyczną, co odzwierciedla utrzymującą się zależność od produkcji energochłonnej i wysokoemisyjnej. Uzyskane rezultaty podkreślają potrzebę spójnego łączenia modernizacji struktury gospodarczej z bodźcami cenowymi jako warunku realizacji unijnych celów klimatycznych.

Słowa kluczowe: CS-ARDL, efektywność energetyczna, transformacja energetyczna, przemysł UE

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How Climate Resilience Shapes Sovereign Credit Risk: A Cross-Country Comparative Study

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Abstract

This article aims to identify the impact of a country's climate risk resilience on its sovereign credit rating, and to answer whether a country's vulnerability can be mitigated by its readiness. The analysis also examines the robustness of the identified relationships, assessing their relevance to both investment-grade and speculative-grade countries. The study is based on a cross-country sample of 67 countries. It examines the relationship between sovereign credit ratings issued by Standard & Poor's and Moody's and the ND-GAIN climate risk index, including the effects of its vulnerability and readiness components. To examine the link between sovereign credit ratings and climate resilience, we employ a cluster analysis based on climate vulnerability, adaptive capacity, and sovereign credit ratings, complemented by a linear regression model. The results indicate a positive relationship between climate resilience and sovereign credit rating. Vulnerability to climate risk negatively affects the rating, whereas the positive impact of climate readiness is more pronounced in countries with higher credit ratings than in those with lower ratings. The conclusions offer new insights into the determinants of sovereign credit ratings and the impact of climate risk on a country's credibility, providing important implications for climate policy and for the methodologies used by credit rating agencies to assess sovereign ratings.

Keywords: climate risk, sovereign rating, vulnerability, readiness, ND-GAIN index
JEL: G24, G28, Q51, Q58

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Introduction

One of the most fundamental questions in economics concerns the reasons behind the wealth and stability of some countries and the poverty of others. In classical economic thought (Kuznets 1966; Kaldor 1967; Chenery, Robinson, and Syrquin 1986), development and prosperity are seen as a function of the availability of production factors and the ability to use them efficiently. The range of goods produced and the structure of export baskets also play a significant role (Felipe, Kumar, and Abdon 2014).

Contemporary growth theories emphasize the importance of research and development investment, innovation, education, institutional quality, and natural resources (Oikawa 2023). Climate change, on the one hand, depletes and reduces the economic efficiency of resources such as arable land and forests. On the other hand, it has a negative impact on human well-being. Climate risks significantly impact global financial markets, influencing asset pricing, diversification, and stability (Karkowska and Urjasz 2025). According to the International Monetary Fund, between 1970 and 2018, natural disasters caused damage amounting to 3–10% of GDP in emerging markets and 1–3% in advanced economies (International Monetary Fund 2020). These findings are consistent with empirical stress tests on the materialization of physical risk, which show GDP contractions of up to 5%, comparable to major recessions (Financial Times 2025).

S&P Global Ratings estimates that in the absence of adaptation measures, under a slow transition scenario where global temperatures rise by 3.6°C by the end of the 21st century, annual losses could reach up to 4.4% of global GDP (Feng et al. 2025). This leads to the conclusion that sovereign creditworthiness is increasingly exposed to physical and transition-related climate shocks. The result is strained fiscal profiles, which increase sovereign spreads and default risk, particularly in emerging markets (Li, Li, and Lu 2024).

The existing literature focuses either on microeconomic channels and mechanisms through which climate risk affects economic agents or on macroeconomic parameters. However, there is a distinct research gap regarding the impact of climate risk on sovereign creditworthiness, specifically when measured by long-term, stable sovereign ratings. Other measures of sovereign risk – both CDS premiums and premiums embedded directly in government bond yields – are highly volatile (especially default spreads), and their levels are determined not only by fundamental factors but also by speculative capital activity. Ratings assigned by rating agencies are much more stable and are assigned in accordance with the "through the cycle" and "forward-looking" philosophy, i.e., they take into account changes in the economic situation in the medium term. The nature of sovereign ratings corresponds to the nature of climate indices, which, due to slow changes in climate risk exposure and limited opportunities to adapt to climate change in the short term, are also characterised by relative stability. Therefore, sovereign ratings seem to be appropriate measures of sovereign risk to be confronted with climate resilience measures.

Previous research has focused on the relationships between climate risk and sovereign bond yields, risk premiums (Boitan and Marchewka-Bartkowiak 2022), and default probabilities (Cevik and Jalles 2022) – that is, parameters characterized by high volatility compared to sovereign

ratings. In contrast, studies that do use sovereign ratings as the dependent variable tend to focus on specific climate risk components (Bernhofen et al. 2024) or their decomposition into physical and transition risk (Cappiello et al. 2025). However, there is a lack of research aimed at integrating the static dimension of climate risk (exposure, sensitivity, and capacities to adapt) with its dynamic dimension. This latter dimension encompasses the ability to leverage investments into adaptation actions, as well as the quality and effectiveness of climate risk management. Therefore, our goal is to assess how climate risk resilience ultimately impacts sovereign risk.

This approach raises several important research questions: (i) To what extent does a country's climate resilience affect its sovereign credit rating, and does the strength of this effect differ across rating categories (investment-grade vs. speculative-grade)? (ii) Does higher climate vulnerability translate into lower sovereign credit ratings, indicating that vulnerability constitutes a material long-term credit risk? (iii) Can stronger adaptive capacity and climate readiness mitigate climate-related risks and contribute to higher sovereign credit ratings?

Accordingly, this article assesses the impact of a synthetic measure of climate risk resilience on sovereign ratings, as well as two key dimensions: vulnerability and readiness. We also examine the robustness of these relationships across countries with high (investment grade) and low (speculative grade) creditworthiness.

The ND-GAIN (Notre Dame Global Adaptation Initiative) Country Index is used as a comprehensive measure that integrates these two dimensions. The index combines vulnerability (reflecting exposure, sensitivity, and adaptive capacity) with readiness (encompassing economic, governance, and social components). We chose the ND-GAIN index for several reasons. First, it covers 180 of the 195 countries recognized by the United Nations and provides consistent time-series data dating back to 1995. Second, the index integrates both the passive (exposure) and active (capacities and conditions for its mitigation) dimensions of climate risk. Third, S&P used the tool to capture facets of potential vulnerability when ranking sovereigns for its report *Climate Change Is A Global Mega-Trend For Sovereign Risk* (Standard and Poor's 2014). Therefore, due to its stability and multidimensionality, it is highly suitable for comparison with sovereign ratings.

To investigate the impact of climate risk on sovereign creditworthiness, we analyse a cross-country sample of 67 countries over the period 2012–2023, exploring the relationship between S&P sovereign credit ratings and the ND-GAIN index. To estimate these relationships, we employed five models: (1) Pooled OLS as the baseline; (2) a model with additional macroeconomic variables; (3) a model with interaction terms to test for differing effect between investment-grade and speculative-grade countries; (4) a fixed-effects panel model controlling for unobservable, time-invariant characteristics (e.g., institutions, geography); and (5) a dynamic model that incorporates a lagged dependent variable to capture the persistence of ratings.

Although high correlation among ratings issued by all three entities is confirmed by Korzeb, Kulpaka, and Niedziółka (2019), we verified our results through robustness tests using Moody's ratings as an alternative.

Our findings suggest that, in general, a country's climate resilience has a positive influence on its sovereign credit rating. While high climate vulnerability and exposure to climate risk

correlate with lower ratings, this impact can be mitigated by readiness, which contributes positively to the rating. The strength of this readiness-driven effect diminishes as sovereign ratings decline.

This study presents a novel perspective on the credibility and stability of rating agency assessments and the determinants of rating changes – factors that are crucial for financing availability and cost, as well as the intensity and direction of international capital flows. By aligning with widely accepted climate risk transmission mechanisms used in stress testing, our findings offer predictive value for future rating agency methodologies and the ratings they assign.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature and develops the hypotheses. Section 3 outlines the methodology and data. Section 4 presents the empirical results, and Section 5 discusses them and provides a conclusion.

Literature review and hypotheses development

Climate risk is linked to the increasing frequency of extreme weather events and long-term climate changes that adversely affect ecosystems (Sheedy, Griffin, and Barbour 2017). These phenomena pose significant threats to human health, life, and overall well-being. Floods, rising sea levels, droughts, ozone layer depletion, wildfires, hurricanes, earthquakes, changes in seawater chemistry, and biodiversity loss cause substantial material damage, reduce access to drinking water, degrade formerly arable land, and lead to asset and income losses.

The growing frequency of extreme weather events and persistent climate change is classified as a physical risk. Individual extreme events represent acute physical risk, while long-term climate changes correspond to chronic physical risk (European Banking Authority 2020; Korzeb et al. 2024). Conversely, the economic and social consequences of climate mitigation efforts constitute the second component of climate risk, transition risk. This type of risk arises from additional costs associated with the energy transition, including regulatory changes (e.g., carbon taxes), shifting social preferences, and changes in market sentiment. These factors can weaken the financial position of high-emission companies by restricting access to capital or increasing its cost, reducing profitability, and impairing debt-servicing capacity (Monasterolo and Raberto 2018; NGFS 2025). Physical and transition risks are interconnected and may amplify each other (IPCC 2021).

Climate risk leads to reduced economic activity, disrupted supply chains, poverty, and unemployment. Beyond purely economic consequences, these effects also trigger social tensions, political polarization, migration, and international conflicts. The materialization of climate risk weakens the economy, which is why climate risk influences sovereign credit risk, measured by sovereign ratings (Korzeb, Kulpaka, and Niedziółka 2019). Two main transmission channels can be distinguished: climate risk's impact on the banking sector's condition and the resulting financial stability (Stawasz-Grabowska 2020), as well as its effect on the economy's macroeconomic parameters (Mitra et al. 2025).

Climate shocks worsen the quality of bank loan portfolios by weakening borrowers' financial standing and straining macro-financial conditions (Bank for International Settlements 2023),

which in turn affects the broader economy. Overall, rising climate risk leads to a deterioration in bank creditworthiness, as highlighted by Graff Zivin and Neidell (2014) and Dafermos, Nikolaidi, and Galanis (2018). However, Chalabi-Jabado and Ziane (2024) find that transition risks may positively influence both bank performance and lending growth, whereas physical risks exert a negative impact.

The deteriorating financial position of businesses and households, combined with the declining value of collateral (which negatively affects loan-to-value ratios), reduces borrowers' ability to service debt (Muzuva and Muzuva 2024). This ultimately impacts the financial sector, causing instability (Garmaise and Moskowitz 2009; Nieto 2019; Zhai et al. 2024; Ma et al. 2025), particularly within the banking system (Noth and Schüwer 2018; Zhang, Chang, and Xuan 2022). Financial instability resulting from worsening bank solvency and liquidity negatively affects sovereign ratings (Hu et al. 2020).

The performance of non-financial corporations, financial institutions, and households also influences the overall economy. Li, Li, and Lu (2024) suggest that climate risk significantly reduces credit supply to the private sector. A typical response to rising climate risk is a contraction in lending (Faiella and Natoli 2018). This weakening of credit activity negatively affects consumption and investment, which are key drivers of GDP (Barauskaitė Griškevičienė et al. 2021). Climate risk deteriorates key macroeconomic indicators (Bank for International Settlements 2021). Changes in these indicators, such as GDP growth, inflation, unemployment, fiscal imbalances, and external debt-to-GDP ratios, are among the primary determinants of sovereign ratings (Cantor and Packer 1996; Mellios and Paget-Blanc 2006; Afonso and Gomes 2010; Sehgal et al. 2018; Proença et al. 2022; Takawira and Mwamba 2022; Ben Mim, Nouira, and Mabrouk 2023; Overes and van der We 2023).

Among studies that examine the direct relationship between climate risk and sovereign ratings, Cappiello et al. (2025) stand out. Analyzing a sample of 124 countries, they suggest that higher physical risk – approximated by temperature anomalies and the frequency of natural disasters – is associated with lower sovereign ratings. In contrast, transition risk measures are not systematically incorporated into credit ratings. More ambitious CO_2 reduction targets and actual emission cuts have been linked to higher ratings following the Paris Agreement. Countries that have benefited from the green transition have also received better ratings since 2015.

Sovereign rating methodologies (Fitch Ratings 2020; S&P 2025; Moody's 2026) and empirical research findings increasingly integrate climate risk into their assessments. Furthermore, Lim, Goh, and Kwek (2023) suggest that for speculative-grade countries, institutional factors like government effectiveness and the ability to generate domestic resources to meet public obligations outweigh factors such as GDP growth and other macroeconomic variables – which are themselves influenced by climate risk. Based on these transmission channels, we formulate the following hypothesis:

H1: A country's climate resilience positively affects its sovereign credit rating; however, the climate-resilience premium is substantially weaker for speculative-grade countries.

Some research on the impact of climate risk on sovereign creditworthiness has focused on variables reflecting investor perceptions or country credit risk, such as sovereign bond yields and risk premiums (Boitan and Marchewka-Bartkowiak 2022) or default probabilities (Cevik and Jalles 2022). These studies incorporate the two key dimensions of climate risk: vulnerability and readiness.

A relatively new research area examines the impact of climate risk on sovereign ratings, i.e., rating agencies' assessments of a country's debt-servicing capacity. Using ratings from "the Big Three" agencies (S&P, Moody's, and Fitch) for 117 countries between 1995 and 2020 and the ND-GAIN index, Sun et al. (2023) found that after controlling for traditional sovereign rating determinants, vulnerability has a significant negative effect on sovereign ratings, while readiness positively influences creditworthiness. The impact is relatively stronger for developing and highly climate-affected countries.

Conversely, Ali, Usman, and Ahmad (2025) find that climate vulnerability and resilience indices do not strongly predict sovereign credit ratings in 15 countries (2020–2024) across developed or developing economies. This suggests that current sovereign rating methodologies may not fully incorporate climate-related risks, particularly in developed countries. Considering these empirical findings and the fact that countries in the Global South are relatively more exposed to climate risk, and that extreme climate events have a significant impact on their economies, we hypothesize:

H2: More climate-vulnerable countries receive lower sovereign ratings, confirming vulnerability as a material source of long-term sovereign credit risk.

Both climate readiness (Notre Dame Global Adaptation Initiative 2025) and sovereign credit ratings (Bissoondoyal-Bheenick 2005; Mutize and Nkhalamba 2021; Proença et al. 2022; Sun et al. 2023; Goel and Singh 2024; 2025) depend on factors, such as economic capacity for investment, governance quality, and social factors (including social inequality, ICT infrastructure, education, and innovation). Building on this overlap, we propose:

H3: A country's climate readiness positively affects its sovereign credit rating, reflecting its capacity to manage climate challenges effectively.

Hypothesis H3 is also consistent with the conclusion drawn by Shang et al. (2024), which states that national wealth and financial stability create the potential for effective climate risk management, for example, through investments in renewable energy.

Data and Methodology

To investigate the impact of climate risk on sovereign credit risk, we conduct an empirical study that integrates sovereign credit ratings with climate risk indicators. The analysis uses Standard & Poor's and Moody's country credit ratings, as well as climate risk measures derived from the ND-GAIN indices (Notre Dame Global Adaptation Initiative n.d.). Our study focuses on the period 2012–2023 and a sample of 67 countries (see Appendix), reflecting data availability

and the need to optimise the number of observations in the final dataset. It comprises two key dimensions of climate adaptation: vulnerability and readiness, calculated as follows:

$$NDG = (RI - VI + 1) \cdot 50, \tag{1}$$

where:
NDG – ND-GAIN Country Index ranges from 0 to 1; higher values indicate better climate resilience,
RI – Readiness Indicator ranges from 0 to 1; higher values indicate better preparation to adapt to climate change,
VI – Vulnerability Indicator ranges from 0 to 1; the lower the value, the less vulnerable the country is to climate-related risks.

For the estimations, alphanumeric sovereign credit ratings were transformed into a continuous numerical scale. The primary transformation follows the 21–0 scale applied by Korzebm Niedziółka, and Nistor (2023), where 21 corresponds to the highest creditworthiness (AAA) and 0 to default (D). To verify robustness, we employed the alternative 17–1 numerical conversion proposed by Afonso (2011) and re-estimated the models to assess the stability of the findings. This mapping ensures consistency across rating agencies and enables econometric analysis using a single numerical variable.

Our primary explanatory variables, climate indices (gain, vulnerability, and readiness), are derived from the ND-GAIN index. The vulnerability component captures exposure, sensitivity, and adaptive capacity across six critical sectors: food, water, health, ecosystem services, human habitat, and infrastructure. The readiness component reflects a country's ability to convert adaptation needs into actions by evaluating three domains: economic readiness, governance readiness, and social readiness. Together, these indices provide a comprehensive measure of both the challenges posed by climate hazards and the institutional and socioeconomic conditions that enable effective responses. Sourcing these indices from ND-GAIN ensures a transparent, standardized methodology for cross-country comparisons.

To investigate the relationship between climate risk and sovereign creditworthiness, we first conducted a cluster analysis based on countries' climate vulnerability, adaptive capacity, and sovereign credit ratings. This approach allowed us to group countries with similar climate risk profiles and examine patterns in credit ratings across these clusters. Subsequently, we performed panel regression analyses to verify the impact of climate risk indicators on sovereign credit ratings and to test the statistical significance of the observed relationships.

To validate the relationship between sovereign credit ratings and climate resilience, we estimated a set of regression models using the transformed S&P and Moody's Sovereign Credit Ratings (SCR_rating) as the dependent variable. In addition to the ND-GAIN measures (overall index, Vulnerability, and Readiness), the regressions include macroeconomic and institutional controls identified in the literature: GDP growth, inflation, government consumption (% of GDP), a speculative-grade dummy, and an interaction term (ND-GAIN × speculative-grade). Incorporating this dummy variable – defined as ratings below BB+, the standard S&P threshold separating investment-grade from speculative-grade credit quality – allows us to formally test

whether the impact of climate resilience differs across rating categories. This unified approach offers a more straightforward interpretation of cross-country heterogeneity.

The extended model specification takes the following form:

$$SCR\_rating_i = \alpha + \beta_1 ClimateRisk_i + \beta_2 Macro_i + \beta_3 Institutional_i + \varepsilon_i, \quad (2)$$

where *SCR* denotes the sovereign rating for country *i*, *ClimateRisk* represents the ND-GAIN indices (*Gain Index, Vulnerability, Readiness*), $Macro_i$ denotes the macroeconomic controls, and $Institutional_i$ includes the speculative-grade dummy and interaction term, and ε_i is the error term.

To test the robustness of the results, we estimated four types of models: a baseline OLS model, an OLS model with interaction terms, a fixed-effects (FE) panel model, and a dynamic panel model including the lagged dependent variable. These complementary specifications allow us to assess the stability and persistence of the relationship between climate resilience and sovereign ratings.

The descriptive statistics presented in Table 1 show that both S&P and Moody's sovereign credit ratings cluster around the middle–upper end of their respective scales, with mean values near 14 on the 0–21 scale and around 10 on the 1–17 scale. This indicates that the sample consists largely of countries with moderate to strong credit quality. The climate-related indices show relatively low average vulnerability (mean 0.36) and moderate readiness (0.50), suggesting that while countries generally face some exposure to climate risks, they possess a varying but overall moderate capacity to adapt. The ND-GAIN index exhibits substantial variation, with (mean ≈ 57), highlighting significant heterogeneity in potential climate-related benefits or adaptive opportunities across countries. Macroeconomic variables including GDP growth, inflation, and government consumption display wide ranges that reflect diverse economic conditions without appearing extreme on average.

Table 1. Descriptive statistics

	N	Mean	Median	SD	Min	Max
S&P rating (0–21 scale)	795	14.48	14.00	4.82	0	21
Moody's rating (0–21 scale)	803	14.13	14.00	5.18	0	21
S&P rating (1–17 scale)	803	10.25	10.00	4.93	1	17
Moody's rating (1–17 scale)	801	10.44	10.00	4.79	1	17
NC-GAIN	804	56.81	56.58	10.64	32.86	78.32
VULNERABILITY	804	.36	0.36	.06	.25	.57
READINESS	804	.5	0.48	.16	.15	.82
GDPgrowth	795	2.57	2.66	3.8	−17.67	24.48
Inflation	778	3.79	2.32	6.34	−2.1	72.31
Gov consum exp gdp	753	17.19	17.84	4.45	5.04	26.47

Sources: own study.

Results

To examine the relationship between climate risk and sovereign creditworthiness, we conducted a cluster analysis based on vulnerability, adaptive capacity, and credit ratings, followed by regression estimations assessing the impact of these factors on sovereign ratings. The results from both methods provide complementary insights, highlighting how variations in climate vulnerability and adaptive capacity are associated with differences in sovereign credit risk.

Cluster analysis

To explore patterns in climate risk and sovereign creditworthiness, we performed a cluster analysis using four variables: GAIN, Vulnerability, Readiness, and S&P sovereign credit ratings. A three-cluster solution was selected based on hierarchical and k-means clustering methods. Table 2 presents the summary statistics for each group.

Table 2. Summary statistics by climate-based clusters

	Mean	SD	N
Cluster 1			
ND-GAIN	47.96	5.69	388
VULNERABILITY	0.41	0.05	388
READINESS	0.37	0.08	388
S&P rating (0–21 scale)	10.52	3.03	388
Cluster 2			
ND-GAIN	70.35	3.02	216
VULNERABILITY	0.31	0.04	216
READINESS	0.72	0.05	216
S&P rating (0–21 scale)	20.2	1.13	216
Cluster 3			
ND-GAIN	60.24	3.06	191
VULNERABILITY	0.33	0.03	191
READINESS	0.53	0.05	191
S&P rating (0–21 scale)	16.07	2.22	191

Sources: own study based on credit rating agencies and Notre Dame Global Adaptation Initiative n.d., databases.

The clustering reveals three distinct groups that differ systematically in both climate characteristics and credit ratings.

- Cluster 1: Countries with the lowest climate readiness and the highest vulnerability. This group has the weakest average S&P rating, suggesting limited adaptive capacity and greater exposure to climate risks.
- Cluster 2: The most climate-resilient group. It combines exceptionally high readiness, low vulnerability, and the highest gain potential. This group also exhibits the strongest

credit ratings, indicating that climate resilience and sovereign creditworthiness tend to align.

- Cluster 3: An intermediate group. These countries have moderate readiness and vulnerability, as well as mid-range credit ratings.

Overall, the results show a transparent gradient: as climate resilience improves, sovereign ratings tend to rise. This supports the idea that climate risk factors are reflected in sovereign credit assessments.

Next, we conducted a one-way ANOVA to test whether sovereign credit ratings differ significantly across the three clusters. The analysis reveals a highly significant effect of cluster membership on ratings ($F(2, 792) = 1135.15$, $p < 0.001$). As Bartlett's test indicates strong evidence of unequal variances across clusters ($\chi^2(2) = 206.55$, $p < 0.001$), we also performed a Kruskal-Wallis test, which confirms substantial differences between groups ($\chi^2(2) = 616.77$, $p < 0.001$). Post-hoc Bonferroni comparisons show that all pairwise differences are statistically significant ($p < 0.001$), with Cluster 2 exhibiting the highest ratings and Cluster 1 the lowest. These results reinforce the strong association between climate resilience and sovereign creditworthiness.

Figure 1 illustrates the relationship between climate adaptation capacity and sovereign credit ratings across the three clusters.

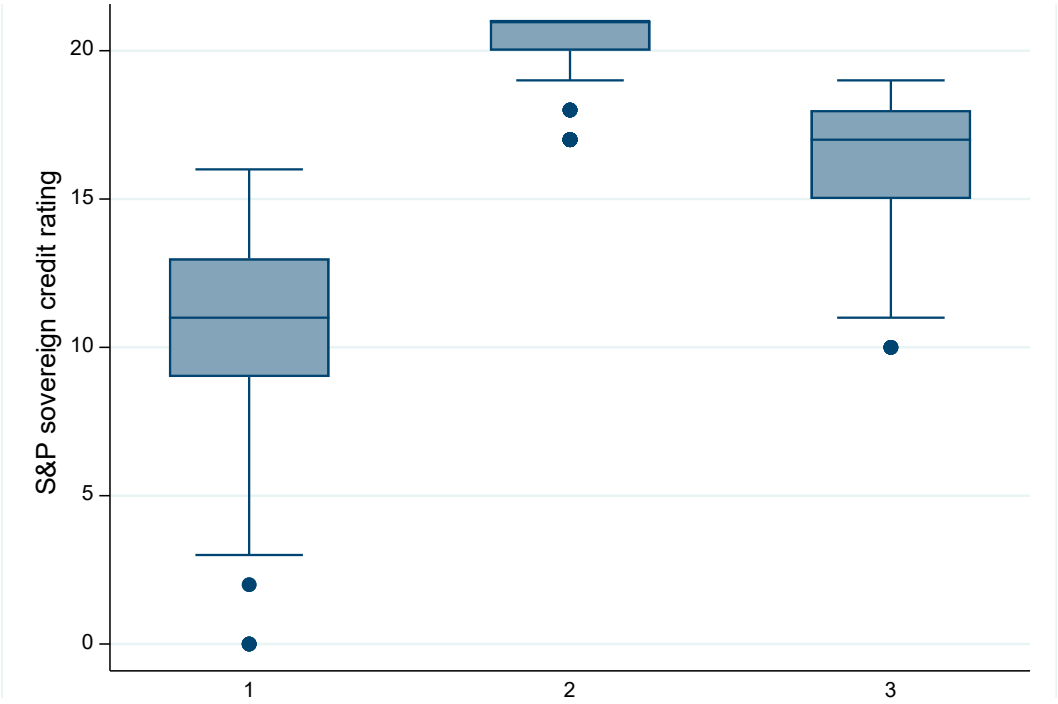

Figure 1. Sovereign Credit Ratings versus Climate Adaptation Capacity by Cluster
Sources: own study based on credit rating agencies and Notre Dame Global Adaptation Initiative n.d., databases.

The boxplot clearly illustrates substantial differences in sovereign credit ratings across the three climate-based clusters.

- Cluster 1 exhibits the lowest and most dispersed ratings, reflecting both weaker creditworthiness and greater heterogeneity among countries with high climate vulnerability and low readiness.
- Cluster 2 shows consistently high ratings with minimal variation, indicating that the most climate-resilient countries also achieve the strongest and most stable credit assessments.
- Cluster 3 occupies an intermediate position; while its ratings are higher than those in Cluster 1, they remain more variable and generally lower than those in Cluster 2.

Overall, the plot visually reinforces the strong relationship between climate resilience and sovereign credit ratings.

Regression analysis

Table 3 presents the regression estimations of the impact of climate resilience indicators on S&P sovereign credit ratings. The results provide robust evidence that climate-related factors significantly affect creditworthiness across multiple model specifications. In the baseline OLS model (1), the ND-GAIN index is strongly and positively associated with ratings (+1.566), indicating that countries better equipped to cope with climate risks tend to receive higher credit assessments. This finding supports Hypothesis 1 (H1) and aligns with prior research demonstrating that greater climate resilience enhances sovereign creditworthiness (e.g., Cevik and Jalles 2023; Naifar 2023; Yang and Hamori 2023).

Model (2), which incorporates an interaction term with speculative-grade status, further reveals that while climate resilience has a positive effect (+1.159), the resilience premium is significantly weaker for speculative-grade sovereigns. This confirms H1 by showing that rating agencies reward climate resilience more strongly in investment-grade countries, whereas resilience gains are discounted for lower-rated economies. This suggests that stronger institutions and greater adaptive capacity enhance the ability of high-rated economies to translate climate readiness into favorable credit outcomes. For lower-rated countries, by contrast, structural vulnerabilities and weaker institutions limit the extent to which climate resilience improves their credit standing.

These findings are consistent with Boehm (2022) who found that rising temperatures and climate anomalies negatively affect the sovereign creditworthiness of emerging economies, increasing borrowing costs. This further supports the view that institutional strength and adaptive capacity play a crucial role in mediating the relationship between climate risks and sovereign credit performance. A deeper interpretation of these findings highlights an important asymmetry in the role of climate factors across different levels of creditworthiness. In high-rated countries, well-developed financial markets, stable macroeconomic fundamentals, and stronger governance frameworks provide a conducive environment in which investments in climate readiness directly translate into measurable improvements in sovereign credit ratings. By contrast, in low-rated countries, fiscal imbalances, weaker governance, and limited adaptive capacity may dilute the observable impact of climate resilience indicators.

Model (8) demonstrates that climate vulnerability exerts a significant negative effect on credit ratings (–1.486), confirming Hypothesis 2 (H2). More climate-vulnerable economies are therefore penalized, likely due to their elevated exposure to climate-induced economic and fiscal stress. This finding is consistent with Sun et al. (2023), who documented that vulnerability to climate change adversely affects sovereign ratings and heightens long-term credit risk, particularly in developing or highly exposed economies.

Conversely, Model (5) demonstrates that climate readiness is positively associated with sovereign credit ratings (+0.889), supporting Hypothesis 3 (H3). This result indicates that countries with stronger institutional capacity and adaptive readiness to address climate-related challenges receive more favourable credit assessments. The significance of this effect across both static and dynamic specifications suggests that adaptive capacity contributes meaningfully to financial stability and investor confidence, consistent with Naifar (2023) and Sun et al. (2023).

Across the dynamic models, the lagged rating variable is large and highly significant, confirming the strong persistence characteristic of sovereign credit evaluations. The explanatory power of the models is substantial, as indicated by the high adjusted R-squared values, underscoring the relevance of climate resilience indicators in explaining variation in S&P's sovereign credit ratings beyond traditional macroeconomic factors.

Importantly, the results for Moody's ratings (Table 4) show a highly consistent pattern. The ND-GAIN index remains strongly positive in the baseline model (+1.824), while the interaction term again indicates a weaker resilience premium for speculative-grade issuers (–0.577), mirroring the S&P findings and reinforcing H1. Similarly, climate vulnerability exhibits a robust negative effect (–1.605), while readiness shows a strong positive association (+1.059), corroborating H2 and H3, respectively, and confirming that both agencies reward countries with greater adaptive capacity. The persistence of ratings is likewise evident in Moody's dynamic models, and the direction and significance of macroeconomic controls remain broadly aligned with the S&P estimations.

Collectively, the consistency between S&P and Moody's strengthens the conclusion that climate resilience, vulnerability, and adaptive readiness constitute meaningful and systematically evaluated components of sovereign credit risk. These findings carry two important policy and financial implications. First, they justify the integration of climate risk assessments into sovereign credit rating methodologies to accurately capture long-term credit risk. Second, they highlight the potential benefits for countries of investing in adaptive capacity, resilience strategies, and institutional readiness, as improved credit ratings reward such efforts. Ultimately, climate resilience is a key determinant of global financial stability, suggesting that credit rating agencies, investors, and policymakers should place greater emphasis on climate-related factors when assessing sovereign risk.

Table 3. Determinants of S&P's Sovereign Credit Ratings: Climate Risk, Macroeconomic Conditions, and Institutional Factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
L.SCR_rating				0.781***			0.781***			0.781***
				(0.032)			(0.032)			(0.033)
ND-GAIN	1.566***	1.159***	0.239*	0.130*						
	(0.046)	(0.044)	(0.123)	(0.077)						
READINESS					0.889***	0.095*	0.054			
					(0.026)	(0.052)	(0.033)			
VULNERABILITY								−1.486***	−0.464**	−0.164*
								(0.064)	(0.211)	(0.091)
GDP growth (%)		0.005***	0.004***	0.002***		0.004***	0.002***		0.004***	0.002***
		(0.002)	(0.001)	(0.000)		(0.001)	(0.000)		(0.001)	(0.000)
Inflation (%)		−0.003***	−0.003***	−0.003**		−0.003***	−0.003**		−0.003***	−0.003**
		(0.001)	(0.001)	(0.001)		(0.001)	(0.001)		(0.001)	(0.001)
Gov. cons. exp. (% GDP)		−0.005***	0.001	−0.001		0.002	−0.001		0.000	−0.002
		(0.002)	(0.003)	(0.002)		(0.003)	(0.002)		(0.004)	(0.002)
Speculative rating (dummy)		1.674***								
		(0.323)								
ND-GAIN x speculative rating		−0.535***								
		(0.083)								

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
Constant	−3.742***	−1.853***	1.652***	0.081	3.268***	2.679***	0.643***	1.091***	2.161***	0.445***
	(0.189)	(0.168)	(0.502)	(0.326)	(0.021)	(0.070)	(0.082)	(0.066)	(0.217)	(0.126)
Obs.	739	739	739	675	792	739	675	739	739	675
N, number of groups			64	64		64	64		64	64
Adj. R-squared	0.667	0.838	0.487	0.691	0.604	0.546	0.691	0.484	0.485	0.690

Note: Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1, speculative rating = 1 for speculative-grade sovereigns (BB+ and below).

Source: own study.

Table 4. Determinants of Moody's Sovereign Credit Ratings: Climate Risk, Macroeconomic Conditions, and Institutional Factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
L.SCR rating				0.705***			0.706***			0.705***
				(0.049)			(0.049)			(0.049)
ND-GAIN	1.824***	1.193***	0.204	0.011						
	(0.068)	(0.070)	(0.200)	(0.121)						
READINESS					1.059***	0.065	−0.018			
					(0.035)	(0.084)	(0.059)			
VULNERABILITY								−1.605***	−0.569*	−0.305**
								(0.094)	(0.343)	(0.151)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
GDP growth (%)		0.006***	0.005***	0.002		0.005***	0.002		0.005***	0.002
		(0.002)	(0.002)	(0.002)		(0.002)	(0.002)		(0.002)	(0.002)
Inflation (%)		−0.003**	−0.005***	−0.003**		−0.005***	−0.003**		−0.005***	−0.003**
		(0.002)	(0.001)	(0.001)		(0.001)	(0.001)		(0.001)	(0.001)
Gov. cons. exp. (% GDP)		−0.009***	0.001	−0.004		0.001	−0.004		−0.001	−0.004
		(0.003)	(0.006)	(0.003)		(0.006)	(0.003)		(0.006)	(0.004)
Speculative rating (dummy)		1.764***								
		(0.514)								
ND-GAIN x speculative rating		−0.577***								
		(0.132)								
Constant	−4.784***	−1.941***	1.780**	0.800*	3.346***	2.649***	0.831***	0.913***	2.044***	0.542***
	(0.273)	(0.267)	(0.816)	(0.437)	(0.029)	(0.113)	(0.158)	(0.097)	(0.353)	(0.147)
Obs.	801	738	738	674	801	738	674	801	738	674
N, number of groups			64	64		64	64		64	64
Adj. R-squared	0.476	0.703	0.564	0.568	0.530	0.436	0.568	0.267	0.474	0.569

Note: Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1, speculative rating = 1 for speculative-grade sovereigns (BB+ and below).

Sources: own study.

Robustness check

To further ensure that our results are not driven by the choice of rating agency or numerical conversion method, we conducted additional robustness estimations using estimations from the Afonso, Gomes, and Rother (2011) 17–1 scale for both S&P and Moody's ratings. Tables 5 and 6 present these results, which remain highly consistent with our baseline results, confirming the stability and reliability of the estimated effects.

Specifically, climate resilience (ND-GAIN) continues to exert a strong, statistically significant positive effect on S&P's ratings across specifications. The interaction term again indicates a weaker resilience premium for speculative-grade sovereigns, confirming the stability of H1. Climate readiness also remains positively associated with credit ratings, supporting H3 and demonstrating that adaptive capacity is robust to alternative transformations of credit ratings. Likewise, climate vulnerability retains its expected negative sign, strongly significant in the baseline OLS model, providing further evidence for H2. The persistence of sovereign ratings is reaffirmed in the dynamic models, with macroeconomic controls exhibiting the same direction and significance as in the main estimations. Overall, the robustness checks confirm that the relationships between climate factors and sovereign credit ratings are not sensitive to alternative rating scales, reinforcing the reliability of the core empirical results.

Table 5. Determinants of S&P's Sovereign Credit Ratings: Climate and Macroeconomic Factors. Ratings calculated according to the scale of Afonso, Gomes, and Rother (2011)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
L.SCR rating				0.690***			0.690***			0.690***
				(0.036)			(0.036)			(0.037)
ND-GAIN	2.524***	1.601***	0.422*	0.306*						
	(0.087)	(0.084)	(0.255)	(0.174)						
READINESS					1.441***	0.182*	0.133*			
					(0.047)	(0.108)	(0.075)			
VULNERABILITY								−2.323***	−0.663	−0.326
								(0.119)	(0.439)	(0.203)
GDP growth (%)		0.011***	0.008***	0.003***		0.008***	0.003***		0.008***	0.003***
		(0.003)	(0.002)	(0.001)		(0.002)	(0.001)		(0.002)	(0.001)
		(0.002)	(0.002)	(0.003)		(0.002)	(0.003)		(0.002)	(0.003)
Gov. cons. exp. (% GDP)		−0.010***	−0.001	−0.002		−0.001	−0.001		−0.003	−0.003
		(0.003)	(0.007)	(0.004)		(0.007)	(0.004)		(0.007)	(0.004)
Speculative rating (dummy)		0.683								
		(0.620)								
ND-GAIN x speculative rating		−0.357**								
		(0.159)								

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
Constant	−7.975***	−3.870***	0.572	−0.489	3.253***	2.399***	0.838***	−0.196	1.627***	0.427*
	(0.349)	(0.322)	(1.042)	(0.683)	(0.038)	(0.144)	(0.125)	(0.124)	(0.451)	(0.219)
Obs.	801	739	739.000	675.000	801	739.000	675.000	801	739.000	675.000
N, number of groups			64	64		64	64		64	64
Adj. R-squared	0.515	0.778	0.666	0.575	0.542	0.588	0.575	0.321	0.549	0.574

Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1, speculative rating = 1 for speculative-grade sovereigns (BB+ and below).

Sources: own study.

Table 6. Determinants of Moody's Sovereign Credit Ratings: Climate and Macroeconomic Factors. Ratings calculated according to the scale of Afonso, Gomes, and Rother (2011)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
L.SCR rating				0.819***			0.819***			0.819***
				(0.058)			(0.058)			(0.058)
ND-GAIN	2.669***	1.617***	0.220	0.082						
	(0.099)	(0.113)	(0.296)	(0.203)						
READINESS					1.506***	0.067	0.011			
					(0.053)	(0.125)	(0.097)			

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline OLS	OLS model with interaction	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model	Baseline OLS	FE panel model	Dynamic model
VULNERABILITY								−2.444***	−0.833	−0.263*
								(0.135)	(0.508)	(0.146)
GDP growth (%)		0.009**	0.006**	0.002		0.006**	0.002		0.006**	0.002
		(0.004)	(0.003)	(0.002)		(0.003)	(0.002)		(0.003)	(0.002)
Inflation (%)		−0.009***	−0.010***	−0.004*		−0.010***	−0.004*		−0.010***	−0.004*
		(0.003)	(0.002)	(0.002)		(0.002)	(0.002)		(0.002)	(0.002)
Gov. cons. exp. (% GDP)		−0.015***	0.002	−0.006		0.002	−0.006		−0.000	−0.007
		(0.004)	(0.008)	(0.005)		(0.008)	(0.005)		(0.008)	(0.005)
Speculative rating (dummy)		0.470								
		(0.830)								
ND-GAIN x speculative rating		−0.328								
		(0.213)								
Constant	−8.604***	−3.859***	1.315	0.186	3.409***	2.251***	0.525***	−0.367***	1.385***	0.258
	(0.398)	(0.431)	(1.209)	(0.833)	(0.125)	(0.168)	(0.165)	(0.140)	(0.522)	(0.164)
Obs.	803	738	738	674	738	738	674	803	738	674
N, number of groups			64	64		64	64		64	64
Adj. R-squared	0.476	0.692	0.492	0.667	0.485	0.384	0.667	0.290	0.477	0.667

Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1, speculative rating = 1 for speculative-grade sovereigns (BB+ and below).

Sources: own study.

Discussion and Conclusion

This study examines the influence of climate risk on sovereign credit ratings by integrating S&P's and Moody's sovereign credit ratings with climate risk indicators from the ND-GAIN Country Index.

Our results confirm that climate resilience is a significant determinant of sovereign credit ratings, aligning with Boitan and Marchewka-Bartkowiak (2022), Cevik and Jalles (2022), and Cappiello et al. (2025), who demonstrate that increasing climate risk is accompanied by rising costs of government borrowing or increasing sovereign risk. Specifically, higher overall resilience and stronger climate readiness are associated with higher credit ratings, whereas greater vulnerability is associated with lower credit ratings. While Ali, Usman, and Ahmad (2025) find limited support for this dependence, our findings provide robust evidence for the negative impact of vulnerability, consistent with Sun et al. (2023).

The subsample analysis further reveals that the positive effect of climate readiness is more pronounced in high-rated countries, where stronger institutions and adaptive capacity enable climate investments to translate more effectively into favorable credit outcomes. In low-rated economies, by contrast, structural weaknesses and limited institutional capacity diminish the impact of climate factors.

Indeed, Şeker and İşgüven (2025) note that while investment-grade countries would receive lower ratings if environmental factors (biodiversity) were taken into account, speculative-grade countries with lower credit ratings could achieve higher ratings by considering environmental factors. Therefore, our results shed new light on the relationship between climate risk and investment and speculative sovereign ratings. The discrepancy suggests that the direction of the relationship between the synthetic measure of climate risk and the sovereign rating may differ from that of individual climate risk composites or dimensions and the ratings assigned by rating agencies.

The novelty of this study mainly lies in providing new insights into the determinants of sovereign ratings. Our results provide important practical implications for governments since the costs of current and planned climate policies (which positively affect climate resilience) may be partially offset by savings resulting from lower risk premiums, provided that such policies help maintain or even improve a country's creditworthiness, as reflected in its sovereign rating. We also demonstrate the heterogeneity in the impact of climate risks across different country clusters. For high-rated countries, continued investment in climate readiness can be viewed as a strategy to preserve and even enhance creditworthiness over time. For low-rated countries, however, strengthening institutional capacity, reducing structural vulnerabilities, and integrating climate resilience into broader economic development strategies are essential for climate factors to have a more substantial impact on credit ratings. This highlights the need for a differentiated approach: while climate readiness is universally beneficial, its effectiveness in improving sovereign credit ratings depends heavily on the broader economic and institutional context.

The conclusions are also important for rating agencies, as they provide a basis for incorporating climate resilience indices into their sovereign rating methodologies – a need recognized as far back as 2014 by S&P, which identified climate change as a megatrend that has a significant impact on sovereign risk.

The main limitation of our study is that while the ND-GAIN indices provide comprehensive measures of climate vulnerability and readiness, they may not fully capture all dimensions of climate-related financial risk, such as sector-specific exposures or extreme weather events. Additionally, the index decomposition does not correspond to the taxonomy of climate risk widely used in regulatory policy and mandatory disclosures, i.e., physical and transition risks. Future research could address these limitations by integrating more granular climate and economic indicators. Furthermore, investigating the role of institutional quality, governance, and macroeconomic policies in mediating the impact of climate resilience on credit ratings would provide further valuable insights.

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Jak odporność na zmiany klimatu wpływa na ryzyko kredytowe kraju: badanie porównawcze na próbie międzynarodowej

Celem artykułu jest identyfikacja wpływu odporności kraju na ryzyko klimatyczne na jego rating kredytowy oraz odpowiedź na pytanie, czy podatność na ryzyko może być łagodzona przez aktywną politykę klimatyczną państwa. Analiza uwzględnia również trwałość zaobserwowanych zależności w odniesieniu do krajów o ratingu inwestycyjnym oraz spekulacyjnym. Badanie opiera się na próbie 67 państw i koncentruje się na zależności między ratingami kredytowymi nadawanymi przez agencje Standard & Poor's i Moody's a indeksem ryzyka klimatycznego ND-GAIN, w tym jego składowymi – podatnością i gotowością. W celu weryfikacji zależności między ratingami kredytowymi państw a ich odpornością klimatyczną zastosowano analizę skupień opartą na podatności klimatycznej, zdolności adaptacyjnej oraz ratingach kredytowych, a także model regresji liniowej. Wyniki wskazują na pozytywną zależność między odpornością klimatyczną kraju a jego ratingiem kredytowym. Podatność na ryzyko klimatyczne wpływa negatywnie na ocenę wiarygodności kredytowej, natomiast pozytywny wpływ gotowości klimatycznej jest bardziej widoczny w krajach o wyższych ratingach niż w tych o gorszej

ocenie wiarygodności kredytowej. Wnioski dostarczają nowych informacji na temat czynników determinujących ratingi kredytowe państw oraz wpływu ryzyka klimatycznego na wiarygodność kraju, co ma istotne znaczenie dla polityki klimatycznej oraz metodologii wyznaczania ratingów suwerennych przez agencje ratingowe.

Słowa kluczowe: ryzyko klimatyczne, rating państwowy, podatność, gotowość, indeks ND-GAIN

Appendix

List of countries included in the study		
Argentina	Guatemala	Philippines
Australia	Hungary	Poland
Austria	India	Portugal
Bangladesh	Indonesia	Romania
Belgium	Ireland	Russian Federation
Brazil	Israel	Serbia
Bulgaria	Italy	Singapore
Canada	Jamaica	Slovak Republic
Chile	Japan	Slovenia
China	Korea, Rep.	Spain
Colombia	Latvia	Suriname
Costa Rica	Lithuania	Sweden
Croatia	Luxembourg	Switzerland
Cyprus	Malaysia	Thailand
Czech Republic	Malta	Trinidad and Tobago
Denmark	Mexico	Turkey
Ecuador	Morocco	United Kingdom
El Salvador	Netherlands	United States
Estonia	New Zealand	Uruguay
Finland	Norway	Venezuela
France	Pakistan	Vietnam
Germany	Panama	
Greece	Peru	

Source: own study.

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The Consequences of Remote Work – a Comparison of Four Central European Countries

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Abstract

The article examines the similarities and differences in how employees across four Central European countries evaluate the consequences of remote work. The primary objective is to cluster these consequences into closely interrelated advantages and disadvantages that form directly unobservable factors. The research was carried out using a diagnostic survey method that comprised 1,022 respondents from four countries: Czechia, Poland, Slovakia, and Slovenia. The respondents evaluated the positive and negative outcomes of remote work. To achieve the research objective, principal component analysis was used. Six factors common to all the studied countries were identified. Two of these factors are positive, and four are negative, with respondents placing greater weight on the advantages than the disadvantages. Factors such as cost savings and the positive impact on work life, non-work life, and health were indicated as primary advantages. However, perceptions of some advantages varied across the four countries. The issue of exclusion was the most frequently cited disadvantage. The research provides reliable information concerning the comparative assessments of the consequences of remote work. Its significance lies in demonstrating that a broad spectrum of individual outcomes can be distilled into six underlying factors. They contribute to the existing literature on remote work and offer practical insights for both management and remote workers.

Keywords: remote work, hybrid work, Central Europe
JEL: E24, J220, O52

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Introduction

Although the idea of remote work (telework) dates back to the 1970s with research and development projects carried out by Nilles (1998), it appeared in most companies as late as the 1980s (Bailey and Kurland 2002). Its most rapid development occurred in the 1990s, along with the increasing access to the Internet (Graham, Hjorth, and Lehdonvirta 2017). The COVID-19 pandemic in 2020 subsequently accelerated the digital transformation of employment (Huňady et al. 2024). However, the scale of remote work in individual countries of the European Union (EU) varies significantly. The lowest rates of remote work are in Bulgaria and Romania (1.2% of the total workforce in each), while the highest is in Ireland (20.6%) (Eurostat 2024). A relatively small percentage of employees work remotely in Czechia (6.6%), Poland (5.5%), Slovakia (5.7%), and Slovenia (6.9%) (Eurostat 2024). These differences may be determined by, among other things, economic structures, demographic factors (Kapitsinis 2025), and national culture (Wang et al. 2025). They may also be affected by organisational culture (Caraiani et al. 2021), including management's attitude towards working off-site (Bailey and Kurland 2002), the level of digitisation (Huňady et al. 2024), and digital competence (Eurostat 2023), and employee attitudes.

Research on remote work intensified during the COVID-19 pandemic, when numerous companies, especially in knowledge-intensive sectors, switched to remote work. Interest in this issue remains high, even though the prevalence of remote work has since decreased (Eurostat 2023). A major unresolved issue is the impact of remote work on employee productivity (Awada et al. 2021; Ng, Lit, and Cheung 2022; Enaifoghe and Zenzile 2023; Lim et al. 2025). Another frequently raised issue is its impact on work–life balance (Shirmohammadi, Au, and Beigi 2022; de Laat 2023). The impact of remote work on health (Gorshkova and Lebedeva 2023; Mergener et al. 2025) and job satisfaction (Atobishi and Nosratabadi 2023; García-Salirrosas et al. 2023; Glavin and Schieman 2024) has also been studied.

Remote work is occasionally analysed in a broader context, such as national culture (Wang et al. 2025). Attempts have been made to analyse the consequences of remote work from both the employee (Żołnierczyk-Zreda et al. 2025) and the organisational perspective (Tahlyan et al. 2024; Korkeakunnas et al. 2025). However, such research is most frequently limited to a single country, thus lacking a comparative perspective. Therefore, this paper fills a research gap by providing new knowledge concerning the similarities and differences in how employees from Czechia, Poland, Slovakia, and Slovenia assess the consequences of remote work. This approach also allows us to better identify, describe, and compare the consequences of remote work in these countries by isolating directly unobservable factors.

Therefore, the purpose of the paper is to identify the similarities and differences in assessing the consequences of remote work from the perspective of employees in these four Central European countries. To achieve this, the research categorises the consequences of remote work into groups of interrelated advantages and disadvantages that represent directly unobservable factors.

The article is structured as follows. Section 2 reviews the literature on the consequences of remote work from the employee's perspective. Section 3 describes the research methodology.

The data were obtained through a diagnostic survey of 1,022 respondents. The study uses principal component analysis (PCA), Pearson's linear correlation coefficient, and the Kruskal-Wallis test. Section 4 presents the results of the statistical analyses. Finally, the conclusion summarises the findings, discusses the research limitations, and offers suggestions for further research.

The article enriches the academic discourse on remote work by grouping consequences into directly unobservable factors and providing a comparative analysis of employee perceptions across four Central European countries.

Literature review

The digital transformation of work and the development of remote work have raised many questions concerning the consequences for both the organisation and the employee (Rodriguez-Lluesma, García-Ruiz, and Pinto-Garay 2021). Due to the research perspective of this paper, the following review focuses exclusively on the consequences experienced by the employees working remotely.

Remote work is defined as a form of work organisation where tasks are performed entirely or partially outside the organisation's premises using information and communication technologies (ICT) (Król 2023). This concept encompasses both fully remote arrangements and "hybrid work", where employees split their time between the office and off-site locations (Lauring and Jonasson 2025).

Remote work can provide a mix of benefits and challenges. For example, Šafránková and Šikýř (2024) found in a study of 480 Czech workers that the most common benefits include time and cost savings, improved work–life balance, and independence. Conversely, the primary difficulties identified were social isolation, conflicts between work and family life, unlimited work hours, and inadequate space to work at home. Similarly, Vayre et al. (2022) identified greater work autonomy, flexibility, and balancing work and non-work life as key advantages in a study of 28 French workers, while highlighting increased temporary workloads and negative impacts on physical and mental health as disadvantages. As Korkeakunnas et al. (2025) note, these consequences of remote work are not universal.

Autonomy is a central theme in this discourse. In a survey of 313 IT workers in India, Datta et al. (2025) identified four distinct dimensions of work autonomy: location, time, planning, and professional decision-making. Their findings suggest that these forms of autonomy directly influence the well-being and productivity of remote workers.

One of the most commonly cited drawbacks is isolation, also described as "digital ostracism" (Chen 2024). Spilker and Breaugh (2021) examined this phenomenon among 244 remote workers and their supervisors, finding that feelings of workplace loneliness are negatively correlated with an employee's level of choice regarding remote work, the duration of the employee–supervisor relationship, and overall job satisfaction and productivity. Furthermore, isolation is positively

related to a worker's need for affiliation, the extent of remote work, and the physical distance from the organisation's premises.

Marstand, Epitropaki, and Kapoutsis (2025) examined the psychological distance experienced by employees from their manager in the context of remote work. They noted that proper leadership behaviours may reduce remote workers' perceived psychological distance from their manager, and indirectly affect coping with work tasks. They also pointed to the key role of managers in helping remote workers overcome the challenges of physical distance. Remote workers' perceived sense of disconnection from the team was also noted by Korkeakunnas et al. (2025).

Remote work can affect employees' physical health and mental well-being, particularly regarding stress, although findings are inconsistent. For example, Vizcaíno et al. (2025) studied approximately 1,000 Latin American software developers who worked remotely and confirmed that stress negatively impacts their productivity. Orlandi et al. (2024) identified two groups of factors – individual (adequate resources necessary to perform remote work efficiently, e.g., a laptop, an ergonomic chair) and organisational (participative leadership, clearly formulated goals) – that facilitate effective stress management. In contrast, Korkeakunnas et al. (2025) found that remote work had a beneficial effect on employee well-being and stress reduction by eliminating or reducing the daily commute. They also noted that flexible work hours allow some remote workers to increase physical activity, which benefits their health. Similarly, Żołnierczyk-Zreda et al. (2025) noted that remote work contributes to better psychosocial work conditions and psychological well-being compared to office-based workers. Conversely, remote work can lead to musculoskeletal pain and sleep problems (Nowrouzi-Kia et al. 2024).

Xavier et al. (2024) surveyed 288 remote employees in the Brazilian education sector to examine how health problems and organisational support influence attitude towards work. They demonstrated that health problems negatively impact job satisfaction and engagement, which in turn increases staff turnover. In contrast, organisational support can positively impact remote workers' perceptions of their work environment, increasing job satisfaction and engagement, thereby reducing staff turnover.

The availability of mobile devices and unrestricted Internet access has not only popularised remote work but also fuelled the "always on" phenomenon, where employees remain perpetually available to superiors, colleagues, and clients (Øvretveit 2019). A remote employee may find it difficult to disconnect, even during illness (Nowrouzi-Kia et al. 2024). Schmitz, Bauer, and Niehaus (2023), in a study of 233 employees in Germany, found that remote presenteeism – performing work while sick – is common in remote contexts. This is driven by a limited ability to detach from work and insufficient supervisor support. Notably, only nine of the 27 EU countries have regulations ensuring the right to disengage from work (Ropponen 2025).

The impact of remote work on work–life balance is also contested. For example, de Laat (2023) identified a "dual devotion" among 84 American IT workers, where respondents felt equally committed to both work and family. Research shows that work–life integration is facilitated by the flexibility inherent in remote work. However, gender-based differences in these assessments are noteworthy. While women often view remote work as a way to devote more time to work, men see it as

an opportunity to devote more time to childcare. Furthermore, scholars frequently point out that remote work can blur the boundaries between work and non-work time (Chen 2024) and an inability to distinguish between work and home environments (Nowrouzi-Kia et al. 2024).

Research on the consequences of remote work more often focuses on negative than positive aspects. However, the benefits of remote working are central to driving productivity and job satisfaction, serving as a motivation to maintain this work arrangement. Ziomek (2023), based on a survey of 450 remote workers from Poland, Czechia, and Hungary, showed that the motivators behind working remotely include a suitably equipped workplace, a quiet environment, a lack of stress, lower costs, and career development opportunities, as well as the acquisition of knowledge and skills. To this list may be added the ability to shape the workspace (Rymaniak et al. 2021), utilise flexible work schedules (Türkeş et al. 2024), and save time by eliminating the commute (Nowrouzi-Kia et al. 2024). Furthermore, remote work allows individuals to work for geographically distant organisations (Mieriņa and Šūpule 2024; Macias, Ravalet, and Rérat 2025). The lack of geographical barriers increases the spatial and inter-organisational mobility of workers without the need for physical migration (Bamieh and Ziegler 2022; Tsapenko and Grishin 2022).

Methodology

The study employed a diagnostic survey targeting respondents from Czechia, Poland, Slovakia, and Slovenia. The total sample comprised 2,052 individuals and was representative in terms of gender and age. Data collection was conducted by a specialised international research organisation using established consumer panels in each participating country. Respondents completed the survey in their native language between 29 November and 10 December 2024. The return rate of complete questionnaires varied by country from 8.1% to 11.9%.

For this analysis, the sample was limited to respondents who declared that they had performed remote or hybrid work within the last two years. This resulted in a final dataset of 1,022 respondents who provided information on the positive and negative consequences of remote work. Since the responses were expressed on a five-point Likert scale, PCA (Kim and Mueller 1978; Kline 2014; Hair Jr. et al. 2018) was applied to group these consequences and extract new variables as combinations of the original survey statements. The analysis was conducted in four stages:

1. The PCA was performed individually for each country to categorise the original variables into groups representing related consequences of working remotely. Due to the various socio-cultural backgrounds of the four populations, it was anticipated that the results of the analyses would not overlap uniformly across all countries.

2. This stage aimed to identify and group the variables to construct common factors applicable to all the countries studied. The inclusion criterion was that a primary variable must load on the same factor (derived from PCA) in at least three of the four countries. This approach led to the exclusion of variables that did not meet this condition

– for example, those with inconsistent loadings across countries, making it impossible to classify them unambiguously into a common group.

3. Using the variable assignments from the previous stage and specific formulas developed for this study, common factors were constructed for all the countries. These factors ($F^{(k)}$) constitute new variables calculated as a weighted average of the original variables (X_j):

$$\bigwedge_{k=1,\ldots,K} F^{(k)} = \sum_{j=1}^{J_k} \widehat{w}_{\mathrm{jk}} X_j. \tag{1}$$

It was assumed that the weights must reflect the influence of individual variables on the resulting factor created; consequently, the squares of the factor loadings (a^2_{jkm}) were used to construct the weights[1]. Furthermore, the impact was determined by aggregating the results from the four countries:

$$\bigwedge_{k=1,\ldots,K} \bigwedge_{j=1,\ldots,J_k} w_{\mathrm{jk}} = \frac{1}{4} \sum_{m=1}^{4} a^2_{\mathrm{jkm}}, \tag{2}$$

The weights were rescaled so that the sum within one factor equals 1:

$$\bigwedge_{k=1,\ldots,K} \bigwedge_{j=1,\ldots,J_k} \widehat{w}_{\mathrm{jk}} = \frac{w_{\mathrm{jk}}}{\sum_{j=1}^{J_k} w_{\mathrm{jk}}}. \tag{3}$$

In these equations, $\widehat{w}_{\mathrm{jk}}$ represents the final weights, while w_{jk} denotes the preliminary weights derived from the factor loadings a_{jkm}. The index k (for $k = 1, \ldots, K$) identifies the factor, j (for $j = 1, \ldots, J_k$) denotes the original variable, J_k is the number of variables included in factor $F^{(k)}$, and m (for $m = 1, \ldots, 4$) represents the country.

4. The analysis examined the distribution of the constructed factors, their correlations, and whether their values differed significantly based on respondent characteristics. The Kruskal-Wallis test (Kruskal 1952; Kruskal and Wallis 1952) was used to analyse these relationships. When independent variables – gender, age, education, place of residence, financial standing, or organisational sector – indicated significant differences in the perceived impact of remote work, Bonferroni post-hoc tests were applied (Dunn 1961).

Results

In line with the adopted research procedure, PCA was applied to each of the four countries to create directly unobservable factors that represent combinations of remote work consequences. In each case, the Kaiser-Mayer-Olkin (KMO) measure (Kaiser 1970; Kaiser and Rice 1974)

1 The factor loadings a_{jkm} derived from the PCA represent the correlation between variable j and factor k in country m. When squared, these loadings can be interpreted as coefficients of determination, representing the proportion of variance in factor k explained by variable j. The average of these coefficients across the four countries forms the preliminary weights w_{jk}.

exceeded 0.9, indicating that all the original variables could be used in the analysis. The number of factors was determined by the explained variance criterion, with the requirement that the extracted factors should account for at least 60% of the common variance. Six factors were extracted and subsequently analysed after applying the Promax rotation (Harman 1976; Mulaik 2009; Hair Jr. et al. 2018).

The factor loadings obtained via the PCA method for each country are shown in Table 1. They illustrate the strength of the correlation between the survey items and the extracted factors. Based on these loadings and in accordance with Equations (2) and (3), weights were calculated and used to determine the values of the six factors. New variables were thus constructed to reflect the unobservable direct effects of remote work.

Table 1. Results of the factor analysis – common factors across the four countries

		Factor loadings				Weights
		Czechia	Poland	Slovakia	Slovenia	
Factor 1	Saving time commuting to and from work	0.681	0.921	0.916	0.787	0.374
	Financial savings from reduced expenditure on means of transport	0.652	0.819	0.896	0.650	0.313
	Ability to work in a location so distant that daily commuting would be difficult or impossible	0.780	0.830	0.740	0.690	0.313
Factor 2	Positive impact on mental health	0.723	0.924	0.926	0.674	0.201
	Development of digital skills	0.818	0.746	0.683	0.754	0.169
	Increased job satisfaction	0.742	0.806	0.803	0.617	0.167
	Less physical fatigue	0.672	0.895	0.834	0.505	0.165
	More opportunity for an appropriate work–life balance	0.896	0.646	0.813	0.546	0.163
	Ability to combine work with other responsibilities (e.g., studying)	0.638	0.718	0.611	0.704	0.134
Factor 3	The need to independently provide work conditions at home or elsewhere	0.872	0.824	0.881	0.884	0.646
	Reduction in private space as a result of dedicated space for remote work	0.552	0.566	0.673	0.753	0.354
Factor 4	Extended work hours	0.911	0.975	0.770	0.667	0.442
	Imbalance between work and non-work time	0.762	0.653	0.725	0.786	0.337
	Family disagreements due to misunderstanding the characteristics of remote work	0.556	0.600	0.539	0.677	0.222
Factor 5	Limited contact with colleagues	0.914	0.780	0.972	0.895	0.318
	Decreased sense of belonging to a team	0.788	0.782	0.920	0.814	0.273
	Worse communication with colleagues	0.785	0.626	0.843	0.892	0.251
	Decrease in identification with the organisation	0.477	0.645	0.670	0.695	0.157

		Factor loadings				Weights
		Czechia	Poland	Slovakia	Slovenia	
Factor 6	Negative impact on mental health	0.843	0.742	0.879	0.829	0.389
	Negative impact on physical health	0.953	0.716	0.695	0.763	0.356
	Greater overall stress associated with work	0.539	0.780	0.560	0.751	0.255

Source: own calculation.

The first two factors are positive and represent perceived benefits of remote work. Respondents across all countries attributed time savings (weight: 0.37), financial savings (0.31) from not having to commute, and the ability to work from distant locations (0.31) to the first factor, titled *Savings associated with remote work*.

Factor 2, *Positive impact on work–life balance and health,* is strongly related to the development of digital skills (0.17) and increased job satisfaction (0.17). In addition, reduced physical fatigue (0.17) appears to contribute to a better work–life balance (0.16) and the ability to combine work with other professional responsibilities (0.13). Respondents from all countries – particularly those from Poland and Slovakia – indicated a positive impact on mental health (0.2), which is most closely related to these occupational and non-occupational benefits.

The remaining four factors represent negative consequences. Factor 3 is related to the *Need to prepare an off-site workplace*, specifically providing suitable conditions at home or elsewhere (0.65), which often results in a reduction of private space (0.35).

Factor 4, *Negative impact on non-professional and family life,* captures risks that largely mirror the advantages of remote work. These factors include extended working hours (0.44) – most prevalent among respondents in Poland and Czechia – an imbalance between work and non-work time (0.34), and family disagreements (0.22).

Factor 5, *Sense of exclusion from the organisation*, comprises concerns about reduced contact with colleagues (0.32), poorer communication with the team (0.25), and a decreased sense of belonging (0.27) and identification with the organisation (0.16).

Factor 6, *Negative impact on health,* incorporates mental (0.39) and physical health risks (0.36), as well as general work-related stress (0.25).

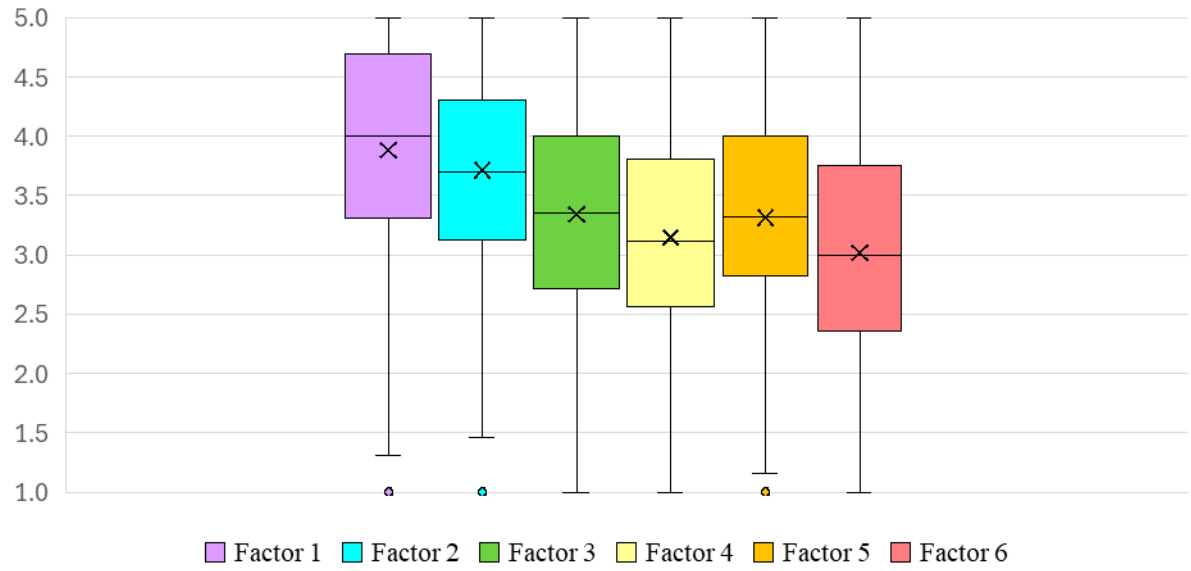

Figure 1. Distributions of factors
Source: own calculation.

Analysis of the factor distribution values (Figure 1) reveals that respondents most frequently identified savings from remote work (Factor 1) as a positive impact. Conversely, they were least likely to perceive a negative impact on health (Factor 6) or on non-professional and family life (Factor 4). Factor 1 exhibits a significant and moderate positive correlation with Factor 2 (Table 2). This suggests that greater savings associated with remote work (e.g., time savings or the ability to work remotely without relocating) translate into greater satisfaction with both work life and family life. Similarly, the four remaining factors are significantly and moderately positively correlated. Therefore, the respondents were aware that, for example, the negative health impact of remote work (Factor 6) and the need to adapt family space to work (Factor 4) can also have undesirable professional and family consequences (Factor 5). Interestingly, the correlations between the positive (Factors 1 and 2) and negative effects (Factors 3–6) are either insignificant or very weak (Table 3). The advantages of remote work are perceived in relative isolation from its negative consequences, with respondents focusing more on the benefits (Figure 1).

Table 2. Matrix of correlation coefficients

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 2	0.557**				
Factor 3	−0.040	−0.034			
Factor 4	−0.064*	−0.046	0.537**		
Factor 5	−0.012	−0.039	0.492**	0.580**	
Factor 6	−0.183**	−0.140**	0.483**	0.629**	0.599**

Note: * significant for $p \leq 0.05$; ** significant at $p \leq 0.01$.
Source: own calculation.

The final stage of the analysis uses a Kruskal-Wallis test to identify which respondent characteristics significantly influence their assessment of the impact of remote work. As shown in Table 3, the perception of *Savings associated with remote work* (Factor 1) depends on gender, age, education, place

of residence, and sector. *Post-hoc* analysis revealed that savings from remote work carry greater weight for women, individuals aged 35–44 and 55–69, respondents with higher education, those living in cities with more than 150,000 inhabitants, and workers in the private sector.

The perceived *Positive impact on work and non-work life* (Factor 2) is influenced by the place of residence and material standing. In this case, higher scores are reported by people from large cities (over 150,000 inhabitants) and those in favourable financial situations.

The assessment of *The need to prepare the workplace* (Factor 3) is influenced by age and education. Preparing a workplace is of greater importance, and therefore a more significant challenge, for those aged 18–24 and those with a general secondary education.

Similarly, age influences the perceived *Negative impact on non-professional and family life* (Factor 4). Younger workers are more likely to agree that remote work adversely affects aspects of their personal and family life.

Notably, *Feeling excluded from the organisation* (Factor 5) does not depend on any socio-demographic characteristic of a given respondent. This means that all respondents, regardless of individual characteristics, perceive this factor in the same way.

Significant differences in terms of perceiving *Negative health impact* (Factor 6) are observed based on age, education, and place of residence. In this case, greater health problems due to remote work are reported by younger individuals (18–34 years), those with secondary or post-secondary education, and residents of the largest cities (Table 3).

Table 3. Results of the Kruskal-Wallis test and post-hoc analysis

Respondent characteristics	Kruskal-Wallis statistics for characteristics significantly affecting the factors under study	Results of *post-hoc* analysis – groups significantly different, with additional indication of the relationship between medians
Factor 1. *Savings associated with remote work*		
Gender	$6.21; p = 0.013$	$\mathrm{Me(F)} > \mathrm{Me(M)}$
Age	$13.86; p = 0.008$	$\mathrm{Me}(35-44) > \mathrm{Me}(18-24)$
		$\mathrm{Me}(55-69) > \mathrm{Me}(18-24)$
Education	$42.57; p < 0.001$	$\mathrm{Me(higher\ edu.)} > \mathrm{Me(vocational\ edu.)}$
		$\mathrm{Me(higher\ edu.)} > \mathrm{Me(general\ secondary)}$
Place of residence	$17.23; p < 0.001$	$\mathrm{Me(over\ 150\ k)} > \mathrm{Me}(50-150\mathrm{k})$
		$\mathrm{Me(over\ 150\ k)} > \mathrm{Me(up\ to\ 50\ k)}$
		$\mathrm{Me(over\ 150k)} > \mathrm{Me(village)}$
Private or public sector	$9.69; p = 0.021$	$\mathrm{Me(private)} > \mathrm{Me(public)}$

Respondent characteristics	Kruskal-Wallis statistics for characteristics significantly affecting the factors under study	Results of *post-hoc* analysis – groups significantly different, with additional indication of the relationship between medians
Factor 2. *Positive impact on work life, non-work life, and health*		
Place of residence	$13.03; p = 0.005$	$\mathrm{Me}(\text{over } 150 \text{ k}) > \mathrm{Me}(50 - 150\text{k})$
		$\mathrm{Me}(\text{over } 150\text{k}) > \mathrm{Me}(\text{up to } 50\text{k})$
Material situation	$11.63; p = 0.020$	$\mathrm{Me}(\text{very good}) > \mathrm{Me}(\text{average})$
Factor 3. *Need to prepare an off-site workplace*		
Age	$10.42; p = 0.034$	$\mathrm{Me}(18 - 24) > \mathrm{Me}(55 - 69)$
Education	$12.80; p = 0.012$	$\mathrm{Me}(\text{general secondary}) > \mathrm{Me}(\text{higher})$
Factor 4. *Negative impact on non-professional and family life*		
Age	$14.75; p = 0.005$	$\mathrm{Me}(18 - 24) > \mathrm{Me}(25 - 34)$
		$\mathrm{Me}(18 - 24) > \mathrm{Me}(35 - 44)$
		$\mathrm{Me}(18 - 24) > \mathrm{Me}(55 - 69)$
Factor 5. *Negative impact on health*		
Age	$15.28; p = 0.004$	$\mathrm{Me}(18 - 24) > \mathrm{Me}(55 - 69)$
		$\mathrm{Me}(25 - 34) > \mathrm{Me}(55 - 69)$
Education	$23.28; p < 0.001$	$\mathrm{Me}(\text{general secondary}) > \mathrm{Me}(\text{higher edu.})$
		$\mathrm{Me}(\text{post} - \text{secondary}) > \mathrm{Me}(\text{higher edu.})$
Place of residence	$9.70; p = 0.021$	$\mathrm{Me}(\text{over } 150\text{k}) > \mathrm{Me}(50 - 150\text{k})$

Source: own calculation.

Conclusions

The study identified six categories of consequences of remote work common to all four countries surveyed. Savings associated with remote work were the most frequently indicated benefit, characterised by high factor loadings across four analyses particularly among respondents from Poland and Slovakia (Table 1). Assessments of these savings were influenced by five respondent characteristics: gender, age, education, place of residence, and private or public sector (Table 3).

In addition to savings, a second positive factor was identified regarding the impact of remote work on work–life balance and health. In contrast, two analogous but inverted factors emerged for negative consequences, reflecting the adverse impact of remote work on various aspects of the respondents' personal lives (Factor 4) and health (Factor 6). Nevertheless, respondents generally perceived the consequences of remote work as more positive than negative, as evidenced by distributions of these factors (Figure 1).

A factor indicating that remote work creates a sense of exclusion from the organisation was also identified. The distribution of this factor does not depend on any socio-demographic characteristics, suggesting that exclusion is experienced equally regardless of age, gender, or education. The PCA conducted among Poles yielded slightly lower factor loadings in this factor than in the other countries (Table 1), which may indicate that this problem is perceived less acutely in Poland.

It is important to note not only the similarities in assessing the consequences of remote work but also the differences between the surveyed countries. The study considered a broad set of advantages, including greater autonomy, scheduling flexibility, increased efficiency, better work organisation, the ability to work at one's own pace, and workspace customisation. However, these factors loaded inconsistently across the national contexts aligning with Factor 1 in Poland and Slovakia, and with Factor 2 in Czechia and Slovenia. Therefore, these variables were excluded from the final extracted factors to maintain the statistical reliability of the model. This heterogeneous assessment of the consequences of remote work aligns with the findings of Korkeakunnas et al. (2025), who showed that perceptions of remote work are not universal.

Summary

The research provides a deeper understanding of how remote workers in Czechia, Poland, Slovakia, and Slovenia perceive the implications of this work arrangement. The findings show that while certain consequences are perceived similarly across national contexts, others vary significantly.

Respondents were fairly consistent in their assessments of the negative effects of remote work, as reflected in Factors 3–6. These factors are loaded by 12 variables relating to negative consequences, which were also the most frequently cited in each country. There was greater divergence in the assessment of the positive effects. The final procedure produced two factors that cover only nine of the 15 statements analysed. The lack of clear attribution for the remaining six positive consequences is evidence of differences between countries in the assessment of these effects.

The research provides reliable insights into the similarities and differences in perceptions of the consequences of remote work among employees from the four countries, extending the scope of comparative research in this field. The value of the research also lies in reducing the vast range of consequences into six meaningful latent factors. The results provide a significant contribution to the literature and offer practical value for both management and remote workers.

The limitations of this study result from the sampling method. The sample comprised employees voluntarily registered on a survey panel, which, despite the representativeness of the sample in terms of age and gender, may have influenced its structure and the results. However, anonymous participation and the lack of time pressure suggest that the answers were thoughtful and reliable.

Future research could extend the research to other EU countries to facilitate further comparative analyses and identify the reasons for the differing assessments of the consequences of remote work between countries.

Contribution of the authors

Conceptualisation M.K. and J.T.; literature review M.K.; methodology M.K. and J.T.; formal analysis J.T.; writing M.K. and J.T.; conclusions M.K. and J.T.

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Analiza konsekwencji pracy zdalnej – porównanie czterech krajów Europy Środkowej

Celem poznawczym artykułu jest identyfikacja podobieństw i różnic w ocenie konsekwencji pracy zdalnej z perspektywy pracobiorców w czterech krajach Europy Środkowej, a celem metodycznym – podział konsekwencji pracy zdalnej na takie grupy zalet i wad, które w ocenie respondentów są ze sobą ściśle powiązane i tworzą nieobserwowalne bezpośrednio czynniki. Badanie zrealizowano metodą sondażu diagnostycznego, którym objęto respondentów z czterech państw: Czech, Polski, Słowacji i Słowenii. Próba badawcza liczyła 1022 osoby, które zapytano o pozytywne i negatywne skutki pracy zdalnej. Do zrealizowania postawionych celów zastosowano analizę głównych składowych. Wśród konsekwencji pracy zdalnej wyodrębniono sześć czynników wspólnych dla wszystkich badanych krajów. Dwa z nich mają charakter pozytywny, a cztery negatywny, przy czym dla respondentów ważniejsze były zalety niż wady. Najczęściej wskazywane były oszczędności z tytułu pracy zdalnej oraz pozytywny wpływ na życie zawodowe, pozazawodowe i zdrowie. Jednak część zalet pracy zdalnej była odmiennie rozumiana przez respondentów z różnych krajów. Wśród wad najczęściej wskazywany był problem wyłączenia z organizacji. Badanie dostarczyło wiarygodnych informacji na temat podobieństw i różnic w ocenie konsekwencji pracy zdalnej przez pracowników z czterech krajów. Jego wartość polega też na wskazaniu możliwości zastąpienia licznej puli konsekwencji pracy zdalnej sześcioma czynnikami ukrytymi. Uzyskane wyniki wnoszą wkład do literatury na temat pracy zdalnej. Mogą być wartościowe zarówno dla kadry kierowniczej, jak i pracowników zdalnych.

Słowa kluczowe: praca zdalna, praca hybrydowa, pozytywne i negatywne konsekwencje pracy zdalnej, Europa Centralna, analiza głównych składowych

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Green Finance's Impact on Economic Resilience – The Moderating Role of Market Integration

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Abstract

This study examines whether and how green finance enhances economic resilience in emerging economies and evaluates the moderating role of market integration in this relationship. Using the System Generalized Method of Moments (SGMM) estimation to address issues of endogeneity and lagged dependent variables, the empirical results indicate that green finance exerts a positive and statistically significant influence on economic resilience. Furthermore, a high level of market integration enhances the effectiveness of green finance in strengthening a country's ability to withstand and recover from economic, social, and environmental shocks. Based on these findings, the study recommends that emerging economies promote the development of green finance by establishing clear policy frameworks, advancing sustainable financial instruments, and encouraging the flow of green capital into the real economy. Simultaneously, efforts should be made to deepen market integration through trade liberalization, regional financial cooperation, and improvements in the investment climate, to fully leverage the spillover benefits of globalization and reinforce the foundation for economic recovery amid increasing global uncertainties.

Keywords: green finance, economic resilience, market integration, emerging economies
JEL: E60, F15, F36, O44, Q56

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Introduction

Recent years have witnessed an increasing frequency of economic, environmental, and geopolitical shocks, making economic resilience a central policy priority for emerging and advanced economies alike. At the same time, the global expansion of green finance instruments such as green bonds, sustainable lending, and low-carbon investment initiatives continues to reshape financial systems and development strategies. Existing studies provide evidence that green finance contributes to sustainable growth, reduces transition risks, and supports environmental quality (Wang et al. 2022; Wei 2024). However, much less attention has been given to its role in strengthening economic resilience, especially within emerging markets where climate vulnerabilities, structural rigidities, and financial constraints are more pronounced.

While several strands of the literature examine the drivers of economic resilience, the interaction between green finance and market integration remains understudied. Market integration through trade openness, cross-border investment, and capital mobility can amplify positive spillovers from green finance by facilitating technology diffusion, deepening green capital flows, and enhancing access to external resources. Conversely, high integration may also expose economies to synchronized shocks and global volatility. Despite these theoretical ambiguities, empirical evidence explaining whether and how market integration moderates the resilience-enhancing role of green finance is still sparse.

Most existing studies also focus on advanced economies or regional case studies; few account for the dynamic nature of resilience or the potential endogeneity between green finance and macroeconomic outcomes. This creates two important research gaps: (i) limited empirical evidence on the interaction between green finance and market integration in shaping economic resilience within emerging markets; and (ii) insufficient use of econometric approaches capable of handling endogeneity and dynamic adjustment processes, which are inherent in resilience analysis.

The objectives of this study are twofold:

1. To examine the effect of green finance on economic resilience across 32 emerging economies from 2014 to 2023.
2. To assess the moderating role of market integration in this relationship.

To address dynamic endogeneity and country-specific heterogeneity, the study employs the System Generalized Method of Moments (SGMM) estimator (Arellano–Bover/Blundell–Bond). By doing so, the study contributes new empirical evidence on the joint role of green financial development and market integration in strengthening resilience in emerging markets – an area where current global discussions are still evolving.

The rest of the paper is organized as follows. Section 2 reviews the theoretical framework and empirical evidence. Section 3 presents the data and methodology. Section 4 discusses the empirical results, and Section 5 concludes with policy implications.

Theoretical framework and Literature review

Theoretical framework

To provide a theoretical foundation for analyzing the effects of green finance and market integration, as well as the moderating role of market integration on the relationship between green finance and economic resilience, this study is grounded in two key economic theories: (1) the theory of comparative advantage, which explains how economies can benefit from specialization and resource efficiency through openness and financial development; and (2) the real business cycle theory, which highlights the role of external shocks and structural factors such as green finance in shaping the dynamics of economic fluctuations and recovery.

First, the Real Business Cycle (RBC) theory developed by Kydland and Prescott (1982) posits that economic cycles are not primarily driven by fluctuations in aggregate demand or monetary policy. Instead, they represent natural responses of the economy to supply-side shocks, particularly changes in labor productivity, technological progress, and production conditions. According to this theory, shifts in technology, access to production resources, and external factors such as climate change or environmental policy adjustments can generate fluctuations in GDP, employment, and investment.

Empirical studies by Long Jr. and Plosser (1983) and Hansen (1999) have shown that the RBC model can partially explain economic volatility based on how firms and investors respond to such shocks. Applying the RBC theory to green finance, it becomes evident that investments in cleaning technology and sustainable development can play a crucial role in enhancing productivity and mitigating risks associated with economic shocks caused by environmental degradation. When supply-side shocks such as energy crises, natural disasters, or the depletion of natural resources impact the economy, a transition toward green production models and sustainable investments can help minimize adverse effects, sustain employment, and promote long-term economic growth. Recent studies by Yang, Zheng, and Wang (2023) and Wei (2024) reinforce this view by showing that green finance has a positive impact on maintaining economic stability and fostering sustainable development, especially amid global uncertainties. Similarly, Shen, Ma, and Chen (2024) argue that green finance initiatives not only drive sustainable growth but also enhance the economy's resilience against environmental challenges. Accordingly, this study proposes the following hypothesis:

Hypothesis 1: Green finance has a positive impact on economic resilience in emerging economies.

Second, the Comparative Advantage Theory, developed by David Ricardo in 1891, suggests that a country should focus on producing goods for which it has a lower opportunity cost compared to other nations, thereby optimizing international trade efficiency (Ricardo 2001). This theory argues that even when a country holds an absolute advantage in all industries, it can still benefit from trade by specializing in sectors where it holds a higher comparative advantage. The theory has been further reinforced and expanded by studies from Dornbusch, Fischer, and Samuelson (1977) and Krugman (1980), showing that comparative advantage is influenced not only by technology

and labor productivity but also by transportation costs, trade policies, and technological advancements. According to Ricardo, when countries expand trade and integrate into global markets, they can maximize their comparative advantages, optimize production structures, improve productivity, and increase exports. This not only fosters economic growth but also enables countries to recover more quickly from economic shocks. Participation in global value chains opens access to large markets, attracts investment, and provides momentum for sustainable recovery.

At the same time, the RBC theory shows that countries can adapt more effectively to economic shocks when they diversify resources, optimize supply chains, and enhance productivity. By integrating into global markets, nations can access technologies, capital, and human resources from other countries, thereby mitigating the adverse effects of shocks such as financial crises or climate change. Furthermore, RBC theory serves as a foundation for the expectation that market integration positively influences a country's economic resilience. Economic agents can better adapt to shocks by diversifying resources, improving productivity, and optimizing supply chains. As countries further integrate into global markets, they can leverage advanced technologies, capital, and human resources from abroad, helping reduce the negative impacts of economic shocks and accelerating the recovery process. Based on these arguments and previous studies, this thesis proposes the following hypothesis regarding the positive impact of market integration on the economic resilience of the countries in the sample:

Hypothesis 2: Market integration has a positive impact on the economic resilience of emerging economies.

Moreover, market integration is also considered a key factor in enhancing the relationship between green finance and economic resilience. As countries increasingly integrate into the global market, they not only leverage comparative advantages in production but also gain opportunities to exchange knowledge and experiences in developing green finance, particularly in sustainable sectors such as renewable energy, clean technology, and natural resource conservation.

According to the theory of comparative advantage, expanded market integration enables economies to access advanced technologies, capital, and human resources from other nations, thereby mitigating the negative effects of external shocks. In this context, green finance plays a pivotal role in promoting environmental protection initiatives and sustainable development, while simultaneously contributing to the construction of a resilient economic foundation. The synergy between green finance and market integration not only reduces environmental risks but also creates pathways for long-term development and rapid economic recovery. Wang et al. (2022) highlight that the interaction between green finance and market integration generates a synergistic effect that strengthens resilience to economic shocks and supports sustainable recovery. In addition, Wei (2024) emphasizes that market integration facilitates the transfer of green technology and expertise, allowing countries to effectively adopt advanced solutions that enhance economic resilience while addressing environmental challenges. Based on the theoretical and empirical foundations discussed above, this study hypothesizes that market integration positively moderates the relationship between green finance and economic resilience in emerging economies.

Hypothesis H3: Market integration positively moderates the relationship between green finance and economic resilience in emerging economies.

Literature review

Green Finance and Economic Resilience

The concept of economic resilience has been widely debated across economics, regional science, and development studies. Foundational reviews highlight that resilience encompasses absorption capacity, recovery speed, adaptive efficiency, and long-term transformative ability (Rose 2007; Bristow and Healy 2014). The measurement of resilience also remains contentious: while some studies use GDP volatility, others construct multidimensional indices that combine exposure, sensitivity, and adaptive capacity (Martin 2012). These differences imply that empirical results may vary depending on how resilience is operationalized.

Recent studies have clarified the role of green finance in promoting economic recovery and sustainable growth, particularly in the post-COVID-19 context and the transition toward a low-carbon economy. Overall, green finance is identified as an effective policy tool that helps direct capital flows into environmentally friendly sectors, enhances resource efficiency, and mitigates systemic risks through market-based mechanisms.

An important branch of the literature focuses on the relationship between green finance and economic resilience. Wei (2024) shows that green finance positively influences regional economic recovery in China, and this effect is amplified by market integration. Similarly, Tengfei and Ullah (2024) highlight the role of green finance especially green credit and tax incentives – in stabilizing energy prices and reducing reliance on fossil fuels, thereby supporting medium-term economic recovery. Additionally, Nenavath and Mishra (2023) and Zhang (2023) expand the analysis to South Asia and India, affirming that both green finance and financial technology (FinTech) promote sustainable growth by improving environmental performance and increasing access to green capital. Saydaliev and Chin (2023) show that a 1% increase in the green finance index leads to a 0.321% reduction in environmental pollution, thereby promoting sustainable economic recovery. In addition, the study highlights the role of green energy transition policies in improving environmental quality and proposes climate finance measures to ensure long-term growth.

Several studies investigate the specific mechanisms of green finance, such as green credit, green bonds, and green technology investment. Using a difference-in-differences (DID) approach, Li et al. (2024) find that green credit policies in China have encouraged high-pollution industries to boost green investments, thereby reducing emissions and improving resource efficiency. Guan and Zhao (2024) take a technological perspective, emphasizing that green financial investment in resource innovation can simultaneously ensure growth and environmental protection. Green bonds, in particular, are highlighted as key instruments during times of crisis: Fatica and Panzica (2024) find that investors were more likely to retain green bonds than conventional ones during the COVID crisis, helping reduce sell-off pressure and stabilize the market.

Similarly, Ning et al. (2023) underscore the role of green bonds and green banks in financing energy-efficient projects and supporting post-pandemic green recovery.

Some studies also examine supporting factors and interaction conditions that enhance the effectiveness of green finance. Tengfei and Ullah (2024) and Wei (2024) both argue that the success of green economic recovery depends on the level of market integration and the coordination of fiscal, monetary, and environmental policies. Ning et al. (2023) further analyze political, governance, technical, and market-related factors, suggesting that a transparent institutional environment and effective regulatory frameworks are prerequisites for scaling up the green finance market. In a global context, Wang et al. (2022) extend the analysis to the international level, emphasizing the importance of green investment, green FDI inflows, and technological innovation in fostering sustainable economic recovery and realizing the Sustainable Development Goals (SDGs).

In summary, the literature consistently agrees that green finance serves not only as a financial tool for post-crisis recovery but also as a long-term driver of sustainable growth. However, maximizing its impact requires careful policy design, effective cross-sectoral coordination, and broader access through financial technology.

Market Integration and Economic Resilience

Market integration is similarly multidimensional. Trade openness, cross-border investment flows, and capital account liberalization can increase diversification benefits and accelerate the diffusion of green technologies, potentially enhancing resilience. Several studies argue that integrated markets are more capable of reallocating resources efficiently during downturns (Eichengreen, Park, and Shin 2024). However, other scholars caution that highly integrated economies may be more exposed to external shocks, contagion, and synchronized crises (Rodrik 1998). Many studies find a mixed relationship between integration and resilience. While integration can enhance resilience by increasing flexibility, diversifying resources, and expanding access to capital/technology, it also opens additional channels of risk contagion when there is a global shock. Thus, the results depend on the nature of integration and national institutions (Eichengreen, Park, and Shin 2024).

Using the evaluation index developed by Zhou et al. (2023) for agricultural economic resilience and rural industrial integration, this paper employs panel data from 30 Chinese provinces (2000–2020) to examine the impact of rural industrial integration on agricultural economic resilience. Using panel data from 241 prefecture-level and above cities in China between 2010 and 2019, Feng, Lee, and Peng (2023) treat urban agglomeration planning as a quasi-natural experiment to assess the impact of regional integration on economic resilience through a difference-in-differences (DID) approach. The study finds strong evidence that regional integration significantly enhances economic resilience, with the results holding robust across multiple checks. Importantly, the effect of regional integration is not uniform; it varies across periods, regions, and urban structures, suggesting that the depth and form of integration play a crucial role in shaping the capacity of local economies to withstand and recover from external shocks.

Yang (2023) assessed the impact of market integration on economic growth from 2010 to 2019 in the Pearl River Delta urban cluster, which includes 27 cities in China. The study applied a threshold model and analyzed the non-linear relationship. Results showed that commodity market integration had a positive impact on economic recovery, while capital market integration had a negative initial impact but gradually decreased as the level of integration increased. Labor market integration had no significant impact, suggesting the need for additional measures to improve efficiency. In addition, the degree of economic openness and consumption promotion were identified as important factors in economic recovery. The study recommended investment in transport infrastructure and technology, optimization of inter-regional financial institutions, and strengthening of consumption support policies and economic openness to ensure sustainable recovery.

Lyu et al. (2023) evaluate the impact of market integration on economic growth in nine cities in the Pearl River Delta urban cluster, China, during the period 2010–2019. Through spatial autocorrelation analysis and spatial econometric models, including the Spatial Autoregressive Model (SAR), the Spatial Error Model (SEM), and the Spatial Durbin Model (SDM), the study measures the degree of market integration using indicators such as the relative price index, wage volatility, and the coefficient of variation. The SAR model captures spatial dependence in the dependent variable, the SEM model accounts for spatial correlation in the error term, while the SDM model incorporates spatial lags of both the dependent and independent variables to better reflect spatial spillover effects. The study shows that market integration has a negative impact on economic growth as well as regional economic recovery. However, this has a negligible impact on neighboring regions. The main reasons come from domestic trade barriers and local protectionism, which reduce the efficiency of resource allocation and hinder economic recovery.

Oprea and Stoica (2018) examine the impact of capital market integration on economic growth in 28 European Union (EU) countries from 2004 to 2016, using research methods such as the Autoregressive Distributed Lag (ARDL) model, Granger causality analysis, and Johansen cointegration. The results show that capital market integration has a positive impact on sustainable economic growth and recovery through increasing stock market capitalization, improving capital mobility, increasing transaction value, developing stock indexes, and encouraging foreign portfolio investment.

Lester and Nguyen (2016) indicate that a higher level of economic integration, measured by occupational diversity among immigrants across U.S. metropolitan areas, can contribute to enhanced regional economic resilience. The findings suggest that regions with more broadly distributed immigrant populations across occupations tended to maintain stronger real wage growth and better control of unemployment rates during the 2008–2010 economic crisis. This implies that deeper economic integration may serve as a reinforcing factor for economic resilience in the face of external shocks.

Research method

Model

Based on the research of Zhang (2023) and Wei (2024), to test the proposed hypotheses, we sequentially construct two models, specifically as follows:

Model 1 is used to test hypotheses 1 and 2:

$$\mathrm{ER}_{i,t} = \alpha_0 + \beta_0 \mathrm{ER}_{i,t-1} + \beta_1 \mathrm{GF}_{i,t} + \beta_2 \mathrm{MI}_{i,t} + \beta_3 X_{i,t} + \varepsilon_{i,t}. \tag{1}$$

Model 2 is used to test hypothesis 3:

$$\mathrm{ER}_{i,t} = \alpha_0 + \beta_0 \mathrm{ER}_{i,t-1} + \beta_1 \mathrm{GF}_{i,t} + \beta_2 \mathrm{MI}_{i,t} + \beta_3 \mathrm{GF\_MI}_{i,t} + \beta_4 X_{i,t} + \varepsilon_{i,t}, \tag{2}$$

where:
$\mathrm{ER}_{i,t}$ is economic resilience, proxied by the inverse of the five-year rolling standard deviation of GDP growth. $\mathrm{ER}_{i,t-1}$ is the lagged dependent variable used to capture persistence in resilience and justifies the use of dynamic SGMM estimation;
GF denotes green finance, a composite measure derived from green bonds, government environmental spending, and low-carbon trade;
MI represents market integration, calculated as the ratio of total inward and outward investment to GDP;
GF_MI is the interaction term between green finance and market integration;
X denotes a vector of control variables;
i and *t* denote the country and year indices, respectively;
α_0 is the constant term, and $\varepsilon_{i,t}$ represents the idiosyncratic error term.

The vector of control variables, $X_{i,t}$, includes the logarithm of Gross Domestic Product (GDP), the logarithm of GDP per capita (GDPC), the number of listed companies (Listed), the share of the tertiary sector as a percentage of GDP (Tertiary), and government health expenditure as a percentage of GDP (HE). To construct the green index (GFI), the study uses an improved entropy weighting method. Suppose z_{ij} denotes the *j*-th index of the *i*-th country. The following matrix, *Z*, serves as a basic index of the level of green finance development.

$$Z = (z_{\mathrm{ij}})_{\mathrm{mn}} = \begin{pmatrix} z_{11} z_{n1} \\ z_{m1} z_{\mathrm{mn}} \end{pmatrix}_{\mathrm{mn}}, \tag{3}$$

where:
z_{ij} denotes the original value of indicator *j* for country (or region) *i*;
m denotes the number of observations (countries/regions);
n denotes the number of indicators used in the evaluation system.

Since the indices have different units of measurement, equations (3) are normalized with equation (4):

$$\mathrm{r_{ij}} = \begin{cases} \frac{\mathrm{z_{ij}} - \min \mathrm{z_{ij}}}{\max \mathrm{z_{ij}} - \min \mathrm{z_{ij}}} & \mathrm{if z_{ij}\ \ is\ a\ positive\ index} \\ \frac{\max \mathrm{z_{ij}} - \mathrm{z_{ij}}}{\max \mathrm{z_{ij}} - \min \mathrm{z_{ij}}} & \mathrm{if z_{ij}\ \ is\ a\ negative\ index} \end{cases} \tag{4}$$

where:
r_{ij} represents the normalized value of indicator j for country i after the normalization process.

Matrix Normalization:

$$\mathrm{r_{ij}} = \begin{cases} \frac{\mathrm{z_{ij}}}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{z_{ij}}^2}} & \mathrm{ifz_{ij}\ \ is\ a\ positive\ index} \\ \frac{\frac{1}{\mathrm{z_{ij}}}}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{m}} \left(\frac{1}{\mathrm{z_{ij}}}\right)^2}} & \mathrm{ifz_{ij}\ \ is\ a\ negative\ index} \end{cases} \tag{5}$$

Adjust the normalization matrix as follows:

$$b_{\mathrm{ij}} = r_{\mathrm{ij}} + 0.0001, \tag{6}$$

$$P_{\mathrm{ij}} = \frac{b_{\mathrm{ij}}}{\sum_1^m b_{\mathrm{ij}}}, \tag{7}$$

where:
b_{ij} is the adjusted normalized value obtained by adding a small constant (0.0001) to avoid the logarithm of zero;
P_{ij} denotes the proportion of the ith observation under the jth indicator in the normalized matrix.

The entropy index H_j and the difference coefficients G_j are then calculated as follows:

$$H_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{\mathrm{ij}} \ln P_{\mathrm{ij}}, j = 1, 2, 3 \ldots . n, \tag{8}$$

$$G_j = 1 - H_j j = 1, 2, 3 \ldots . n, \tag{9}$$

where:
H_j represents the entropy value of indicator j, reflecting the amount of information provided by that indicator;
G_j denotes the difference coefficient of indicator j, which measures the degree of variation among observations.

Determine the Improved Entropy Weighting Factor:

$$w_j = \frac{G_j + 0.1\sum_{j=1}^{n} G_j}{\sum_{j=1}^{n}\left(G_j + 0.1\sum_{j=1}^{n} G_j\right)} = \frac{1 - H_j + 0.1\sum_{j=1}^{n}(1 - H_j)}{\sum_{j=1}^{n}\left(1 - H_j + 0.1\sum_{j=1}^{n}(1 - H_j)\right)}. \tag{10}$$

Normalization matrix:

$$V = (v_{\mathrm{ij}})_{\mathrm{mn}} = \begin{pmatrix} w_1\gamma_{11} \ldots . w_n\gamma_{1n} \\ w_1\gamma_{m1} \ldots . w_n\gamma_{\mathrm{mn}} \end{pmatrix}_{\mathrm{mn}}. \tag{11}$$

The positive ideal solution v_j^+ and the negative ideal solution v_j^- for the j-th index can be expressed as follows:

$$v_j^+ = \max\{v_{\mathrm{ij}} | i = 1, 2, 3, \ldots . m\}, \tag{12}$$

$$v_j^- = \min\{v_{ij} | i = 1, 2, 3, \ldots . m\}. \tag{13}$$

The Euclidean distances of the positive and negative ideal solutions are calculated as s_i^+ and s_i^-, respectively, as follows:

$$s_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} i = 1, 2, 3, \ldots, m, \tag{14}$$

$$s_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} i = 1, 2, 3, \ldots, m, \tag{15}$$

where:
v_j^+ represents the positive ideal solution for indicator j;
v_j^- represents the negative ideal solution for indicator j;
w_j represents the entropy weight assigned to indicator j;
v_{ij} denotes the weighted normalized value of indicator j for observation i;
s_i^+ represents the Euclidean distance to the positive ideal solution, where a smaller value indicates a more desirable alternative;
s_i^- denotes the distance to the negative ideal solution, where a larger value is preferred.

GFI_i is calculated based on the Euclidean distance between a country's positive and negative ideal solutions. Higher (lower) *GFI* values indicate higher (lower) levels of green financial development.

$$\mathrm{GFI}_i = \frac{s_i^-}{s_i^+ - s_i^-} i = 1, 2, 3, \ldots, m. \tag{16}$$

This indicator reflects the ability to access external capital and technology, as well as the level of connectivity with the global economy. Countries with high market integration typically take better advantage of development opportunities, attract investment, foster technological innovation, and enhance competitiveness. Studies by Feng, Lee, and Peng (2023) and Yang and Deng (2025) show that high market integration supports rapid economic growth, strong resilience, and sustainable development.

Data

The sample consists of 32 economies (see Appendix) selected according to three main criteria. First, the countries provide consistent and comparable information for all components of the green finance index and the market integration indicator over the period 2014–2023. Second, they are classified as emerging markets by the IMF or the World Bank, which makes them particularly suitable for examining resilience in economies that are highly exposed to external shocks while experiencing rapid financial and environmental transformation. Third, the selection ensures geographic and institutional diversity, covering Asia, Latin America, Eastern Europe, and Africa, thereby improving the external validity of the analysis.

Several countries were removed from the initial pool due to substantial data gaps or inconsistencies in key variables related to green finance. For observations with minor missing values (one or two consecutive years), linear interpolation was applied to maintain continuity. After this

screening and cleaning process, the final dataset constitutes a balanced panel of 32 countries with 320 country–year observations.

Empirical Strategy (Step-by-Step)

Step 1: Data construction. Panel data covering 32 emerging economies from 2014 to 2023 were assembled using the World Bank, IMF, Climate Bonds Initiative, WTO, and national statistical sources. Missing values were screened, and harmonization procedures were applied where necessary to ensure consistency across countries and years.

Step 2: Variable measurement.

- Economic resilience (ER) is measured as the inverse of GDP growth volatility. This transformation ensures that higher values correspond to stronger resilience.
- Green finance (GF) is constructed as a composite index combining green bond issuance, government environmental expenditure, and low-carbon trade, using entropy weighting.
- Market integration (MI) is proxied by the ratio of total cross-border investment flows to GDP and alternative measures for robustness.

Step 3: Model specification. Two dynamic models are estimated: (i) a baseline model assessing the effect of GF on ER; and (ii) an interaction model including GF × MI to capture moderation. Lagged ER is included to reflect dynamic adjustment processes. Controlling variables capture macroeconomic, institutional, and energy-related characteristics.

Step 4: Addressing endogeneity. Since lagged ER and the main regressors may be endogenous, the System GMM estimator (Arellano–Bover/Blundell–Bond) is applied. Internal instruments are constructed using second- and higher-order lags. Serial correlation and over-identification are checked using AR (1)/AR (2) tests and Hansen/Sargan tests.

Step 5: Robustness checks. To verify the stability of the baseline results, the composite green finance (GF) index is replaced with an alternative proxy measured by renewable energy investment. This substitution allows us to examine whether the estimated relationship remains consistent when a different representation of green financial development is employed.

Step 6: Interpretation and validation. Coefficient patterns are evaluated against theoretical expectations and previous empirical findings. Instrument validity, model diagnostics, and economic interpretation guide the discussion and policy implications.

Research results

Table 1 presents the descriptive statistics of the variables, including the number of observations, mean, standard deviation, minimum value, and maximum value.

Table 1. Descriptive statistics

Variable	Obs.	Mean	Std	Minimum	Maximum
ER	320	2.7072	1.8992	0.1073	8.6790
GF	320	0.097	0.081	0.017	0.553
MI	320	3.910	2.867	0.756	19.375
GF_MI	320	0.379	0.481	0.013	10.715
GDP	320	8.0860	1.4422	5.0254	12.0941
GDPC	320	9.3273	0.8046	7.3485	11.2852
Listed	320	650.1063	1709.8420	8	12730
Tertiary	320	56.5652	6.2238	39.8625	70.5563
HE	320	4.0803	1.6534	0.8600	8.1770

Source: Stata output.

The results from Table 1 show that the economic resilience variable (ER) ranges from 0.1073 to 8.6790, with an average of 2.7072 and a standard deviation of 1.8992, indicating a significant disparity among countries. Peru recorded the highest ER (8.6790 in 2023), while Indonesia had the lowest (0.1073 in 2019), highlighting differences in recovery capacity across nations. The green finance variable (GF) ranges from 0.017 to 0.553, with an average value of 0.097 and a standard deviation of 0.081. Hungary led with the highest GF in 2023, while Russia recorded no green finance activities during the last two years of the study period. The market integration variable (MI) shows significant volatility, ranging from 0.756 to 19.375, with an average of 3.910 and a standard deviation of 2.867. Both the highest and lowest values were observed in Hungary, suggesting that the integration process in some emerging economies remains unstable and is influenced by external economic and political factors.

Table 2. Results: Model 1 and Model 2

	Model 1	Model 2
L1.ER	0.9619***	0.9336***
GF	0.7159***	0.9667***
MI	0.0781***	0.0249***
GF*MI		0.0211***
GDP	−0.4411***	−0.4142***
GDPC	−2.8361***	−3.5223***
Listed	0.0002***	0.0002***
Tertiary	0.0180	0.0484

	Model 1	Model 2
Cons	0.8001***	0.8549***
AR (2)	0.275	0.243
Sargan test	0.342	0.335
Hansen test	0.183	0.165

Note: *** denotes statistical significance at the 1% levels.

Source: Stata output.

The SGMM regression results from Models 1 and 2 show that, except for the *Tertiary* variable, all independent and control variables in the model are statistically significant in explaining economic resilience, at the 1% significance level. Specifically:

First, regarding the green finance variable, the findings demonstrate that green finance significantly enhances economic resilience, aligning with prior studies showing that green financial instruments strengthen environmental and economic stability through improved resource allocation and reduced transition risk (Fatica and Panzica 2024; Wei 2024). For emerging markets, this result suggests that expanding green investment channels can help buffer economies against shocks by fostering cleaner and more efficient production structures. This finding is consistent with the Real Business Cycle (RBC) theory, which posits that external shocks such as climate change or environmental policies can affect national productivity and output, thereby influencing the business cycle. At the same time, the results reinforce the initial hypothesis and align with previous studies by Wang et al. (2022), Fatica and Panzica (2024), Guan and Zhao (2024), Li et al. (2024), Tengfei and Ullah (2024), and Wei (2024), which argue that green finance enhances an economy's resilience to environmental and energy-related shocks. In the context of increasing climate-related risks, green finance supports the transition to a low-carbon growth model, while also fostering innovation and improving growth quality (Nenavath and Mishra 2023; Ning et al. 2023; Saydaliev and Chin 2023). In practice, in Vietnam during the 2020–2025 period, over USD 10 billion was invested in renewable energy projects such as solar and wind power. These initiatives not only contribute to reducing carbon emissions but also strengthen economic resilience against global risks. Thus, green finance is not only a post-crisis recovery tool but also a driving force for sustainable development in emerging economies.

Second, regarding the market integration variable, market integration (MI) is found to have a positive impact on economic resilience (ER) in emerging economies, with statistical significance at the 1% level in both regression models. This finding suggests that a higher level of integration may enhance a country's capacity to cope with economic, environmental, and social shocks. In practice, market integration through trade liberalization, capital flow openness, and global financial connectivity helps improve resource allocation efficiency. It also facilitates access to investment capital, advanced technologies, and modern governance practices from abroad. These factors play a vital role in boosting productivity, accelerating structural economic transformation, and strengthening the adaptability of economies amidst increasingly complex global dynamics. Recent studies by Lester and Nguyen (2016), Oprea and Stoica (2018), Feng, Lee, and Peng

(2023), Lyu et al. (2023), and Yang and Deng (2025) also demonstrate that countries with higher levels of market integration tend to recover more quickly from crises, due to their ability to maintain capital inflows and stable trade activities. The cases of Singapore and South Korea provide clear evidence that these two countries have effectively leveraged market integration to build resilient financial systems and strengthen risk management capabilities, thereby mitigating the adverse effects of external shocks.

Moreover, market integration contributes to the diversification of external economic relations, which helps reduce the risks associated with overdependence on a single market or region. This also enhances flexibility and adaptability in the face of increasing global economic uncertainty. This finding aligns with Ricardo (2001) theory of comparative advantage, which posits that market integration allows countries to specialize in production based on their relative strengths, thereby optimizing resource use and improving economic efficiency. Simultaneously, the results are consistent with Kydland and Prescott's (1982) Real Business Cycle (RBC) theory, which emphasizes that market integration enables countries to diversify production resources, optimize supply chains, and access modern technology, thus minimizing the economic losses caused by shocks.

Third, the moderating role of market integration provides additional insights. The positive and significant interaction term indicates that higher levels of integration amplify the resilience-enhancing effect of green finance. This is consistent with arguments that integrated markets facilitate technology diffusion, enable access to global green capital, and accelerate structural upgrading (Eichengreen and Leblang 2003). However, the effect appears stronger in countries with more stable institutional environments, suggesting that integration benefits are conditional rather than automatic, a point not sufficiently addressed in earlier studies.

The implication is that a higher level of market integration further strengthens the positive relationship between green finance and resilience. In the context of globalization, market integration serves as a crucial transmission channel that enables green capital flows to access advanced technologies, international standards, and strategic investors. This, in turn, enhances capital allocation efficiency and boosts the positive economic impact of green finance.

Moreover, integration promotes information transparency, strengthens governance, and improves institutional quality factors that facilitate the effectiveness of green finance in enhancing the economy's resilience and adaptability to complex and unpredictable shocks.

Next, regarding the control variables in the model. Both Gross Domestic Product (GDP) and Gross Domestic Product per capita (GDPC) exhibit a negative impact on economic resilience in emerging economies, with statistical significance at the 1% level across both models. This result contrasts with initial expectations and diverges from previous findings by Ilter (2017), Simonova (2019), Awan and Azam (2021), and Kaneva et al. (2022), which generally suggest that higher GDP and GDPC are associated with greater resilience. However, in the context of emerging economies, rapid growth is often accompanied by excessive resource exploitation, leading to environmental degradation and pollution (Acheampong and Opoku 2023), which can undermine long-term resilience. Additionally, the relationship between GDP, GDPC, and economic resilience may be influenced by various confounding factors, making the overall impact ambiguous.

The number of listed companies (Listed) shows a positive and statistically significant effect at the 1% level in both models, indicating that an increase in the number of listed firms contributes to enhanced economic resilience in emerging markets. This finding aligns with the research hypothesis and is consistent with the results of Hassan and Halbouni (2013), Bonfim, Custódio, and Raposo (2023), and Zhang (2023). The expansion of stock markets helps diversify capital mobilization channels, improve liquidity, and enhance shock resistance. Moreover, the development of financial markets fosters more efficient resource allocation and risk mitigation, thereby strengthening macroeconomic stability. Government expenditure on health (HE) has a positive and statistically significant impact at the 1% level in both models, underscoring the critical role of healthcare investment in bolstering economic resilience. This finding supports the research expectation and echoes earlier studies by Bedir (2016), Wang, Wang, and Huang (2016) and Chen and Zhang (2025). Increased spending on healthcare not only enhances the quality of health systems but also improves labor productivity and fosters sustainable growth. Particularly in emerging economies, health investment is a key factor in reinforcing crisis response capacity and promoting long-term economic recovery.

Taken together, this study provides new empirical evidence that the interaction between green finance and market integration is a key mechanism shaping economic resilience in emerging markets, and it employs a dynamic GMM approach that enhances identification accuracy. These insights offer valuable implications for policymakers aiming to design integrated strategies for green transformation and resilience building.

Robustness check

To test the reliability and consistency of the results, the study conducts a robustness check by using an alternative proxy for green finance. Specifically, instead of using a composite green finance index constructed from multiple components (including green bonds, government investment in the environment, and carbon trading), the study replaces it with the ratio of renewable energy investment to total energy investment, a specific indicator commonly used in previous studies (e.g., Zhan, Wang, and Zhong 2023; Chin et al. 2024; Yadav, Pathania, and Ramesh 2024; Jawadi, Pondie, and Cheffou 2025) and shown to be correlated with the original composite green finance variable. This alternative variable directly reflects the extent to which financial resources are mobilized for environmentally friendly projects and represents one of the clearest forms of green finance (Table 4). The use of this variable helps assess whether the model's conclusions depend on how green finance is measured.

Table 3 further confirms that the composite green finance index is positively and significantly correlated with the alternative measure of green finance at the 1% significance level.

Table 3. Correlation Matrix

	GF	GF_replace
GF	1.0000	
GF_ replace	0.2928*	1.0000

Note: * denotes statistical significance at the 10% level.

Source: Stata output.

The regression results using the alternative variable show that the positive and statistically significant relationship between green finance and economic resilience remains robust (Table 4). At the same time, the moderating effect of market integration in this relationship retains its sign and level of significance, indicating that the model's results are reliable. These findings suggest that the positive impact of green finance on economic resilience is consistent and not sensitive to changes in the measurement of the green finance variable.

Table 4. Results of Models 1 and 2 with GF_replace

	Model 1	Model 2
L1.ER	0.95609***	0.9614***
GF_replace	0.0056***	0.0221***
MI	0.0288***	0.1303***
GF_replace*MI		6.3638***
GDP	0.5522***	−0.5634***
GDPC	−0.2566***	−0.0273***
Listed	−0.0055***	−0.6768***
Tertiary	0.1082	0.0299
HE	0.0018	0.4490***
Cons	0.0967***	1.1614***
AR (2)	0.705	0.771
Sargan test	0.549	0.543
Hansen test	0.209	0.520

Note: *** denotes statistical significance at the 1% level.

Source: Stata output.

Conclusion

This study contributes to clarifying the role of green finance in enhancing economic resilience in emerging economies, while also emphasizing the importance of market integration as a key moderating factor. Using the SGMM method on a panel dataset of 32 economies over the period 2014–2023, the empirical results reveal that green finance has a positive and statistically significant impact on economic resilience. In addition, market integration plays a catalytic role by amplifying the effectiveness of green finance in strengthening resilience, highlighting the complementary interplay between institutional quality, financial development, and global integration in building a sustainable and resilient economy.

Based on the findings, it is evident that the development of green finance plays a pivotal role in enhancing economic resilience in emerging economies. Accordingly, it is essential to implement targeted policy measures tailored to each component of green finance to fully leverage their individual contributions. First, regarding green bonds, emerging economies should improve the legal

framework and enhance transparency in the issuance and supervision processes. Establishing unified standards and independent evaluation systems can strengthen investor confidence and channel capital into high-impact green projects, thereby supporting sustainable and resilient growth. Second, in terms of public environmental expenditure, governments should prioritize budget allocations for critical sectors such as pollution treatment, climate adaptation, and sustainable infrastructure development. In addition, mechanisms for evaluating the efficiency of public environmental investment should be put in place to ensure optimal use of resources and to strengthen long-term resilience. Third, with respect to low-carbon trade, it is important to create enabling conditions for enterprises to participate more deeply in global green supply chains. This includes upgrading technological capabilities, standardizing environmentally friendly production processes, and improving green trade infrastructure. Furthermore, implementing green trade agreements and effective carbon pricing mechanisms will incentivize the private sector's transition toward greener practices. Finally, strengthening market integration by advancing trade liberalization, financial linkage, and investment climate improvement are essential measures to enhance market integration. These steps not only facilitate the flow of capital and international technology but also broaden policy space to bolster resilience against external shocks.

Although this study provides empirical evidence on the positive impact of green finance on economic resilience, as well as clarifying the moderating role of market integration in this relationship, there remain several limitations that should be acknowledged. First, the measurement of green finance remains a major challenge due to the lack of a globally standardized index. Both the composite index and the alternative proxy used in this study reflect only certain aspects of green finance and may not capture the full scope of green financial activities. Second, the dataset primarily operates at a macro level, which may overlook important differences in the level of green finance development and market integration across country groups. Third, the study mainly focuses on assessing the role of market integration, while other relevant factors have not yet been taken into consideration. Furthermore, although the SGMM approach was applied to address potential endogeneity, the possibility of reverse causality or unobserved variable bias cannot be entirely ruled out. Therefore, future research could be extended in several directions: (i) adopting more comprehensive and standardized measures of green finance as data becomes available; (ii) conducting subgroup analyses by country characteristics (e.g., developed vs. developing economies, or different geographic regions); (iii) incorporating institutional quality, environmental policies, or governance capacity as additional moderating variables; and (iv) evaluating long-term effects to fully capture the impact of green finance strategies on economic resilience.

Competing interests

I declare that I have no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

Appendix: List of 32 countries that comprise the sample: Albania, Algeria, Argentina, Bangladesh, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica, Egypt, Estonia, Georgia, Guatemala, Honduras, India, Indonesia, Iran, Latvia, Lithuania, Malaysia, Mexico, Morocco, Nicaragua, Pakistan, Peru, Philippines, Poland, South Africa, Thailand, Turkey, Vietnam.

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Wpływ zielonych finansów na odporność gospodarczą – moderująca rola integracji rynkowej

Niniejszy artykuł odpowiada na pytania, czy i w jaki sposób zielone finanse zwiększają odporność gospodarczą w gospodarkach wschodzących, a także poddaje ocenie moderującą rolę integracji rynkowej w tym zakresie. Wyniki badań empirycznych, uzyskane z wykorzystaniem systemowej uogólnionej metody momentów (SGMM) w celu uwzględnienia problemów endogeniczności i opóźnionych zmiennych zależnych, wskazują, że zielone finanse wywierają pozytywny i statystycznie istotny wpływ na odporność gospodarczą. Ponadto wysoki poziom integracji rynkowej zwiększa skuteczność zielonych finansów w umacnianiu zdolności danego kraju do przetrwania wstrząsów gospodarczych, społecznych i środowiskowych oraz do odbudowy po nich. Na podstawie tych ustaleń rekomenduje się, aby gospodarki wschodzące promowały rozwój zielonych finansów poprzez ustanowienie jasnych ram politycznych, promowanie zrównoważonych instrumentów finansowych oraz zachęcanie do napływu zielonego kapitału do gospodarki realnej. Jednocześnie należy podjąć wysiłki na rzecz pogłębienia integracji rynkowej poprzez liberalizację handlu, regionalną współpracę finansową oraz poprawę klimatu inwestycyjnego, aby w pełni wykorzystać pożytki płynące z globalizacji i wzmocnić podstawy ożywienia gospodarczego w obliczu rosnącej niepewności na świecie.

Słowa kluczowe: zielone finanse, odporność gospodarcza, integracja rynkowa, gospodarki wschodzące

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State-owned Banks and Profitability in Central and Eastern Europe: Testing the State-owned Banks Advantage Hypothesis

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Abstract

This paper presents and tests an original state-owned banks advantage hypothesis, according to which the nationalisation of a part of the banking sector may positively influence the financial results and reduce risks associated with banking activity. The hypothesis was tested using a model comparing three groups of banks: state-owned banks, foreign owned banks, and domestic privately owned banks. The estimation of model parameters was carried out using a fixed-effects panel data analysis for banks based in Central and Eastern European countries over the period 2014–2020. Based on the models for ROA and, separately, ROE, a statistically significant negative relation was observed in the returns generated by state-owned banks compared to private domestic and foreign banks. The results also indicate a higher business risk for state-owned banks, measured by the level of non-performing loans, which is likely to be related to involvement in projects that are not always profitable but often involve higher credit risk. Therefore, we argue that elements of a country's economic or social policies matter when conducting business but negatively affect the performance of state-owned banks. The results of the model also demonstrate that a bank's market size negatively affects its performance.

Keywords: banking sector, state-owned banks, nationalisation, banks' profitability, Central and Eastern Europe
JEL: E59, G18, G21, G32

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Introduction

The study objective

In the early years of their economic and political transformations, Central and Eastern European (CEE) countries were characterised by a significant share of state-owned enterprises. Privatisation involved reducing the direct influence of the state on enterprise activities. It was one of the most important parts of the reform process in post-communist countries, undertaken in parallel with the political liberalisation and stabilisation (Lipton et al. 1990). The banking sector underwent a particularly significant transformation. As Patev, Lyroudi, and Kanaryan (2003) point out, in the last decade of the twentieth century, the ownership structure of the banking sector in CEE changed from 100% state participation to about 90% private ownership. As Domanski (2005) discusses, in some cases, the unsatisfactory results of domestic privatisation prompted governments to encourage foreign capital to invest in domestic banks, which were subsequently acquired by foreign investors. This led to the dominance of foreign capital in CEE's banking sector, as pointed out by Darvas, Schoenmaker, and Veron (2016) and Iwanicz-Drozdowska, Smaga, and Witkowski (2017). Banks in the region also evolved from the 1990s onwards, driven by the accession of post-communist countries to the European Union (EU). Another factor was the 2008–2009 financial crisis and the subsequent implementation of post-crisis regulations, including the Capital Requirements Directive IV (CRD IV), the Capital Requirements Regulation (CRR), and the Bank Recovery and Resolution Directive (BRRD). Their main objective was to restore financial stability in Europe and stimulate the real economy through public investment (including public-private partnerships) and the protection of selected sectors of the economy (Koleśnik 2014). The outcome of the 2008–2009 financial crisis, as discussed by Maudos and Vives (2019), was the progressive consolidation of the banking sector, particularly in countries where the need to restructure the banking sector emerged.

However, the key issue is the impact of the financial crisis, which led to an increase in the number of politicians calling for direct state intervention through the takeover of companies in difficulty. As Panizza (2023) notes, it is likely that banking crises lead to an increase in state ownership. In recent years, the acquisition of a bank at risk of insolvency has become possible thanks to the resolution procedure provided for in Directive 2014/59/EU (BRRD), which allows for the sale of banking activities, the establishment of a bridge institution, the application of debt write-down or conversion instruments, and the separation of assets (Kozińska 2018). As a result, the renationalisation of the banking sector – primarily the Polish banking sector – lasted for several years. According to our calculations based on data from Deloitte (2020) and the European Central Bank, at the end of 2020, the state's share in the banking sector in Poland increased from around 23% to 45% between 2016 and 2020. This was mainly due to the state takeover of the second and ninth-largest credit institutions by asset value. Analysing the situation in other countries, the share of state ownership in Hungary and Romania at the end of 2020 increased by approximately 3 percentage points (compared to the previous year) and amounted to over 12% of the entire sector. Minor increases were also recorded in Bulgaria and Croatia.

The study examines whether state-owned banks (SOBs) differ in terms of efficiency and risk-taking behaviour compared to both foreign owned banks (FOBs) and domestic privately owned banks

(DOPBs). This article contributes to the discussion on the advantages and disadvantages of state involvement in the banking sector. The approach presents the viewpoint of the banks' shareholders, who seek to increase their rate of return and reduce business risk. This study is original because, to date, there has been little research on the impact of the renationalisation of the banking sector (i.e. the state's reacquisition of shares in banks), in contrast to the numerous articles analysing the relationship between shareholding structure and bank performance. There are also few analyses concerning whether SOBs exhibit greater efficiency than FOBs and DOPBs.

Motivation of the research

State participation in the banking sector, viewed as a one-sided process of nationalisation, is associated mostly with rescuing the economy in both developed and developing countries by providing assistance to systemically important entities at risk of insolvency. In recent years, however, other solutions have prevailed over nationalisation processes, mainly due to the mechanisms provided for in the BRRD Directive and the obligations arising therefrom. The latest research on the Polish case of resolution was published by researchers such as Iwanicz-Drozdowska, Kurowski, and Witkowski (2024).

This article analyses the phenomenon of state participation in the economy through shareholding. This was the case in European countries, including Croatia, which Hočevar (2021) described as state consolidation. According to Voszka (2018), a similar process of nationalisation in Hungary was part of a complex political process and was not aimed solely at crisis management. Voszka argues that it stems from the government's policy of taking over strategic sectors of the economy. Méró and Piroska (2016) point out that in 2013–2014, the Hungarian government acquired shares in several smaller banks, guided by political preferences for banking nationalism. They present the "banking nationalism" concept as giving priority to the national interest when developing policies towards banks, including their ownership, regulation, and supervision. This process spread to Poland as "renationalisation" and is particularly interesting because it involves the repurchase of previously privatised companies. According to Pyka and Pyka (2017), successive state acquisitions of banks were motivated by the belief that domestic banks were too dependent on foreign capital, which exerted too much influence. The need to "repolonise" this sector had previously emerged as the government's response to concerns about the large share of foreign capital in the Polish banking sector (Węcławski 2015).

The process of "denationalisation" took place at the same time in another CEE country, Slovenia, which had the largest state share in the banking sector in the region. By the end of 2019, the government had sold its majority stakes in the country's first and third largest banks, in line with EU recommendations. The state's share in the assets of the Slovenian banking sector fell from around 40% to around 6% within just one year. A study on this topic was conducted by Piroska and Podvršič (2020), who link it to the policy of "New European Banking Governance" (NEBG), which includes new European regulations and policies for restructuring the banking sector. The state had to sell its shares so that foreign institutions could recapitalise the sector. According to that study, NEBG led to a significant weakening of democratic institutions in favour of supranational supervision of the banking sector, as well as to a prolongation of the banking crisis in Slovenia. This policy met with strong public resistance. In Romania, most SOBs were

taken over by foreign institutions in response to the need to revive the banking sector, which had suffered from inefficiency and public corruption (Dumitriu, Stefanescu, and Nistor 2012).

In other CEE countries, state participation in the banking sector is negligible and is mainly limited to so-called export-import (EXIM) or development banks. These banks mainly carry out activities commissioned by the government, such as supporting economic and social programmes (Zaleska 2007).

Literature review

Reasons for the re-nationalisation of banks

The literature on the subject cites measures intended to "rescue" the sector or individual entities as the main reasons for the nationalisation of banks in EU countries. Recent developments in the sector indicate that renationalisation is a long-term policy, although its assessment in existing research remains clearly ambiguous. The primary driver for the state takeover of banks is the concept of "banking nationalism" presented by Méró and Piroska (2016). This concept is defined as giving priority to the national interest when developing policies towards banks, including their ownership, regulation, and supervision. That study points out that the banking sector and the policies of individual EU countries are influenced by the integration of the financial sector, and in particular by the Banking Union itself. However, banking nationalism, manifested in strong links between banks and the government, is identified as one of the causes of the crisis in the Eurozone in 2010 (Epstein and Rhodes 2014). A process of renationalisation can be observed in the banking sector in Poland. The need to "repolonise" it had already emerged earlier (Węcławski 2015), mainly as a response by the government to concerns about the large share of foreign capital in the Polish banking sector. According to Pyka and Pyka (2017), further acquisitions are motivated by the belief that domestic banks are too dependent on foreign capital and that their influence on the activities of Polish credit institutions is too significant. Mazzucato and Penna (2016) point out that the objective of development banks is not only to rectify market failures but also to shape the financial market and policies for development. In some countries, such as Poland, these banks are called "national" or "state" banks. In addition to commercial activities, they carry out activities mandated by the government, such as supporting economic and social programmes (Zaleska 2007).

Studies indicating the benefits of state-owned banks in the sector

Several studies point to the benefits of banks remaining under state capital control. Using Croatia as an example, Davidovic, Uzelac, and Zelenovic (2019) found that SOBs were more efficient than banks owned by private investors. Furthermore, the banking crisis in Croatia did not significantly affect the performance of SOBs compared to other entities in the sector. Their study suggests this was due to the proper management of asset and liability maturities, as well as the operational flexibility of the SOBs. Research by Pyka and Nocoń (2018) on the nationalisation of several banks in Poland focused mainly on two commercial banks: Alior Bank S.A.

and Pekao S.A. After the nationalisation of these banks, a significant increase in the efficiency of their operations in terms of profitability was observed. According to a study by Krasovskis, Limanskis, and Pancenko (2016) on the competitiveness of the banking sector in Latvia, the largest banks in the country – SEB Banka, DNB Banka, and Swedbank, which are all foreign banks – had lower liquidity ratios than other banks. They also performed poorly in terms of ROE compared to smaller entities.

Work on the benefits of SOBs is also based on the experience of various regions where this is structurally conditioned, including India, Russia, and China. These conclusions were drawn by Belousova et al. (2021) based on the example of the Russian sector. Their observations from 2004–2015 show that although SOBs are not the most efficient, their performance is significantly better than that of DOPBs. This relationship is explained by the large amount of government support and guarantees that allow SOBs to provide cheaper financing and work with more reliable customers. On the other hand, FOBs have a comparative advantage in terms of better technology and management, including a developed risk management system. The Chinese sector was studied by Koroleva et al. (2021), who argue that larger SOBs with higher credit quality have accordingly higher profitability compared to other banks. Sengupta and De (2020) note that the nationalisation of the banking sector in India was intended to stabilise the country's weak banking system and encourage the public to use banking services. The study argues that both goals were achieved. Boubakri and Saffar (2019) present evidence that state ownership of banks has a positive impact on banks' use of debt financing, and therefore, private companies derive greater benefits from these banks.

Pak (2019) analyses banks based in the countries of the Eurasian Economic Union. The research notes the positive impact of state ownership on a bank's probability of survival (but not on its Net Stable Funding Ratio). Haque and Brown (2017) examine the banking sector in the Middle East and North Africa (MENA) countries and observe a significant impact of the ownership structure on the efficiency of the sector. In particular, they argue that the participation of governments as shareholders of banks had a positive impact on their cost efficiency, but not on their profitability. Unlike the SOBs, the FOBs covered by the study did not show a significant advantage in terms of cost management or profitability. Furthermore, increasingly stringent capital requirements had a negative impact on the cost efficiency of foreign banks, unlike domestic banks.

Cho and Kalinowski (2010) raise another important issue. In Korea, a banking sector model was introduced in which the state became the majority shareholder of banks. Its objective was not exactly to prevent the effects of financial crises in the short term, but to restructure banks in the long term. According to that research, the role of the government was crucial to the success of the subsequent commercialisation of banks. This is an example of the socialisation of losses and privatisation of profits as the basis for economic initiative. Cho and Kalinowski conclude that SOBs performed better in many areas than privately managed enterprises. This is important because, in their view, the privatisation process is not justified by economic efficiency but is solely the result of free market ideology as well as international pressure.

Studies indicating the disadvantages or the indifference of state-owned banks in the sector

Another group of studies points to the detrimental role of state ownership in the banking sector and the lack of significant differences between the profitability or risk-taking of state-owned and private banks. Research on the disadvantages of state ownership in CEE includes the work of Stančić, Čupić, and Obradović (2014) on four transition economies in South-Eastern Europe between 2005 and 2010. That study found that DOPBs perform better than SOBs, which may be due to lower ownership concentration and smaller boards of directors – factors that also negatively affect bank profitability. Jackowicz, Kowalewski, and Kozłowski (2013) emphasise that the view that the state should participate as a shareholder in the banking sector's ownership structure is becoming increasingly popular in CEE countries. However, they note that SOBs are sensitive to political pressure. In the long term, any decision not supported by economic factors may adversely affect the stability of the financial sector. Fang, Hasan, and Marton (2011) obtained similar results for the same region between 1998 and 2008. Their research describes how foreign banks are characterised by higher profit efficiency but lower cost efficiency, while SOBs are associated with lower profit efficiency than DOPBs. Bonin, Hasan, and Wachtel (2005), analysing the performance indicators of the largest banks in Bulgaria, the Czech Republic, Croatia, Hungary, and Romania, concluded that FOBs were more efficient compared to SOBs. Nevertheless, in their opinion, the timing of privatisation was fairly important, as early privatisation gave management more time to implement strategies designed to ensure efficiency.

Recent research by Panizza (2023) shows that, contrary to earlier publications, there is no difference between the profitability of privately owned banks and SOBs. Davydenko et al. (2023) highlight the costs of recapitalising SOBs, claiming that these costs disrupt state finances and make Ukraine even more dependent on debt. Doan, Lin, and Doong (2020), analysing the process of income smoothing among banks, indicated that around election periods, there was a strong tendency for SOBs to smooth their results. Ismiyanti, Rahman, and Mahadwartha (2018) conclude that both foreign and state ownership can increase banks' propensity to take risks. However, in the case of SOBs, this is mainly caused by the political objectives that governments strive to pursue.

Research on the banking sector in Asian countries also demonstrates the shortcomings of SOBs. Han, Epetia, and Cheng (2021) observe that while the presence of SOBs in China is strong, the distortions in interest costs associated with state ownership are more severe. Their research shows that the misallocation of credit is also linked to the ownership structure of Chinese enterprises, which is dominated by state ownership. Rosalina and Nugraha (2019) argue that government ownership in Indonesia has a statistically significant negative effect on bank profitability compared to domestic and foreign private ownership. They believe that these results are consistent with the theory of global advantage. Kamarudin, Sufian, and Nassir (2016) highlight that the level of profit efficiency for both state-owned and private banks in Bangladesh declined in the years following the financial crisis, but private commercial banks still show slightly higher levels of efficiency than state-owned commercial banks.

There are also studies pointing to the detrimental impact of state ownership on banks' risk levels and market behaviour. Lee and Hooy (2020), examining the banking sector in Asian emerging markets, demonstrated a link between state ownership of banks and greater risk-taking in terms of credit risk and return volatility. Bai et al. (2020) argue that the problem of moral hazard is greater in SOBs, while it is smaller in listed banks. Meanwhile, based on data from 13 countries in the MENA region, Lassoued, Sassi, and Attia (2016) argue that state ownership of banks is a factor that encourages higher risk-taking, whereas foreign capital has the opposite effect. Analysing a sample of large European banks, Iannotta, Nocera, and Sironi (2013) found that SOBs have lower default risk but higher operational risk than private banks, which may indicate that government protection encourages greater risk-taking. Jia (2009) believes that lending by SOBs is less prudent than lending by joint-equity banks and sees this as consistent with the hypothesis that private banks are accountable to their shareholders and depositors. As a result, private banks have a much greater incentive to lend cautiously than SOBs.

Finally, Bhattacharyya, Lovell, and Sahay (1997), based on data from the Indian banking sector, proved that publicly owned banks were the most efficient in terms of customer service. The study is important because a similar trend in sector ownership was observed in India during the period analysed: an increase in the number of FOBs and a simultaneous decrease in the number of SOBs. At the end of the period analysed, FOBs proved to be almost as efficient as SOBs, considering regulatory constraints and capital requirements. Thus, banks with a majority foreign capital share were able to adapt to an increasingly competitive environment.

Materials and Methods

Research hypothesis

State ownership of banks has been the subject of numerous studies intended to determine the advantages of state ownership in a free-market economy. An influential work presenting the theories on state-owned enterprises is that of Peng et al. (2016), who examine the fundamental theories related to the existence of state-owned enterprises. Indeed, the debate on the revival of state capitalism has been ongoing for a long time, including an important work by Cornett et al. (2010), who note that ownership structure is widely recognised as an essential determinant of company performance. Based on corporate governance theory, agency-cost theory, and contestable-markets theory, that study tests hypotheses regarding differences in performance between state-owned and private banks before, during, and after the Asian financial crisis.

Today, governments and banking regulators can use better, less costly mechanisms to revive a bank, such as the aforementioned resolution procedure. In the CEE region, given the high economic growth, authorities do not necessarily have to buy or own banks that are unprofitable or have no positive prospects. The current renationalisation, although influenced by political factors, no longer appears to be a purely political process but also a commercial one, focused on a long-term policy of developing banks, the market, and the entire economy. Although political factors will certainly continue to have a strong influence on the activities of commercial SOBs, governments as shareholders seek to increase the ability of these banks to generate profits and achieve economic

policy objectives. An inefficient bank would represent a financial burden on the state treasury; however, financial inefficiency does not necessarily mean total inefficiency, as potential social benefits must also be taken into account. They were analysed by Relaño (2011), who argued – using the example of social banks – that companies have options other than just following the logic of maximising financial profits. He also found that social banks are much more consistent in this respect. In our view, however, even the financial profits of SOBs benefit the entire economy, as in most cases these profits are redistributed. Furthermore, issues regarding the relationship between the principal and agent, which often arise in relation to state-owned enterprises, may no longer be as relevant as before. The banks analysed are commercial in nature and are subject to corporate governance principles in the same way as other commercial companies. Some of the banks analysed are listed on stock exchanges, which means these entities must maintain a high level of transparency by publishing periodic reports and applying rules on confidential information. In such cases, the government is not the sole shareholder.

Given the political environment, which differs significantly from the situation in the 1990s and 2000s, the support of some CEE countries for state ownership of banks, and the research presented in this article, we wish to examine whether theories predicting that SOBs are not beneficial for the economy are correct. We therefore propose to test an original hypothesis, hereafter referred to as the "state-owned banks' advantage hypothesis". According to this hypothesis, the nationalisation (or re-nationalisation) of a bank has a positive impact on its financial performance and on the risks associated with its activities. The main research question is whether the acquisition of banks by state capital has a significant positive impact on their profitability and risk-taking behaviour. This will be measured using return on assets (ROA), return on equity (ROE), and non-performing loans (NPL); on this basis, we will attempt to prove the original hypothesis. In addition to seeking answers to the research question, this article also strives to find – based on available research and our observations – associations between the results obtained and possible causes, rather than specifically identifying the channels through which a potential benefit may arise.

Based on the literature and our observations, arguments that would justify such a hypothesis and support the claim that state ownership has a positive impact on financial performance and risk include, for example, greater credibility of state entities in economic transactions, the possibility of obtaining state guarantees, and general capital stability. This is relevant in the context of the COVID-19 pandemic, as the financial collapse was caused by purely external factors, not factors within the financial system. Furthermore, although the banking system is subject to a higher level of special protection compared to other sectors of the economy, SOBs that have been "renationalised" are of greater importance to the state authorities, as funds were spent on their acquisition (Koleśnik 2019). These characteristics make listed banks attractive to shareholders due to their potentially lower investment risk or higher likelihood of dividend payments. States generate revenue from their economic entities mainly through the distribution of profits from controlled companies.

However, there are arguments which may challenge this hypothesis. In addition to the goal of profit optimisation, such banks may be required to pursue "national interest" objectives, such as benefiting the national economy and citizens. A change in the ruling party may result

in a change in both the bank's policy and the composition of its management board, which may also prevent the implementation of long-term strategies. Furthermore, banks that have an infrastructural advantage or are given preferential treatment by state authorities may impose higher costs or fees on their customers and partners. At the same time, they do not have to bear a high risk of losing their customer base.

Data selection

The analysis uses data from 2014 to 2020 for banks based in 11 CEE countries (Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia). This period was chosen to eliminate the effects of the 2008–2009 global financial crisis and the subsequent restructuring measures taken by several banks. This selection accounts for a number of credit institutions that failed during this period, as well as mergers and acquisitions carried out by the Hungarian government, among others. In addition, the transition period resulting from the accession of Romania and Bulgaria (in 2007) and Croatia (in 2013) to the EU was eliminated, as these countries had to adapt their legal systems to the common regulatory requirements of the EU. Finally, on 1 January 2014, the most important regulations governing banking activities – the CRD IV/CRR package – came into force. This analysis does not cover branches of credit institutions, branches of foreign banks, cooperative banks, or other financial institutions that are not credit institutions and are not subject to CRD IV/CRR under Article 2 (5) of the Directive (i.e., Bank Gospodarstwa Krajowego, Magyar Fejlesztési Bank, Magyar Export-Import Bank, and Sid Banka).

A potential drawback affecting the reliability of the analysis could be a situation in which the banks within the research sample that were renationalised or remain under state control – represented by varying SOB variables in the sample depending on the year – were so-called "bad banks". Such entities are characterised by low profitability or equity levels that threaten their operations and ability to meet liabilities. This was not the case in our study, as the renationalised or denationalised banks in the sample were characterised by high, stable profitability. The ROE and ROA ratios of these banks significantly exceeded the average values for the banks surveyed. It is worth noting that they were some of the largest banks on the market. In the case of other SOBs, the results also showed average, albeit in some cases below-average, profitability. However, the cost-to-income and impaired loans-to-equity ratios remained at an average level. The capital ratios of all SOBs – in particular the Tier 1 ratio, which in the EU is intended to ensure a secure capital base – also remained stable and higher than required by applicable regulations. Therefore, the data suggest there are no "bad banks" in the sample of SOBs where profitability or liability burden would remain consistently low.

The data used in the analysis are derived from the banks' financial statements, as well as data provided by the European Banking Federation, the European Central Bank, the World Bank, and the Orbis database as of 12 March 2022. A list of SOBs is provided in Appendix A.

Model estimation

Regression analysis was used to examine the relationship between a bank's efficiency and its ownership structure. This methodology is a commonly used tool for evaluating the impact of explanatory variables on the dependent variable – the efficiency of a given bank (Zoli 2001; Bojāre and Romānova 2017; Haque and Brown 2017; Fekri and Shawtari 2018). The analysis was conducted by comparing SOBs with FOBs, as well as SOBs with DOPBs, i.e., banks domiciled in the country of their largest shareholder. To examine these relationships, data on the variables listed in Table 1 were collected from the banks' financial statements and the economic databases mentioned above.

Table 1. Explanatory variables adopted in the regression model

Category	Variable	Description
Internal factors relating to the bank's business	NetLoansDep	Loans-to-deposits ratio
	lnLossProv	Loan loss provisions
	lnNetFees	Revenue from net fees and commissions
	lnTax	Income tax from the financial statement
	CosttoInc	Cost-to-income ratio
	lnShaf	Equity and capital funds
Banking sector	BMS	Share of the bank's assets in the market in which it operates
Macroeconomic indicators	IR	Long-term interest rate in the country of operation
Shareholding structure	SOB	*Dummy* variable: 1if state-owned, 0 otherwise

Source: authors' own work.

Two income efficiency measures – return on assets (ROA) and return on equity (ROE) – and one risk indicator – natural logarithm of non-performing loans (lnNPL) – were adopted as the response variables. ROA and ROE are two key indicators measuring profit generation efficiency. The NPL ratio is a commonly used risk indicator as it measures credit risk and asset quality (Alizadeh Janvisloo and Muhammad 2013). Zhang et al. (2016) note that non-performing loans are a major obstacle to banking sector development; an increase in NPLs indicates riskier lending, which may lead to a deterioration in credit quality. Hence, this ratio reflects the level of moral hazard within such institutions. The NPL ratio provides insight into whether SOBs are exposed to moral hazard on the part of management or the largest shareholder, the state.

Several variables listed in Table 1 were adopted as explanatory variables. These encompass both internal factors related to bank operations – which vary by institution and sector – and external factors affecting profitability. These include lending capacity relative to customer deposits, which measures the ability to generate a return on assets, as well as non-interest income (commissions and fees) and cost efficiency. Another factor is taxation, the level of which is determined by both tax shields and mechanisms for optimising taxable profits. This is also related to the size of shareholders' funds and, consequently, the cost of equity compared to debt capital. For the banking sector, the BMS variable accounts for market share, explaining advantages resulting from economies of scale or large-base effects. Regarding macroeconomic indicators, the most significant

external factor is the interest rate (IR) in the country of operation, which relates to monetary stability and determines the interest cost of operations. The SOB variable is a dummy variable, taking a value of 0 for non-SOBs or 1 for SOB, and serves to determine the impact of ownership structure on the response variables.

To test the state-owned banks' advantage hypothesis, the following general multiple regression model has been applied:

$$\begin{aligned} E_i = \alpha_i + \beta_1 \text{NetLoansDep} + \beta_2 \text{lnLossProv} + \beta_3 \text{lnNetFees} + \beta_4 \text{lnTax} + \beta_5 \text{CosttoInc} \\ + \beta_6 \text{lnSHAF} + \beta_7 \text{BMS} + \beta_8 \text{IR} + \beta_9 \text{SOB} + \varepsilon_{it}, \end{aligned} \quad (1)$$

where E represents the response variables (ROA, ROE or lnNPL), α_i is a constant for a given observation, and ε_{it} is the standard error term. To control for cross-section heteroskedasticity, standard errors were estimated using cluster-robust variance estimators (*Huber–White* or *sandwich* estimators). The remaining variables are defined in Table 1.

The model is intended to determine whether the performance or risk-taking behaviour of SOBs differs significantly from that of banks owned by other investor types. Parameter estimation was carried out using fixed-effects (FE) panel data analysis on two sets of unbalanced panel data. This method is widely employed to evaluate the impact of cross-sectional data over a specific period (Yaffee 2003) and effectively captures differences both between entities within the same period and across different periods for the same entity. The advantages of panel data analysis include the generation of more accurate results for individual units by aggregating and pooling data. Furthermore, panel data containing time-series observations for multiple units are well-suited for analysing issues of homogeneity versus heterogeneity (Bresson, Hsiao, and Pirotte 2006). This approach has been validated by studies of similar scope regarding banking sector efficiency (Gul, Irshad, and Zaman 2011; Bojāre and Romānova 2017; Fekri and Shawtari 2018). The use of panel data allows us to estimate and test structural changes observed across individual units in both short- and long-term dynamics (Blundell and Mátyás 1992).

The adoption of the fixed-effects model was confirmed by a robust Hausman specification test of overidentifying restrictions, with the exception of the regression model for ROE for FOBs (χ^2 p-value = 0.6386). Because this specific test did not confirm the validity of the FE model, those results will only be treated as supplementary.

Results and discussion

Model estimations

The model parameters were estimated based on observations from the periods described in section 3.2. The results of the parameter estimation using the FE panel data analysis method are presented in the tables below. All estimations were performed using Stata 17 software.

Table 2. Fixed-effects regression results for ROA:
State-owned banks (SOB) vs domestic privately owned banks (DOPB)

					[95% Conf. Interval]		
ROA	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	−.002	.001	−2.33	.023	−.004	0	**
lnLossProv	−.405	.105	−3.85	< .001	−.616	−.195	***
lnNetFees	−.137	.133	−1.03	.308	−.404	.13	
lnTax	.09	.048	1.86	.069	−.007	.186	*
CosttoInc	−.031	.007	−4.21	< .001	−.046	−.016	***
lnSHAF	.366	.271	1.35	.182	−.176	.909	
BMS	−1.276	.605	−2.11	.039	−2.488	−.065	**
IR	−.173	.116	−1.49	.141	−.405	.059	
SOB	−.435	.122	−3.56	.001	−.679	−.19	***
Constant	3.889	4.682	0.83	.41	−5.489	13.267	
Mean dependent var		0.730	SD dependent var			1.118	
R-squared		0.526	Number of obs			235	
F-test		24.674	Prob > F			0.000	
Akaike crit. (AIC)		356.565	Bayesian crit. (BIC)			387.701	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Table 3. Fixed-effects model regression results for ROE:
State-owned banks (SOB) vs domestic privately owned banks (DOPB)

					[95% Conf. Interval]		
ROE	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	−.003	.001	−2.50	.016	−.005	−.001	**
lnLossProv	−.348	.122	−2.85	.006	−.593	−.103	***
lnNetFees	−.166	.124	−1.34	.186	−.415	.082	
lnTax	.13	.067	1.94	.058	−.004	.265	*
CosttoInc	−.033	.008	−4.21	< .001	−.049	−.018	***
lnSHAF	.652	.389	1.68	.099	−.127	1.431	*
BMS	−.924	.605	−1.53	.132	−2.135	.287	
IR	−.113	.123	−0.92	.361	−.36	.133	
SOB	−.231	.131	−1.76	.083	−.494	.031	*
Constant	−.194	5.83	−0.03	.974	−11.872	11.484	
Mean dependent var		0.804	SD dependent var			1.047	

					[95% Conf. Interval]		
ROE	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
R-squared		0.552	Number of obs			235	
F-test		9.624	Prob > F			0.000	
Akaike crit. (AIC)		371.803	Bayesian crit. (BIC)			402.939	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Table 4. Fixed-effects model regression results for ROA: State-owned banks (SOB) vs foreign owned banks (FOB)

					[95% Conf. Interval]		
ROA	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	−.001	.001	−0.73	.469	−.004	.002	
lnLossProv	−.286	.055	−5.17	< .001	−.396	−.176	***
lnNetFees	−.189	.082	−2.31	.023	−.351	−.027	**
lnTax	.128	.044	2.92	.004	.041	.215	***
CosttoInc	−.026	.003	−7.89	< .001	−.033	−.019	***
lnSHAF	.627	.217	2.89	.005	.197	1.057	***
BMS	−.61	.311	−1.96	.052	−1.226	.006	*
IR	−.021	.05	−0.42	.677	−.12	.078	
SOB	−.379	.07	−5.43	< .001	−.518	−.241	***
Constant	−1.392	2.421	−0.57	.566	−6.191	3.406	
Mean dependent var		0.879	SD dependent var			1.327	
R-squared		0.637	Number of obs			507	
F-test		58.000	Prob > F			0.000	
Akaike crit. (AIC)		748.205	Bayesian crit. (BIC)			786.262	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Table 5. Fixed-effects model regression results for ROE: State-owned banks (SOB) vs foreign owned banks (FOB)

					[95% Conf. Interval]		
ROE	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	−.003	.003	−1.19	.238	−.009	.002	
lnLossProv	−.277	.072	−3.85	< .001	−.419	−.134	***
lnNetFees	−.341	.116	−2.93	.004	−.571	−.11	***

					[95% Conf. Interval]		
ROE	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
lnTax	.105	.075	1.40	.165	−.044	.255	
CosttoInc	−.027	.005	−6.00	< .001	−.036	−.018	***
lnSHAF	1.225	.52	2.36	.02	.195	2.255	**
BMS	−.59	.49	−1.20	.231	−1.561	.381	
IR	−.004	.067	−0.06	.956	−.137	.129	
SOB	−.368	.21	−1.75	.082	−.783	.048	*
Constant	−7.265	5.585	−1.30	.196	−18.333	3.803	
Mean dependent var		0.842	SD dependent var			1.784	
R-squared		0.517	Number of obs			507	
F-test		15.907	Prob > F			0.000	
Akaike crit. (AIC)		1078.753	Bayesian crit. (BIC)			1116.810	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Table 6. Fixed-effects model regression results for lnNPL:
State-owned banks (SOB) vs domestic privately owned banks (DOPB)

					[95% Conf. Interval]		
lnNPL	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	.001	0	2.20	.032	0	.002	**
lnLossProv	.207	.054	3.84	< .001	.099	.315	***
lnNetFees	−.018	.081	−0.22	.829	−.18	.145	
lnTax	−.018	.055	−0.34	.739	−.128	.092	
CosttoInc	.001	.003	0.35	.724	−.004	.006	
lnSHAF	.719	.191	3.76	< .001	.335	1.103	***
BMS	−.479	.282	−1.70	.096	−1.045	.088	*
IR	.093	.044	2.09	.041	.004	.182	**
SOB	.372	.133	2.79	.007	.104	.64	***
Constant	.614	2.47	0.25	.805	−4.342	5.57	
Mean dependent var		11.113	SD dependent var			1.966	
R-squared (overall)		0.7978	Number of obs			220	
F-test		5.133	Prob > F			0.000	
Akaike crit. (AIC)		85.960	Bayesian crit. (BIC)			116.502	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Table 7. Fixed-effects model regression results for lnNPL:
State-owned banks (SOB) vs foreign owned banks (FOB)

					[95% Conf. Interval]		
lnNPL	Coef.	Std. Err.	t-value	p-value	Lower	Upper	Sig
NetLoansDep	0	.001	−0.08	.938	−.002	.002	
lnLossProv	.17	.028	5.99	< .001	.114	.227	***
lnNetFees	.242	.07	3.44	.001	.103	.382	***
lnTax	−.047	.024	−1.95	.054	−.096	.001	*
CosttoInc	.002	.001	2.14	.035	0	.004	**
lnSHAF	.094	.118	0.79	.43	−.141	.328	
BMS	.237	.248	0.96	.342	−.255	.729	
IR	.158	.024	6.47	< .001	.11	.207	***
SOB	.553	.162	3.42	.001	.232	.874	***
Constant	6.125	1.49	4.11	< .001	3.172	9.077	***
Mean dependent var		11.781	SD dependent var			1.589	
R-squared (overall)		0.7579	Number of obs			499	
F-test		15.006	Prob > F			0.000	
Akaike crit. (AIC)		173.949	Bayesian crit. (BIC)			211.862	

*** $p < .01$, ** $p < .05$, * $p < .1$.

Source: authors' own work based on banks' financial statements, data made available by the European Banking Federation, the European Central Bank, the World Bank and the Orbis database.

Results discussion

Based on the results obtained, a statistically significant relationship was observed between a bank's ownership structure and its returns, specifically return on assets (ROA) and return on equity (ROE). The coefficients obtained for the SOB variable were negative across all models; they were statistically significant at the 0.01 level for the ROA models and at the 0.1 level for the ROE models. With regard to risk-taking behaviour, the regression results for non-performing loans (lnNPL, Tables 6–7) showed a statistically significant positive relationship between state ownership and non-performing loans when comparing SOBs with both DOPBs and FOBs. These results indicate that SOBs performed statistically worse than banks where the majority or sole shareholder is a domestic private investor or foreign investor, although they were more heavily burdened with riskier assets. As previously mentioned, studies across different regions have yielded ambiguous results; however, our empirical findings suggest that concerns regarding the potentially lower profit-making capacity of SOBs are justified. Our analysis indicates that the state-owned banks' advantage hypothesis may be unfounded, particularly as the data include banks that have undergone "denationalisation" and account for the economic factors driving these processes.

In seeking explanations for these identified associations, it should be noted that Brei and Schclarek (2013) claim that customers perceive state-owned enterprises as safer and "more secure" because

they are owned by the state. However, in both models, a statistically significant positive relationship was found for SOBs regarding credit portfolio risk; hence, SOBs appear more prone to granting "risky" loans. For banks with a significant proportion of assets composed of difficult-to-recover loans, profitability is likely negatively affected by high debt-servicing costs – a trend reflected in the negative relationship between state ownership and ROA. The results for the loan-to-deposit ratio are also negatively correlated with ROA in the model for DOPBs, suggesting that counterparty risk materialises and leads to an increase in bad debts.

Zhang et al. (2016) claim that the lending activities of SOBs contribute to moral hazard. The increase in the NPL ratio in SOBs does indeed indicate riskier lending, which may stem from a focus on generating higher revenues to meet government expectations. The combination of these factors may result in higher credit risk-taking, which is ostensibly offset by a higher capacity to absorb losses. Thus, SOBs may be more likely to grant risky loans when financially backed by the state – the "most solvent" financial market participant – as evidenced by Iannotta, Nocera, and Sironi (2013). However, this does not necessarily mean that their financial stability is at risk; rather, stability may depend on capital or guarantees provided by the government. Our models show that ROE improves when shareholder funds are higher. Combined with the fact that government takeovers of banks were relatively recent, this raises the question of selection bias. Nationalised banks with political ties to the government may enjoy a higher level of state protection, which is why, in theory, their risk of insolvency is much lower. At the same time, taking on more unpredictable risk ultimately proves detrimental to profitability – a fact that becomes even more apparent when comparing SOBs with DOPBs, which are often considered "riskier" or "less profitable" by the market.

These results prompt the issue of whether these banks are poorly managed, as their profitability is statistically worse, but at the same time, they are exposed to greater risk. According to Peng et al. (2016), the question of whether state-owned enterprises outperform the private ones should be considered based on what economic criteria state-owned enterprises can outperform private ones. As Relaño (2011) suggests, profit generation alone may not be the most important factor shaping the profitability of SOBs; instead, the "social banking" dimension should be considered. Based on this, it can be argued that "monetary" profit does not appear to be the only priority for SOBs, as such banks in the research sample were not "bad" banks. They perform social functions that generate social profits, which cannot be measured by classic ROA or ROE.

The lower profit-generating capacity of SOBs may result from their strong involvement in non-banking activities through various forms of sponsorship, social initiatives, or support programmes. In fact, commercial banks controlled by governments have most likely become another source of financing for economic or social activities, which certainly affects financial efficiency and risk-mitigating measures. Ismiyanti, Rahman, and Mahadwartha (2018) suggest that in the case of SOBs, their higher riskiness stems from the political objectives that governments want to pursue. Projects financed by SOBs are often not as profitable. Research by Lapteacru (2017) also showed that involvement in non-interest-income activities actually worsened the risk profile of state-owned institutions. More risky financing could therefore be explained by the fact that SOBs are involved in various projects implemented by the state or local authorities – they may be more willing to finance public or public-private projects than private institutions.

The discussion of the model results should be supplemented with an analysis of the statistically significant negative relationship between banks' market share (BMS) and ROA in Tables 2 and 4 (models for ROA), as the impact of the BMS variable proved to be statistically significant and negative. The results show that larger banks in CEE do not benefit from economies of scale or their market position. This may be attributable to the high need to secure and maintain an adequate capital base in order to meet regulatory requirements, as high capital needs generally result in a higher cost of capital. This argument is founded, for example, on the findings of Lassoued, Sassi, and Attia (2016), who note that SOBs tend to increase their capital adequacy ratio to hedge against high levels of risk. The model results seem to confirm this, as on the one hand, the SOBs analysed were more prone to non-performing lending than privately owned banks and lower profitability. At the same time, however, a large number of non-performing loans necessitates hedging, which increases costs. The ECB (European Central Bank 2015) also found that bank size had a significant negative impact on its profitability, which was explained by the more complex and costly structure of larger banks. Řepková (2014) found that a group of large banks in the Czech Republic was less efficient than other banks in the Czech banking sector. According to that study, this was due to excessive deposits on the balance sheet and an inadequate size of operations. This is also related to a study by Laeven, Ratnovski, and Tong (2016), which found a positive relationship between systemic risk and bank size and a negative relationship between systemic risk and bank capital.

The results of the regression analysis show that smaller banks generated better profits (measured by ROA). However, SOBs represent both large and small banks, so considering the arguments above, internal factors may be more important than sectoral ones. Theoretically, these banks could achieve higher profits because, as the literature suggests, they are perceived as safer, as their main shareholder is the state and their capital base is more robust. However, the results demonstrate that these banks performed statistically worse in terms of ROA and ROE. Hence, it may be argued that elements of the economic or social policy of the bank's home country are relevant to these banks' activities and constitute an additional factor that shapes the banking sector in CEE countries. They are, in a sense, unique actors in the CEE market that do not fit into the general framework of the sector.

Conclusions

The objective of this article was to examine and test the "state-owned banks' advantage hypothesis". According to this hypothesis, the nationalisation of segments of the banking sector positively affects the financial results achieved by such banks and the risk associated with their operations. This article provides further evidence for the long-standing debate concerning the raison d'être of SOBs and state-owned enterprises more broadly. However, it is based on recent developments related to the changing environment in Central and Eastern Europe – a rapidly developing sector gaining an increasingly prominent position in the global economy. This study identifies, based on available research and empirical observations, associations between the results obtained and their possible causes. It is also relevant for comparative research in economics, as it addresses different ownership structures and the effect of state participation as a shareholder within a free-market

economy – specifically, how ownership affects the efficiency of a given sector and the appropriate role of the state in the banking sector.

The analysis, conducted using a fixed-effects panel data model based on data from CEE countries – a region susceptible to structural changes due to renationalisation and denationalisation processes between 2014 and 2020 – confirmed a statistically significant relationship between a bank's return on assets (ROA) and return on equity (ROE) and the level of state capital control. The relationship was negative for SOBs when compared to both DOPBs and FOBs. SOBs were also characterised by higher operational risk, measured by the level of non-performing loans, compared to both groups studied. Thus, the assumption of higher profitability and lower credit risk for SOBs was not confirmed, and the state-owned banks' advantage hypothesis should be rejected. The higher burden of non-performing loans on SOBs is a significant cause for concern; based on the literature and our observations, it may indicate a potential risk of moral hazard resulting from the perception of such banks as more secure due to a stable capital base, as well as from selection bias.

These results raise the question of whether the relatively weaker financial performance of SOBs is attributable to poor management or other factors affecting their operations. It is argued that factors related to the "social" purpose of these banks are more decisive, since profit measured by ROA and ROE is expressed purely in monetary terms. SOBs pursue objectives set by their management boards, which are appointed directly or indirectly by the state. The objectives of SOB management, therefore, may not focus primarily on achieving the best rates of return in the sector – even if the bank is a listed company – but may seek to achieve social objectives, such as supporting commercial, relatively less profitable projects. A higher burden of non-performing loans may result from such a credit base. Secondly, larger CEE banks, including SOBs, do not benefit from economies of scale or greater market share, as a bank's market share was shown to be negatively correlated with return on assets. Therefore, it can be argued that it is not merely a matter of poor management, but rather a reflection of the economic or social policy of the country, which undoubtedly plays a role in the activities of these banks and is an additional factor shaping the banking sector in CEE countries.

Regarding policy implications, further research is essential, particularly concerning the efficiency of SOBs, potential moral hazard risks, the soundness of their capital base, and the level of social returns generated by their existence and operations. The aim of SOBs is not only to generate profit measured in monetary units, but also to generate social returns for their customers, beneficiaries, or the economy as a whole. Social benefits should be measured in order to compare those outcomes with the results of this study and contribute to testing the "state-owned banks' advantage hypothesis" in non-monetary terms. Only then will it be possible to assess whether the state rightfully has a place in the banking sector as a shareholder and decide whether there is any added value from such state activity. Banks are specific enterprises which serve as a source of credit for the economy and thus indirectly determine the economic growth of a country. This may explain why generating high profits will not always be the primary priority for the state. Moreover, it would be useful to assess the performance of SOBs in terms of their ESG (Environmental, Social, and Governance) activity, as these aspects have proven to be significant policy priorities for the EU. Finally, the study points to the need for further research on the relationship between the capital base of SOBs and their profitability.

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Appendix A
List of state-controlled banks at the end of 2020

- Bulgarian Development Bank – Bulgaria
- Českomoravská záruční a rozvojová banka, a.s. – Czechia
- Česká exportní banka, a.s. – Czechia
- Hrvatska poštanska banka d.d. – Croatia
- Croatia Banka – Croatia
- Powszechna Kasa Oszczędności Bank Polski S.A. – Poland
- Bank Polska Kasa Opieki S.A. – Poland
- Alior Bank S.A. – Poland
- Bank Ochrony Środowiska S.A. – Poland
- Bank Pocztowy S.A. – Poland
- PKO Bank Hipoteczny S.A. – Poland
- Pekao Bank Hipoteczny S.A. – Poland
- Bank Gospodarstwa Krajowego – Poland
- Magyar Fejlesztési Bank – Hungary
- BUDAPEST Hitel- és Fejlesztési Bank – Hungary
- KELER Központi Értéktár Zártkörűen Működő Részvénytársaság – Hungary
- Magyar Export-Import Bank – Hungary
- Banca de Exp-Imp a României – Eximbank – Romania
- CEC Bank – Romania
- Slovenská záručná a rozvojová banka, a. s. – Slovakia
- Sid Banka – Slovenia

Hipoteza przewagi banków państwowych w kontekście renacjonalizacji banków w Europie Środkowo-Wschodniej

Celem artykułu jest przedstawienie i przetestowanie oryginalnej hipotezy dotyczącej przewagi banków państwowych, zgodnie z którą nacjonalizacja części sektora bankowego może pozytywnie wpłynąć na wyniki finansowe i zmniejszyć ryzyko związane z działalnością banków. Hipotezę przetestowano przy użyciu modelu porównującego trzy grupy banków – banki państwowe, prywatne banki zagraniczne oraz prywatne banki krajowe. Oszacowanie parametrów modelu przeprowadzono przy użyciu analizy danych panelowych w modelu efektów stałych dla banków z siedzibą w krajach Europy Środkowej i Wschodniej w latach 2014–2020. Na podstawie modelu dla ROA i – oddzielnie – ROE zaobserwowano statystycznie istotną ujemną zależność w wynikach finansowych generowanych przez banki państwowe w porównaniu z prywatnymi bankami krajowymi i zagranicznymi. Wyniki wskazują również na wyższe ryzyko biznesowe w przypadku banków państwowych, mierzone jako kwota kredytów zagrożonych, co prawdopodobnie wynika z zaangażowania w projekty, które nie zawsze są rentowne, ale często wiążą się z wyższym ryzykiem kredytowym. Z tego wynika, że elementy polityki gospodarczej lub społecznej danego kraju mają znaczenie przy prowadzeniu działalności gospodarczej, ale negatywnie wpływają na wyniki banków państwowych. Rezultaty estymacji modelu dowodzą również, że wielkość rynku bankowego ma negatywny wpływ na jego wyniki.

Słowa kluczowe: sektor bankowy, banki państwowe, nacjonalizacja, rentowność banków, Europa Środkowo-Wschodnia

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International R&D Collaboration in Response to Global Disruptions: A Comparative Bibliometric Analysis of Research Networks

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Abstract

This study examines the international research and development (R&D) collaboration related to global crises or disruptions, focusing on its role in addressing challenges arising from diverse crises. Bibliometric analysis of 160 peer-reviewed articles identified patterns of collaboration and mapped global research networks. We adopted a comparative analytical framework to examine differences in research collaboration focus and forms across multiple types of disruption or crisis. The results show that R&D collaboration related to disruptive events was concentrated in research centers such as the United States, the United Kingdom, and Germany, with the strongest links between the United States and China and between China and the United Kingdom. Other countries occupy more peripheral positions in global collaboration networks, reflecting lower overall engagement in research on the topic. In Central and Eastern Europe (CEE), Czechia stands out as one of the few countries whose research activities on collaboration during turbulence are internationally visible. Existing networks of connections between research centers are mostly bilateral, with researchers from CEE and the Global South being underrepresented. Furthermore, six thematic areas related to crises emerged as focal points for R&D collaborations: environmental crises, health emergencies, technological change, economic shocks, institutional instability, and humanitarian challenges. By identifying patterns of international R&D collaboration related to destabilizing events, the results of the analyses may inspire more effective responses to global challenges and support the development of more resilient and crisis-responsive R&D strategies.

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JEL: D8, F2, F6, O3

Introduction

Over the past two decades, the global economy has been repeatedly shaken by major crises, beginning with the 2008 Great Recession and culminating in the COVID-19 pandemic. These events disrupted socio-economic systems worldwide and underscored the need for coordinated scientific efforts across borders. The COVID-19 pandemic, in particular, highlighted the critical role of international research collaboration in generating rapid and impactful solutions (Guimón and Narula 2020; Lee and Haupt 2021a). Yet crises are not solely destructive – they also create valuable opportunities for learning and innovation. In this context, research and development (R&D) collaboration becomes an essential tool. Through co-creation, knowledge sharing, and technology transfer, collaborative R&D facilitates the development of new innovative solutions to complex global problems.

As economic systems have become more interconnected, international research collaboration has gained growing significance. This form of cooperation encompasses partnerships among multinational corporations, universities, and research institutions across national boundaries (Belderbos et al. 2014; 2022; Du, Leten, and Vanhaverbeke 2014; Fu and Li 2016; Suzuki, Belderbos, and Kwon 2017; Yoon, Yang, and Park 2017; Hurtado-Torres, Aragón-Correa, and Ortiz-de-Mandojana 2018; Gretsch, Salzmann, and Kock 2019; Zhang, Chen, and Fu 2019; Belderbos, Park, and Carree 2021; Fu et al. 2021; O'Dwyer, Filieri, and O'Malley 2022). At the same time, protectionism, geopolitical tensions, wars, and rising security concerns increasingly threaten the openness, trust, and researcher mobility required for sustained collaboration. On the other hand, these crises can constrain international R&D collaboration by introducing political barriers, shifting national priorities, or altering the dynamics of who collaborates with whom and which topics receive attention.

Although international collaborative research is widely recognized for its benefits – such as knowledge sharing, learning effects, and technology transfer – there is still limited understanding of how collaboration evolves in response to global disruptions. This article addresses that gap through a bibliometric review of 160 peer-reviewed articles, complemented by a systematic assessment of collaboration patterns. We analyze who is studying international R&D collaboration, how networks are structured, and which themes dominate the literature. We also identify underexplored areas that represent critical gaps in current research. By doing so, the study provides researchers and practitioners in diverse development contexts with evidence to design more inclusive, resilient, and context-sensitive responses to disruption.

The study is guided by the following research questions: **How has existing research explored R&D collaborations focused on finding solutions to disruptive events or crises? What key themes have emerged, and what research gaps remain in the current literature?** Based on these questions, the study pursues the following objectives:

- To map the scientific literature on international R&D collaboration under conditions of uncertainty;
- To identify the geographic distribution and intensity of collaborative research networks;
- To classify the dominant areas of crisis-related R&D activity and group them into thematic clusters;
- To evaluate intellectual trends and identify future research directions, particularly in relation to innovation systems, cross-border knowledge flows, and institutional asymmetries.

Using bibliometric methodology, we trace collaborative publishing patterns and examine how researchers have jointly responded to various crises and disruptions. By applying co-authorship (Newman 2001; Janssen et al. 2006; Becken 2013; Mokhtari et al. 2020; Bengoa et al. 2021; Cerver Romero, Ferreira, and Fernandes 2021; Gao et al. 2022; 2023) and co-occurrence network analyses (Li et al. 2021; Yalcin and Daim 2021; Daim and Yalçın 2022; Fernandes and Ferreira 2022; Tomeczek 2022; Wang et al. 2022; Yadav, Kumar, and Malik 2022), we quantitatively show the responses to specific types of crises. To enrich the bibliometric findings, we also draw on a systematic literature review to reveal patterns of international R&D collaboration during times of disruption, as well as the key themes and focal areas explored within the existing body of development research.

This paper is organized into six sections. Section 2 reviews the literature on international research collaboration and crises. Section 3 outlines the methodology. Section 4 presents the results: subsection 4.1 maps the geographic distribution of research networks and knowledge flows, while subsection 4.2 identifies the key thematic clusters. Section 5 discusses the findings, and Section 6 concludes.

Literature review

Conceptualization and measurement of research collaboration

Studies on research collaboration have been conducted for several decades; however, the development of information and communication technologies, the growth of internationally funded projects, and the rise of global challenges requiring joint scientific efforts have made such collaboration increasingly international. Patel (1973) defines research collaboration as a process of generating new knowledge through the integration of efforts by individual researchers. International research collaboration has emerged as a significant area within innovation studies. It is broadly defined as collaborative projects involving researchers affiliated with institutions in different countries (Anderson and Steneck 2010; Wagner, Whetsell, and Mukherjee 2019). Some scholars have extended this definition to emphasize the output dimension, arguing that research collaboration is conducted to advance scientific knowledge, which includes knowledge transfer and application, and eventually leads to practical implementation (Yao 2021).

The open innovation framework (Chesbrough 2003; 2024) conceptualizes R&D collaboration as a deliberate strategy for integrating internal and external knowledge flows. From the perspective

of resource dependence theory, organizations that control critical resources (e.g., funding, infrastructure, and specialized expertise) exercise disproportionate influence over the terms, structure, and governance of collaborative relationships (Pfeffer and Salancik 1978; Drees and Heugens 2013). Open innovation emphasizes the strategic integration of internal and external knowledge flows, while resource dependence theory draws attention to how unequal access to critical resources influences interorganizational relationships. In this context, the importance of governance structures and power relations in shaping collaborative outcomes must be highlighted. Gray, Purdy, and Ansari (2022) highlighted that partnerships addressing complex societal problems (i.e., grand challenges) often fall short when power differences among actors are not adequately addressed. Ruangpermpool, Igel, and Siengthai (2020) indicated that balanced formal and informal governance supports the commercialization of research in university–industry collaboration. Case-based research of power asymmetries conducted by Macaulay (2025) demonstrated how imbalances can shift over time within interorganizational partnerships, affecting collaboration dynamics and the capacity for joint action.

Taken together, these theoretical perspectives and empirical findings suggest that successful R&D collaboration depends not only on the integration of diverse knowledge sources but also on the distribution of resources, which may be related to the geographical configuration of partner organizations, management of collaborative relations, and broader contextual factors.

In general, collaborations between researchers are typically documented through scientific publications that are co-authored by scholars from different scientific institutions or the analysis of patent collaborations (Ye, De Moortel, and Crispeels 2020; Tsouchnika et al. 2022). Many studies use co-authorship as the primary indicator of scientific collaboration (e.g., Patel 1973; Pao 1992; Wagner, Whetsell, and Mukherjee 2019; De Stefano et al. 2023), acknowledging, however, that it is not the only measure of collaborative R&D efforts, as it captures only a part of research collaboration. Other measures include joint research projects, co-patenting, and cooperative R&D agreements (Bozeman and Boardman 2014; Amoroso, Coad, and Grassano 2018), as well as the extent of knowledge sharing, the scope of technology transfer, and the sustainability of collaboration efforts (Philbin 2008). The methods for measuring international collaboration are still evolving and have not yet reached full standardization (Chen, Zhang, and Fu 2019).

The intensity of collaboration varies significantly across scientific disciplines. In some fields, such as science, technology, engineering, and mathematics (STEM), over 90% of research projects and publications are carried out in collaboration, which leads to a "collaboration imperative" (Bozeman and Boardman 2014). Overall, the level of scientific collaboration has shown a consistent upward trend over time (Wagner, Park, and Leydesdorff 2015).

Bibliometric analysis offers quantitative tools to assess large volumes of scientific output (Chen, Zhang, and Fu 2019; Wagner, Whetsell, and Mukherjee 2019), which may capture collaboration patterns across individuals, institutions, and countries, reflecting changes linked to globalization and shifts in scientific communication (Glänzel and Schubert 2005). It is worth noting that bibliometric methods can also be used in the analysis of patents (Tomeczek 2025). Network analysis of patents is related to technological profiles and capabilities of firms and other institutions (e.g., universities). Bibliometric analysis systematizes and maps

knowledge regardless of whether it is applied to scientific publication data or patent data. Furthermore, previous keyword co-occurrence bibliometric analysis of open innovation and university-industry collaboration identifies five thematic clusters related to technology transfer, university-industry knowledge transfer, academic entrepreneurship, knowledge exchange, and universities (Ballesteros-Ballesteros and Zárate-Torres 2025). Another bibliometric study of innovation intermediaries reveals clusters related to innovation performance, knowledge networks, and technology transfer (Zhang and Liu 2024). Lattu and Cai (2023) highlight six institutional logics: state, market, corporation, profession, traditional trust-based community, and sustainability-based community. Researchers increasingly apply institutional logics to understand how norms, values, and governance systems influence university-industry collaboration patterns.

Overall, the literature shows that research collaboration is a multidimensional phenomenon that can be anchored in the open innovation concept and aims to advance scientific knowledge through the integration of talents and resources while taking diverse forms. Theoretical perspectives indicate that R&D collaboration can be shaped by knowledge integration, access to critical resources, and power relations among partners. The open innovation framework highlights the importance of combining internal and external knowledge, while resource dependence theory explains how control over key resources influences collaborative governance. This integrated perspective also encompasses selected knowledge management-related issues, such as knowledge flows and spillovers, as they are embedded in broader innovation and collaboration processes and, to some extent, reflected in the empirical findings analyzed above. Existing studies (e.g., Gray, Purdy, and Ansari 2022; Macaulay 2025) suggest that unbalanced power relations can weaken partnerships, while appropriate governance arrangements may support effective and sustainable collaboration.

It also should be pointed out that collaborative efforts cannot be fully captured by any single indicator. Co-authorship or co-patenting are commonly used measures of research collaboration, and although studies typically rely on one of these indicators depending on data availability and research focus, their inherent limitations should be carefully acknowledged and considered in interpretation. This study follows this approach.

Global disruption and R&D collaboration

It is widely acknowledged that crises and disruptions introduce new risks and challenges that are too complex to be addressed in isolation. Therefore, questions remain about how this imperative for R&D collaboration functions during periods of disruption or crisis, particularly whether it develops at local or global levels. Such contexts call for multi-organizational collaboration in risk management and coordinated responses to extreme events (Kapucu, Arslan, and Collins 2010). Effectively navigating critical tasks requires collaborative capacity, that is, the ability to integrate, generate, and apply new knowledge under pressure in order to innovate and find solutions to complex problems (Weber and Khademian 2008). Furthermore, Rani et al. (2025) emphasized the strategic role of digitalization and green technologies in promoting collaboration within the BRICS-T economies.

There is also a growing body of literature on international scientific collaboration during the COVID-19 pandemic, which has confirmed a rise in "scientific globalism" as a response to the crisis (e.g., Cai, Fry, and Wagner 2021; Lee and Haupt 2021b; OECD 2021; Abramo, D'Angelo, and Di Costa 2022). According to these studies, engagement in international collaboration during crises depends on several factors, including the severity of the crisis and a country's level of development. Shih, Chubb, and Cooney-O'Donoghue (2024) showed that intensifying geopolitical tensions, particularly those involving China, have prompted countries such as Australia and Sweden to redesign risk-management protocols and funding guidelines for international collaboration. Wagner and Cai (2022) identified an emerging decline in China-USA co-publications from 2020 onward, suggesting that the pandemic triggered a broader shift in collaboration dynamics. In contrast, ties between China and Europe or the USA and Europe remained relatively stable, highlighting how the pandemic selectively reshaped global research networks rather than uniformly weakening them. These findings indicate that R&D collaboration may either increase or diminish in times of disruption, depending on contextual factors.

War and geopolitical tensions can sharply reduce scientific output and weaken international collaboration networks. For instance, Russian research productivity in Web of Science-indexed journals has decreased since 2022, following years of growth prior to the war (Zhang et al. 2024). Similarly, Ukrainian research networks experienced a reduction in collaboration diversity in 2022 due to institutional damage and loss of research capabilities (Damaševičius and Zailskaitė-Jakštė 2023). A comprehensive econometric analysis found that EU-Russia co-publication rates significantly declined since 2014 due to sanctions and counter-sanctions, before their total suspension in 2022 (Makkonen and Mitze 2023). The EU's suspension of Russia from Horizon Europe in 2022 reflects a shift toward selective closure in international research collaboration (Bamberger and Huang 2025). After the full-scale invasion, Russia experienced significant declines in publication activity linked to restricted funding, reduced mobility, and loss of access to international research infrastructures (Kozmenko et al. 2025). According to Zhang et al. (2024), domestic policy changes, such as the termination of the academic excellence initiative "Project 5top100", may have played an even greater role in isolating Russian science and its long-term collaboration declines.

Damaševičius and Zailskaitė-Jakštė (2023) showed how war-related crises, such as the conflict in Ukraine, led to a decline in international output for some regions, thereby providing evidence that the nature of the crisis – whether health-related, political, or economic – can shape collaborative trajectories differently. These contributions underscore the need to understand collaboration not only as a reactive mechanism during crises but also as a strategic response to crises shaped by technological, political, and institutional capacities.

Given the inconsistent patterns of collaborative R&D reported in the literature, there is a clear need to systematically analyze studies in the social sciences that explore research collaboration during periods of disruption and uncertainty caused by various types of crises. This paper aims to address that gap by uncovering patterns, themes, and underexplored areas of international R&D collaboration in crisis contexts.

This study focuses specifically on R&D collaboration related to the context of crises, disruptions, and unexpected events. While international research collaboration is a broad phenomenon, our analysis is limited to those collaborative efforts that explicitly address disruptive challenges, such as natural disasters, pandemics, geopolitical conflicts, and other forms of crisis and uncertainty. We do not examine R&D collaboration in general, but rather the subset of literature that explores how researchers work together across borders in response to, or in anticipation of, such events. Our aim is to examine how existing research in economics and business has addressed R&D collaborations in response to disruptive events or crises, and to identify and compare key thematic areas, revealing remaining research gaps in the literature. This targeted approach, focusing on country-level co-authorship, allows us to contribute to understanding in which countries researchers are most intensively studying R&D collaboration in the context of crises, whether and how researchers from different countries collaborate on these studies, and what networks are formed, which specific aspects are being investigated, and which areas remain critically underexplored.

Methods and data

To identify how patterns of R&D collaboration related to crises and disruptions have evolved, we apply bibliometric analysis – a robust, data-driven approach for uncovering key research patterns and trends. Bibliometrics has developed significantly over the decades, gaining prominence through the seminal work of Garfield (1995) and the influential contributions of the 1960s (Kessler 1963; de Solla Price 1965).

To explore the geographical patterns of researchers' affiliations, they are aggregated at the level of countries or territories. Additionally, to complement the country profiles of researchers actively publishing on R&D collaboration in the context of crises or disruptions, we identify co-authorship networks to illustrate how research teams are formed to study this topic. Co-authorship networks represent authors (nodes or vertices) and the co-authorships of scientific documents (edges or links).

To contribute to understanding which topics are most frequently explored and where gaps remain in the literature, we apply a keyword co-occurrence network that enables the knowledge mapping of existing research.

Keyword co-occurrence networks represent keywords (nodes or vertices) and their co-occurrence in scientific articles (edges or links). This type of analysis can illustrate thematic clusters and trends within a body of scientific literature. Methodologically, some degree of keyword standardization might be necessary for this type of bibliometric analysis, as otherwise, synonymous keywords can dilute the results (Lee and Su 2010; Li et al. 2016; Kiani Mavi et al. 2021). The articles collected for this analysis require data normalization. Standardization included aligning plural and singular forms (e.g., "collaborations" and "collaboration"), abbreviations (e.g., "R&D" and "research and development"), and synonyms (e.g., "coronavirus" and "COVID-19"), consistent with previous bibliometric studies. The most dominant keyword, "research collaboration," aggregates 28 related terms, such as "co-research," "international

research," and "R&D collaboration." In total, 153 keyword groupings were made for keyword analysis and the identification of thematic clusters.

To better understand the structure of scientific knowledge and reveal how research themes are organized and interconnected, we applied modularity analysis. This network analysis method identifies clusters or "communities" within a network – groups of nodes (in this case, keywords) that are more densely connected to each other than to the rest of the network.

The identified thematic clusters are further examined through a systematic literature review, which, according to the methodological guidelines outlined by Kraus et al. (2022), is well-suited for domain-focused reviews in specific research fields.

We used the Scopus database to collect our data. Network construction and visualizations are carried out using Gephi software, a widely used tool for network analysis. The steps of the systematic literature selection process are outlined in Table 1. A common practice in bibliometric analyses, particularly for keyword co-occurrence networks, is to focus on peer-reviewed scientific articles (Moody 2004; Li et al. 2021; Wood et al. 2021; Bhandal et al. 2022; Corrêa et al. 2022; Fernandes and Ferreira 2022; Gao, Lin, and Lu 2022; Healy, Hammer, and McIlveen 2022; Oliveira, Carvalho, and Reis 2022; Xu, Hou, and Wang 2022; Yadav, Kumar, and Malik 2022; Zhao and Strotmann 2022; Kryszak, Świerczyńska, and Staniszewski 2023; Nazzal, Sánchez-Rebull, and Niñerola 2023; Pennetta, Anglani, and Mathews 2023), and we followed this approach in our study. The search query was designed to include synonyms and wildcard variations of "disruption," and synonyms and wildcard variations of "scientific collaboration." The query resulted in 1,020 publications that analyze scientific collaboration related to crises and periods of uncertainty. Additionally, we limited the results to English-language literature in the social sciences and related disciplines. After cleaning the data (removing irrelevant articles and those with missing keywords), we were left with 160 scientific articles. In recent years, both the world and the nature of crises it faces have changed rapidly. The period analyzed in this article is bookmarked by the COVID-19 pandemic and its aftermath. The pandemic was a monumental short-term shift in global production with long-term geopolitical consequences. The analysis of future crises and uncertainty, likely related to the reshoring of global value chains and the widespread adoption of AI technologies, can both learn from the past and provide new insights that should be explored in future studies.

Table 1. Systematic literature selection (conducted in Scopus database, 1975–2023)

Step	Search query string	Results
1	TITLE-ABS-KEY ("uncertaint*" OR "disrupt*" OR "unpredict*" OR "imperfect information*" OR "information asymmetr*" OR "external shock*" OR "crisis") AND TITLE-ABS-KEY ("scientific collaborat*" OR "academic collaborat*" OR "research collaborat*" OR "development collaborat*" OR "R&D collaborat*" OR "collaboration in science" OR "collaboration in academia" OR "collaboration in research" OR "collaboration in development" OR "collaboration in R&D" OR "scientific network*" OR "academic network*" OR "R&D network*" OR "research and development network*" OR "scientific cooperat*" OR "academic cooperat*" OR "research cooperat*" OR "development cooperat*" OR "R&D cooperat*" OR "scientific co-operat*" OR "academic co-operat*" OR "research co-operat*" OR "development co-operat*" OR "R&D co-operat*" OR "scientific consortium*" OR "academic consortium*" OR "research consortium*" OR "development consortium*" OR "R&D consortium*" OR "international research and development" OR "international R&D" OR "global research and development" OR "global R&D" OR "collaboration analysis" OR "collaboration network" OR "co-authorship analysis" OR "coauthorship analysis" OR "co-author analysis" OR "coauthor analysis" OR "co-authorship network" OR "coauthorship network" OR "co-author network" OR "coauthor network" OR "patent analysis" OR "patent network")	1,020
2	published in English	975
3	research articles and review articles	690
4	subject areas (Business, Management, and Accounting; Economics, Econometrics, and Finance; Social Sciences; Decision Sciences)	375
5	cleaning the data	160

Source: authors' elaboration.

Results

The research landscape on crisis-driven R&D collaboration

Research on international R&D collaboration in the context of crises and disruptions is predominantly conducted by scholars affiliated with the United States (36 articles), China (24 articles), and the United Kingdom (20 articles), which in our sample have the highest number of co-authors originating from these countries and publishing on this topic. These countries not only contribute the largest volume of publications but also form the core of international co-authorship networks studying this topic, as reflected by their large node sizes and dense interconnections in the network visualization (Chart 1). The United States stands out as the leading actor, with strong collaborative ties to both European and Asia-Pacific countries, including links with China, the United Kingdom, and Australia. Some other countries, such as the United Kingdom and Germany, also play important roles, serving as key connectors within European and transatlantic collaborations, with the United Kingdom acting as a central bridge between North American, European, and Asia-Pacific partners. In contrast, countries such as Italy, Greece, South Africa, Malaysia, and Czechia appear at the periphery, indicating lower levels of engagement in research on this topic (Chart 1), as evidenced by their smaller node sizes and limited number of collaborative ties. Other countries from Central Europe occupy more peripheral positions in global collaboration networks, reflecting lower overall engagement

in research on disruptions and crisis-related topics. It may be associated with structural constraints such as more limited research funding, weaker integration into international research consortia, and reduced access to global scientific infrastructures as documented by policy studies (European Parliamentary Research Service 2018; European Commission 2025).

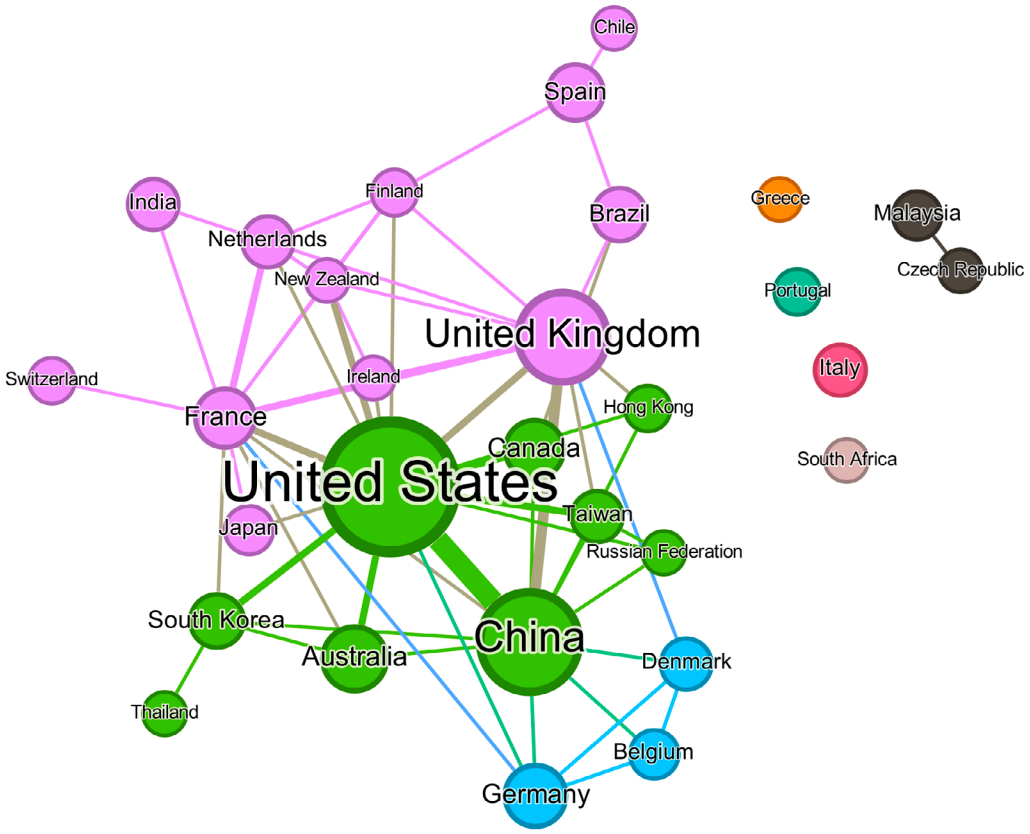

Chart 1. Geographical distribution of authors studying international R&D collaboration in the context of crises, and their scientific networks (size: occurrence count, color: modularity class)
Source: authors' elaboration.

Overall, the authorship structure of the papers highlights a concentration of research efforts in high-income countries, with notable gaps in cross-regional participation, including the region of Central and Eastern Europe.

Mapping knowledge and emerging research hotspots

This subsection presents the knowledge map and identifies the key research topics addressed by authors publishing on international R&D collaboration in the context of crises and disruptions.

Chart 2 illustrates the communities in the keyword co-occurrence network, revealing distinct thematic clusters within the literature on international R&D collaboration in the context of crises and disruptions.

The keyword co-occurrence network shows that keywords can be grouped not only by research topics but also by methods applied. The key methods include bibliometric analysis, patent analysis, social network analysis, and cluster analysis, highlighting the diverse methodological

approaches used to examine R&D collaboration. Bibliometrics has seen a surge in popularity, particularly as the COVID-19 pandemic underscored the need to organize and systematize rapidly expanding scientific output. Bibliometric and scientometric approaches play an integral role in studying collaboration, as shown by the prominent cluster containing general methodological terms (e.g., "bibliometric analysis" and "scientometrics"), analytical methods (e.g., "co-authorship" and "co-citation analysis"), and tools (e.g., "Scopus," "VOSviewer," and "CiteSpace") occurring as keywords in some publications (e.g., Sahil and Sood 2021; Vong, Rita, and António 2021; Castelló-Sirvent and Roger-Monzó 2022; Sardana and Singhania 2022).

The keyword co-occurrence network (visualized in Chart 2) further shows relatively strong linkages between bibliometric analysis, co-authorship, and co-citation analysis, indicating that publication-based indicators remain the dominant tools for studying collaborative structures. Furthermore, patent analysis is closely linked with social network analysis and technology-related keywords, reflecting the frequent use of patent data to examine technological collaboration and relational dynamics. Overall, the co-occurrence structure suggests that quantitative, data-driven approaches form the methodological core of the field, with standardized bibliometric databases and software further reinforcing this orientation. At the same time, the relatively limited visibility of qualitative or mixed-method approaches indicates that they remain underrepresented, pointing to an ongoing methodological bias toward large-scale, data-driven research designs in this field (Chart 2).

Based on the keyword co-occurrence network (Chart 2), we also observe how scientific themes are organized and interconnected, allowing for the detection of both dominant research areas and emerging hotspots.

A significant shift toward pandemic-related research is visible in the network, with the COVID-19 crisis driving an unprecedented increase in collaborative activity. The global nature of the pandemic demanded unorthodox and accelerated responses, reflected in intensified international co-authorship and the development of adaptive collaborative frameworks (Belli et al. 2020; Wu et al. 2021; Abramo, D'Angelo, and Di Costa 2022; Damaševičius and Zailskaitė-Jakštė 2022).

Our review of selected articles reveals a diversity of collaborative themes shaped by different types of disruption. Some studies aim to address the practical challenges of crisis response, while others focus on mapping R&D collaboration in fields impacted by specific crises, such as global health (e.g., cancer or the Zika virus) (Sampaio et al. 2020; Kameda et al. 2021), technological uncertainty, or environmental instability. Several contributions also explore the geographic dimensions of collaboration (e.g., Orecchini, Valitutti, and Vitali 2012; Banerjee and Siebert 2017; Rocha et al. 2022) and the influence of disruptions on scientific mobility and partnership stability (e.g., Zhao, Bu, and Li 2022).

A large number of studies present in-depth case analyses of R&D collaboration during specific crises, ranging from the water crisis in Nepal (Pandey and Bajracharya 2017) to strategic alliances in pharmaceutical development, such as the collaboration between Pfizer and Bristol-Myers Squibb (Tian, Gurnani, and Xu 2021). Others take a broader perspective, linking scientific cooperation with geopolitical dynamics amid global threats (e.g., Lee and Haupt 2021b). To better

identify thematic concentrations, we excluded the generic keyword "research collaboration" from modularity analysis, as it appeared in every article due to our selection criteria.

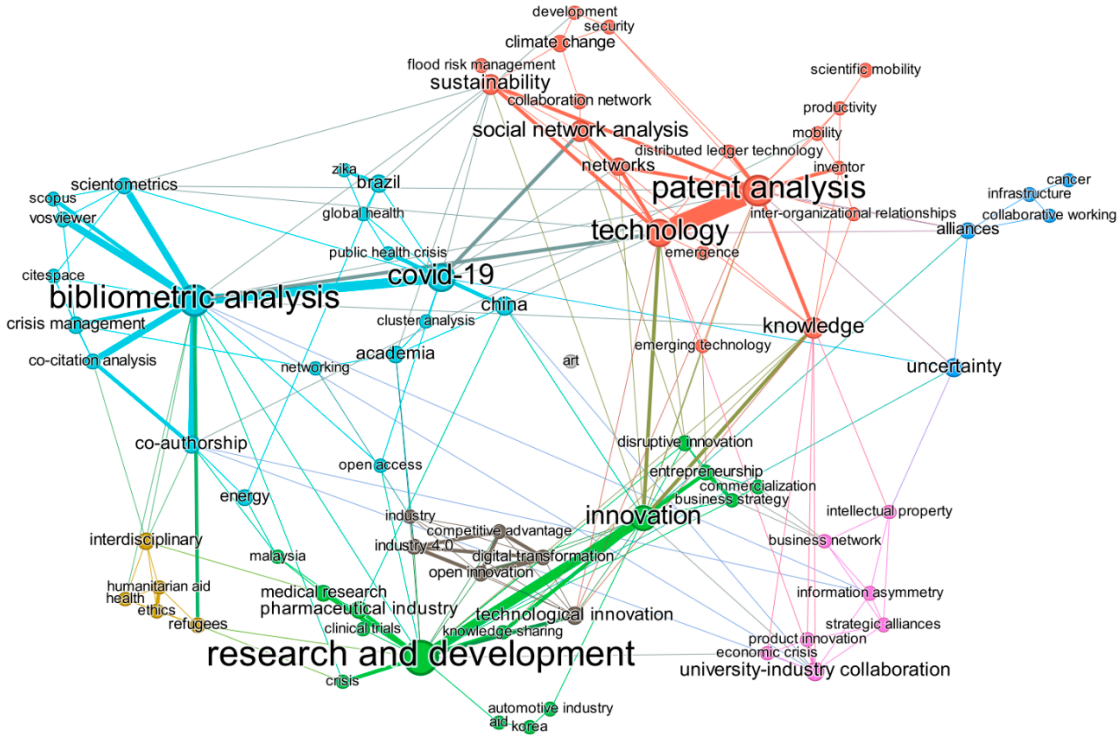

Chart 2. Keyword co-occurrence network excluding keyword "research collaboration" (size: occurrence count, color: modularity class)
Source: authors' elaboration.

Based on the types of disruptive factors, six thematic clusters emerge from the keyword network analysis of the analyzed sample of publications on research collaboration in contexts of disruption or uncertainty. These thematic clusters indicate that research collaboration varies depending on the specific types of uncertainty arising from:

1. **Environmental disruption** (Cluster 1): this cluster includes themes such as sustainability, climate change, and security, with "networking" frequently appearing as a key mode of collaboration.
2. **Global health crisis** (Cluster 2): dominated by research related to COVID-19 and other health emergencies, this cluster also emphasizes the role of academia and international networks in responding to global health threats.
3. **Technological disruption** (Clusters 3): this cluster focuses on digital transformation, open innovation, and disruptive technologies, particularly in the medical and pharmaceutical sectors, highlighting the important role of industry in collaborative R&D efforts.
4. **Financial and economic crisis** (Cluster 4): topics include university–industry collaboration, product innovation, and the influence of economic instability on patterns of research cooperation.

5. **Institutional disruption** (Cluster 5): this cluster explores how alliances and collaborative working arrangements are shaped by uncertainty and instability in institutional environments.
6. **Humanitarian crisis** (Cluster 6): encompassing issues such as ethics, health, and refugee-related research, this cluster underscores the interdisciplinary nature of collaboration in response to humanitarian emergencies.

Research themes, knowledge gaps, and collaboration types

The keywords grouped in each cluster not only define thematic scopes but also indicate the types of actors engaged in R&D collaboration, ranging from science–science partnerships to science–business–government consortia. Together, these clusters illustrate that R&D collaboration during crises is not monolithic but adapts to the type of uncertainty experienced, producing differentiated patterns of partnership, knowledge exchange, and innovation across contexts. Table 2 provides a detailed overview of each cluster, highlighting frequently addressed research topics, key contributors, representative case studies, and suggested directions for future research.

Table 2. Research Themes on R&D Collaboration Amid Crises

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Environmental disruption	**88**	**Sustainability, security, climate change, inventor**	Gaziulusoy et al. (2016)	Science-science (transdisci-plinary research collaboration)	Environmental disruption requires transdisciplinary collaborative research projects. Emergent responses in management, with leadership playing a mediation role, are necessary. Research teams should be co-located and/or trained to facilitate team development.	Not indicated
			Orecchini, Valitutti, and Vitali (2012)	Science–business	The crisis in sustainability requires the intensification of industry–academia collaboration and more entrepreneurial behavior of universities.	Structuring conceptual scientific methods for knowledge exchanges between industry and science.
			Pandey and Bajracharya (2017)	Science–business–citizens	The example of the water crisis in Nepal shows that broad collaboration between research teams and stakeholders can reduce uncertainty and support more sustainable urban water management.	Studying innovative methods of participatory and collaborative research.

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Global health crisis	**87**	**COVID-19, crisis management**	Lee and Haupt (2021b)	Science–science	The COVID-19 crisis intensified international research collaboration, especially on pandemic-related topics. Yet, the extent of this increase varied markedly across countries, revealing uneven patterns of collaborative engagement during the pandemic.	Research on the interdependencies between scientific collaboration and geopolitical rivalry.
			Kim and Cho (2021)	Science–science	The importance of international research collaboration during the COVID-19 pandemic varied across countries, with the United States and Europe collaborating more intensively than Asian countries. Some countries (e.g., Belgium and Pakistan) expanded their research interests through collaboration. Medicine was the predominant research area.	Research on the differences between the impacts of journals and articles.
			Nguyen et al. (2021)	Science–science	International research collaboration during the COVID-19 pandemic varied significantly across countries, with the United States and Europe collaborating more intensively than Asian countries. Some countries (e.g., Belgium and Pakistan) broadened their research agendas through collaboration, and medicine emerged as the predominant field.	Further development of collaborative studies to address mental health issues.

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Technological disruption	**83**	**Digital transformation, open innovation, industry 4.0; disruptive innovation in the medical & pharmaceutical sector**	Baba and Walsh (2010)	Business–science–government	To be successful in disruptive technology development and breakthrough innovations that are new to the world but risky, companies must have: 1. capabilities to access new external knowledge from beyond the firm, and 2. social capital in industry, academia, and government that can be used for collaboration.	Comparative research on the conditions that lead to the creation of breakthrough innovations, including the characteristics of collaborative network structures.
			Kupp, Marval, and Borchers (2017)	Business–business	Main success factors for collaboration: clear goals, a large external network, support from management, and performance indicators.	Not indicated
			Banerjee and Siebert (2017)	Business–business	In the bio-pharma industry, motivation for R&D cooperation increases with the severity of uncertainty. Early-stage collaborations primarily aim to reduce technological demand and profit uncertainty, while in later stages, funding becomes the dominant driver of R&D cooperation.	Exploring why late-stage R&D cooperation in drug development reduces the number of R&D projects, and examining the sources of different types of uncertainty in the pharmaceutical industry.

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Financial and economic crisis (including market disruptions)	**18**	**Product innovation, university-industry collaboration, information asymmetry**	Azagra-Caro et al. (2006)	Science–business	Industry–science collaboration differs from R&D cooperation, with the latter more strongly influenced by factors such as discipline, gender, and direct university support. Effective industry-science collaboration also depends on local absorptive capacity; in regions where this capacity is low, knowledge exchange has limited impact on development.	Studying the effects of the university's encouragement on R&D cooperation; developing theoretical foundations to explain the equilibrium between the degree of R&D and support for science-industry cooperation.
			Morandi (2013)	Science–business	Management practices and R&D cooperation impact the outcome of the projects. Task uncertainty causes the decentralization of coordination and control practices.	Focusing on different types of cooperative agreements and their implications for management practices.
			Abramo et al. (2011)	Science–business	Geographical proximity matters for partnerships between business and science. The market is inefficient in terms of selecting partners for public-private research collaboration. Bibliometrics can help to reduce the information asymmetry between the industry and science regarding collaboration.	Not indicated

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Institutional disruption/ uncertainty	**16**	**Collaborative working, alliances**	Vargo, Wieland, and Akaka (2015)	All actors in the service innovation ecosystem	Disruption and change of institutions guide interaction among actors in the ecosystem of service innovation. Collaboration and co-creation may provide novel solutions to existing problems.	Developing the effectuation theory of entrepreneurship.
			Sirmon and Lane (2004)	Business–business	When value is created by sharing, combining, and leveraging complementary resources, collaboration becomes more effective when the disruptive sources of cultural differences are eliminated.	Collaboration and cultural differences in inter-firm relationships that focus on cost-cutting or integrating similar resources.
			Gao and Zhong (2022)	Business–business	Collaboration efficiency is associated with a high-quality information environment and transparency. Informal relationships are more important than formal contracts for the improvement of collaborative outcomes.	Not indicated by the authors.

Type of crisis/ disruption	Number of occurrences	Hot topics/areas of collaboration studied in the papers	Authors of the top 3 most cited papers	Type of collaboration	Key findings	Future research directions indicated by the authors
Humanitarian crisis	**13**	**Refugees, health, ethics, humanitarian aid**	de Laat et al. (2021)	Science–business–government (all stakeholders)	Cultural differences, global inequalities, and ethical issues limit research collaboration on humanitarian conflicts. Managing cross-border research teams with various cultural backgrounds poses a challenge to collaboration.	Further studies on research relations are sensitive to vulnerabilities and characterized by unequal power among research partners.
			Dave et al. (2016)	Science–science Science–business	Key themes for collaboration identified: ethics of innovation, responsibilities of humanitarian practitioners and non-governmental organizations (NGOs), and vulnerability.	Collaborative research exploring the integration of new technologies in humanitarian actions and navigating humanitarian aid.
			Zakir Hossain (2022)	Science–science	The most intensive international research collaboration on the Rohingya refugee crisis involved researchers from Bangladesh collaborating with the UK, USA, Germany, Australia, and India.	Studying refugee-related issues in collaboration with scholars from refugee-hosting and asylum-seeking countries.

Source: authors' elaboration.

Across six types of crises and disruptions, R&D collaboration takes distinct forms shaped by the nature of the uncertainty involved. **Environmental disruptions** highlight the need for transdisciplinary and multi-stakeholder collaboration, demonstrating that broad engagement of stakeholders (e.g., in Nepal's water crisis) can reduce uncertainty and support sustainable management. Studies in this area emphasize sustainability, climate change, and security as major hotspots, while pointing to the importance of co-location and capacity-building within research teams. **Global health crises**, especially COVID-19, accelerated international scientific collaboration, though unevenly across countries and disciplines, with medicine emerging as the dominant field. Leading studies reveal persistent geographical asymmetries and call for further research on the interaction between scientific collaboration and geopolitical rivalry, as well as on mental health-related challenges.

In contexts of **technological disruption**, successful breakthrough innovation depends on firms' access to external knowledge and strong ties between actors of the triple helix: industry, academia, and government. Hotspots in this domain include digital transformation, open innovation, and Industry 4.0, particularly in the medical and pharmaceutical sectors. Collaboration motives shift as projects progress: early-stage cooperation reduces technological and market uncertainty, whereas funding drives later-stage partnerships. Future research is encouraged to examine network structures and uncertainty sources that influence innovation outcomes. **Financial and economic crises** emphasize university-industry collaboration, showing that absorptive capacity, geographical proximity, and information transparency shape successful partnerships. However, the relatively limited number of studies in this area indicates a research gap regarding collaboration under prolonged market instability. Under **institutional disruption**, collaboration is driven by shifts in institutional environments, with co-creation and complementary resource sharing helping actors respond to uncertainty, while cultural and informational factors determine effectiveness. Emerging research hotspots focus on alliances, informal governance mechanisms, and service innovation ecosystems, yet empirical evidence remains scarce.

Finally, **humanitarian crises** require collaboration across science, industry, and government, but cultural differences, ethical concerns, and global inequalities often constrain partnership effectiveness, particularly in refugee-related research. Although recent studies highlight the growing importance of interdisciplinary and cross-border cooperation in this field, research gaps persist regarding power asymmetries, vulnerability, and equitable knowledge production.

Despite growing scholarly attention to crisis-related R&D collaboration, important research gaps remain. Existing studies tend to focus on short-term responses, with limited longitudinal and comparative analyses across crisis types. Research is also geographically concentrated in high-income countries, while power asymmetries, governance challenges, and unequal resource access remain insufficiently examined. Moreover, the social and ethical consequences of collaboration are not yet systematically addressed. Addressing these gaps would support the development of more resilient, inclusive, and effective R&D collaboration frameworks.

Across crisis contexts, the reviewed studies reveal considerable variation in dominant collaboration types, reflecting differences in knowledge requirements, institutional settings, and stakeholder involvement. **Environmental and global health crises** are predominantly characterized

by science–science and transdisciplinary collaborations, often involving international research networks and interdisciplinary teams. In some cases, citizens are also included as partners in such collaborative research. **Technological disruptions** are more frequently associated with business involvement, business–science–government and business–business partnerships emerging as the most frequent, which highlighs the importance of innovation ecosystems and triple-helix arrangements for breakthrough development. **Financial and economic crises** often rely on science–business cooperation, with universities and firms jointly addressing market and organizational uncertainty. **Institutional disruptions** emphasize business–business and ecosystem-level collaboration, where informal relationships and complementary resources play a central role. In **humanitarian crises**, multi-actor collaboration involving academia, industry, government, and civil society is visible, reflecting the complex ethical, social, and operational challenges of humanitarian research. Overall, these patterns indicate that collaboration structures adapt to crisis-specific demands.

Overall, the findings show that while collaboration consistently increases during crises, its motivations, structures, and effectiveness vary sharply across crisis types, indicating significant opportunities for future research on governance, equity, and the management of uncertainty in crisis-driven R&D collaboration.

Discussion

This paper is driven by the need to examine the body of research on international collaborative R&D efforts initiated by researchers to address challenges arising during times of crisis or disruptive events. Our analysis shows that while interest in this field is growing, important structural and thematic imbalances remain, both in terms of who participates in collaborative research and what topics dominate the literature.

From a geographical perspective, our mapping of authorship and co-authorship networks reveals a clear dominance of high-income countries, with the United States, the United Kingdom, and China emerging as central hubs. The strongest bilateral ties between the USA and China, and between China and the UK, reflect long-standing strategic partnerships in global science. These patterns align with previous observations (Okamura 2023), though recent geopolitical tensions suggest these ties may be weakening. While our findings do not yet capture this decline, they point to the need for longitudinal studies that examine the evolving geopolitical dynamics of international R&D collaboration.

More broadly, the dominance of high-income countries in this field reflects deep-seated structural inequalities in the global research ecosystem. Access to funding, infrastructure, and international networks remains highly uneven, limiting the participation of scholars from low- and middle-income countries. This pattern reflects broader structural imbalances in the global research ecosystem, where funding availability, research infrastructure, and access to international networks are disproportionately concentrated in wealthier nations (Reuer and Devarakonda 2017; Chan et al. 2020; Yilmazkuday 2025). Language barriers, limited presence in high-impact journals, and divergent research priorities further contribute to this marginalization (Chan et al. 2020;

Yilmazkuday 2025). These challenges are particularly acute during crises, when rapid mobilization of resources and access to established networks can determine whose voices are heard and whose research is represented on the global stage.

Turning to the thematic scope of the literature, different types of crises shape collaboration dynamics in distinct ways. Environmental crises, particularly climate change, are among the most studied drivers of international R&D collaboration. Research results emphasize the need for stakeholder networking and participatory approaches that bridge disciplines, sectors, and regions (Orecchini, Valitutti, and Vitali 2012; Gaziulusoy et al. 2016; Pandey and Bajracharya 2017). Some studies also stress the need to enhance the management of R&D collaboration and point out the growing role of leadership (Gaziulusoy et al. 2016). Future research directions point to the development of new tools for managing collaboration and knowledge exchange in the face of ongoing environmental disruption (Orecchini et al. 2012; Pandey and Bajracharya 2017).

Health crises, such as the COVID-19 pandemic, have also intensified international R&D collaboration, especially in medical sciences. The urgency and scale of the pandemic prompted an unprecedented wave of cooperation, often led by academic institutions and facilitated by global digital networks. At the same time, scholars have begun to question how such collaboration intersects with issues of geopolitical rivalry and long-term scientific independence (Kim and Cho 2021; Lee and Haupt 2021b; Nguyen et al. 2021). These considerations underscore the need to examine not only the mechanics but also the politics of international collaboration in times of crisis.

Technological disruptions, including digital transformation and biotech innovation, are another important driver of R&D collaboration. Technology shocks generate uncertainty while simultaneously creating windows for innovation. Firms, particularly in sectors like biopharma, are incentivized to enter R&D partnerships that offer access to complementary capabilities and market expansion opportunities (Grimes and Miozzo 2015). Successful collaboration in these contexts depends not only on strategic alignment but also on robust management structures, open innovation strategies, and trust-based social capital (Baba and Walsh 2010).

Financial and economic crises (including the Great Recession of 2008) have historically motivated science–business collaboration, with studies highlighting factors such as geographical proximity, local absorptive capacity, and managerial coordination as key to success (Azagra-Caro et al. 2006) and how it has been managed (Morandi 2013). The key conclusions from this strand of research highlight factors that matter for successful science-business collaboration, such as the geographical proximity of partners (Abramo et al. 2011), local absorptive capacity (Azagra-Caro et al. 2006), or well-designed management practices (Morandi 2013). Emerging research topics identified in the literature concern the role of support for science-industry cooperation and types of partnership agreements between business and science.

Institutional uncertainty, including regulatory change, weak governance, and cultural divergence, also plays a complex role in shaping R&D collaboration. Studies emphasize the need to balance formal and informal relationships and to navigate differences in information environments (Gao and Zhong 2022). Future research could build on effectuation theory to better

understand how actors adapt to ambiguous or shifting institutional contexts (Vargo, Wieland, and Akaka 2015).

A growing, yet still underexplored area is humanitarian crises, which call for intensified interdisciplinary R&D collaboration, particularly in addressing health and ethical challenges related to refugees and displaced populations (Dave et al. 2016; de Laat et al. 2021; Zakir Hossain 2022). These contexts introduce unique management challenges tied to cultural differences, inequality, and vulnerability. Scholars have called for research approaches that are sensitive to power imbalances and that promote equity in collaborative relationships (de Laat et al. 2021). This area offers ground for studies that explore inclusive, participatory, and ethically grounded models of collaboration.

Finally, a cross-cutting observation is that most of the existing literature continues to focus on bilateral R&D collaborations: science–science, business–business, or science–business. Very few studies adopt a systemic perspective that includes all relevant innovation actors, such as citizens and civil society organizations, in co-creative or participatory research models. However, it has been observed that although collaborations can foster equity and societal change, asymmetries between actors risk distorting knowledge and reinforcing inequalities, creating persistent challenges for international development research (Bender 2022), and thus, for realizing the ambitions of open science and responsible innovation frameworks.

The observed collaboration patterns can be further interpreted through the lenses of open innovation and resource dependence theory. From an open innovation perspective, international R&D networks reflect strategic efforts to access external knowledge and manage uncertainty. Resource dependence theory, in turn, highlights that collaborative network structures and asymmetries may be related to differences in access to funding, infrastructure, and expertise. Together, these perspectives provide a framework for understanding why certain countries tend to occupy more central positions, while others remain more peripheral. Our approach focuses on bibliometric analysis of macro-level structures; however, the literature indicates that organizational and individual-level factors, such as leadership, trust, and knowledge governance, also influence collaborative behavior. This highlights a promising avenue for further investigation through complementary research approaches using micro-level data on organizations involved in collaborative R&D projects.

To wrap up, crises, whether environmental, technological, economic, institutional, or humanitarian, act as both disruptors and enablers of international R&D collaboration. They expose weaknesses in current systems while also revealing new pathways for collaboration. Furthremore, the literature review of existing studies on R&D collaboration related to disruptions and crises also reveals that ethical, cultural, and geopolitical dimensions remain a critical challenge in shaping crisis-driven collaboration.

Conclusions, implications, and future research directions

This paper examined international research collaboration in the field of social sciences that focused on responses to global crises and disruptions, with particular attention to how such collaborations are structured and interpreted across diverse thematic contexts. Using a bibliometric

review, complemented by a systematic literature assessment, we addressed the central research questions: **How has existing research explored R&D collaborations focused on finding solutions to disruptive events or crises? What key themes have emerged, and what research gaps remain in the current literature?**

Our findings show that collaboration on various topics related to crises and disruptions remains highly concentrated in the United States, the United Kingdom, and Germany, with notable bilateral ties to China. Yet, overall collaboration density in the global collaboration network is modest, highlighting underdeveloped transnational knowledge exchange despite the global nature of crises. Six thematic clusters dominate the literature: environmental crises, health emergencies, technological disruption, economic shocks, institutional instability, and humanitarian challenges. Together, they reveal how uncertainty reshapes innovation but also creates opportunities for adaptive responses.

At the same time, the bibliometric analysis and the review of the existing studies highlight their major limitations. Researchers from the Global South and from Central and Eastern Europe remain significantly underrepresented in R&D networks, reflecting structural inequalities in resources, access, and visibility. Furthermore, most studies on research collaboration related to disruptive events examine bilateral partnerships (e.g., business–business, science–business), while approaches involving policymakers, citizens, and non-traditional actors are seldom addressed. These asymmetries may limit the participation of some stakeholders in R&D research networks and, to some extent, also influence global research agendas and outcomes.

This study contributes to the existing body of knowledge by mapping prevailing patterns of R&D collaboration related to crises or disruptions, identifying critical knowledge gaps, and offering evidence to potentially guide researchers, practitioners, and policymakers in designing more inclusive, collaborative, resilient, and globally integrated R&D systems.

From a comparative economic perspective, these patterns underscore persistent imbalances in global knowledge production and diffusion, mirroring broader disparities in economic development, institutional capacity, and innovation systems. Such asymmetries affect not only research collaboration but also the ability to respond collectively to shocks and systemic disruptions.

Based on the observed collaboration patterns, these findings suggest tentative implications for comparative and policy-oriented research. The identified research gaps related to geographical asymmetries in collaboration networks and the dominance of bilateral links indicate the importance of further research on inclusive collaboration frameworks that bring together actors from different countries and across stakeholder groups, such as industry, academia, and government. The review of existing studies on R&D collaboration in the context of disruptions and crises suggests that ethical, cultural, and geopolitical dimensions continue to pose significant challenges in R&D collaboration and represent promising topics for future comparative research. Furthermore, recognizing that causal mechanisms cannot be inferred from bibliometric data alone, closer examination of R&D collaboration related to disruptive events using complementary quantitative and mixed-method approaches represents an important direction for further studies.

This study has several limitations related to its time frame and methodological approach. We ended our empirical analysis in 2023 to ensure data completeness and reliability, as more recent bibliometric records are often affected by indexing delays and revisions. As a result, the most recent developments may not be fully captured. In addition, the study relies on bibliometric analysis of journal articles, which may overlook other forms of scholarly output and collaborative activities. The selection criteria and database coverage, while carefully defined, also reflect our methodological choices that may influence the scope and representativeness of the reviewed literature. Consequently, the findings should be interpreted with these limitations in mind, and future research may benefit from using updated data and complementary quantitative, qualitative, or mixed-method approaches.

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Międzynarodowa współpraca B+R w odpowiedzi na globalne zakłócenia: porównawcza bibliometryczna analiza sieci badawczych

W niniejszym badaniu analizowana jest międzynarodowa współpraca badawczo-rozwojowa (B+R) związana z globalnymi kryzysami lub zakłóceniami, ze szczególnym uwzględnieniem jej roli w rozwiązywaniu problemów wynikających z różnorodnych kryzysów. Analiza bibliometryczna 160 recenzowanych artykułów pozwoliła zidentyfikować wzorce współpracy i nakreślić mapę globalnych sieci badawczych. Zastosowano porównawcze ramy analityczne, aby zbadać różnice w tematyce i formach współpracy badawczej w różnych typach zakłóceń lub kryzysów. Wyniki pokazują, że współpraca badawczo-rozwojowa związana z zakłóceniami koncentrowała się w ośrodkach badawczych, takich jak Stany Zjednoczone, Wielka Brytania i Niemcy, z najsilniejszymi powiązaniami między Stanami Zjednoczonymi a Chinami oraz między Chinami a Wielką Brytanią. Pozostałe kraje zajmują bardziej peryferyjne pozycje w globalnych sieciach współpracy, co znajduje odzwierciedlenie w relatywnie mniejszym zaangażowaniu w badania nad tym tematem. W Europie Środkowo-Wschodniej Czechy

wyróżniają się jako jeden z niewielu krajów, których działalność badawcza dotycząca współpracy w czasach turbulencji jest widoczna na arenie międzynarodowej. Ustalono także, że istniejące sieci powiązań między ośrodkami naukowymi prowadzącymi takie badania są najczęściej bilateralne, niedostatecznie reprezentowani są w tych sieciach badacze z krajów Europy Środkowo-Wschodniej i krajów Globalnego Południa. Zidentyfikowano sześć obszarów tematycznych związanych z kryzysami lub zakłóceniami, w których rozwijała się współpraca B+R: kryzysy środowiskowe, zagrożenia dla zdrowia publicznego, zmiany technologiczne, kryzysy ekonomiczne i finansowe, niestabilność instytucjonalna oraz wyzwania humanitarne.
Wyniki analiz, identyfikując wzorce międzynarodowej współpracy badawczo-rozwojowej związanej z wydarzeniami destabilizującymi, mogą inspirować do skuteczniejszych reakcji na globalne wyzwania oraz wspierać rozwój bardziej odpornych i reagujących na kryzysy strategii badawczo-rozwojowych.

Słowa kluczowe: międzynarodowa współpraca B+R, kryzysy i niepewność, innowacja motywowana kryzysem, analiza bibliometryczna, przegląd literatury

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Determinants of Foreign Aid: The Case of Poland

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Abstract

This study examines the determinants of Poland's bilateral official developmental assistance (ODA) per capita allocation between 2013 and 2023 across 127 recipient countries. Employing panel data and multiple regression models, the analysis evaluates whether Poland, as a European Union post-accession donor with a post-communist transition background, allocates aid primarily based on recipient need or donor interest. The results indicate that Poland allocates significantly higher per capita aid to Eastern Partnership countries, reflecting strong regional solidarity rooted in historical ties. Within this regional context, aid allocation exhibits a non-linear income pattern, with middle-income recipients receiving the most support. Contrastingly, among non-Eastern Partnership recipients, income plays a minimal to negligible role in Poland's aid allocation decisions. Trade relationships are relevant within the regional context, whereas democracy promotion shows no significant influence on aid allocation. The analysis further reveals that Russia's invasion of Ukraine had a significant impact on Poland's aid allocation to Eastern Partnership countries. Overall, these findings provide partial support for the dual-track hypothesis identified in the literature on emerging Asian donors. The results suggest that Poland's ODA follows a regionally focused strategy that combines geopolitical concerns with transition solidarity, rather than being driven by humanitarian or commercial motives.

Keywords: ODA determinants, Poland, post-accession donor, Eastern Partnership
JEL: O10, O20, O52

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Introduction

Poland's transition from aid recipient to aid donor represents a striking transformation in the context of international development cooperation. Following its first parliamentary elections after the Round Table Agreements of April 1989, Poland dismantled the communist order, marking a new caesura in the country's economic and political environment (Sulowski 2014, pp. 23–24; Szewczak 2015, pp. 1–3). As Sulowski (2014) notes, Poland was not a newcomer in the international arena, nor was it starting "from scratch." Poland received extensive Western assistance between 1990 and 1994 (Kojder 1998, pp. 247–249), which facilitated its accession to the European Union (EU) in 2004 and subsequently to the OECD's Development Assistance Committee (DAC) in 2013. This transition was not only institutional but also deeply connected to the country's desire to "reverse the aid chain" and repay obligations accumulated when Poland itself depended on international assistance (Drążkiewicz-Grodzicka 2013, pp. 65–66). Yet, despite this transformation, Poland's aid allocation decisions remain largely absent from aid-allocation literature, which has focused primarily on traditional Western donors and, more recently, on emerging Asian donors.

Poland's identity as an aid donor has been largely shaped by its post-communist trajectory and the development of a foreign policy that actively supports the Eastern European region in general and the Eastern Partnership (EaP) countries more specifically. The EaP, launched in 2009 as the "eastern dimension" of the EU's European Neighborhood Policy, constitutes a joint framework involving the EU, its member states, and six Eastern European Partner countries: Armenia, Azerbaijan, Belarus, Georgia, Moldova, and Ukraine (European Union External Action 2025). Poland's post-1989 foreign policy which Sulowski argues is built on "good neighborhood" relations and a pro-Western alignment places eastern neighborhood stability as a priority, explaining why policymakers draw on Poland's own transition experience to justify highly concentrated official developmental assistance (ODA) support for EaP countries.

Recent geopolitical developments have intensified Poland's regional engagement. Bieńczyk-Missala (2025) demonstrates that the 2022 Russian invasion of Ukraine led to a substantial increase in Polish humanitarian and development assistance, with Poland becoming a major hub for bilateral and multilateral support to Ukraine. Public and governmental responses framed this support in terms of solidarity and responsibility (Drążkiewicz-Grodzicka 2013, pp. 65–71; Bieńczyk-Missala 2025, pp. 6–7). These developments raise the question of how much of Poland's ODA allocation reflects structural factors such as income and trade, and how much is shaped by geographical proximity, regional identity, and war-driven considerations.

Table 1. Poland's Official Development Assistance by Region and Volume, 2013–2023

	Bilateral by Region					Bilateral Total	ODA as % of GNI
Year	Europe	Africa	America	Asia	Oceania		
2013	36.89	47.66	0.48	35.21	0.02	120.26	0.1
2014	44.26	44.15	0.51	−4.28	0.03	84.67	0.09

	Bilateral by Region					Bilateral Total	ODA as % of GNI
Year	Europe	Africa	America	Asia	Oceania		
2015	58.37	54.95	0.48	−7.94	0.08	105.94	0.1
2016	78.58	106.43	0.41	−0.24	0.03	185.21	0.15
2017	150.66	30.87	0.41	82.98	0.05	264.97	0.13
2018	136.37	44.85	0.61	83.94	0.04	265.81	0.14
2019	167.25	29.24	2.95	36.57	0.04	236.05	0.14
2020	171.55	22.46	2.39	37.54	0.02	233.96	0.14
2021	184.23	31.44	2.49	74.42	0.03	292.61	0.15
2022	469.41	12.52	2.86	39.75	0.04	524.58	0.53
2023	310.38	8.34	1.37	36.75	0.09	356.93	0.34

Note: Bilateral Total represents geographically allocated bilateral ODA only and excludes in-donor costs. Regional bilateral columns are expressed in USD millions at constant 2023 prices; ODA/GNI is expressed in current prices. ODA/GNI figures for 2013–2017 are based on net disbursements methodology; 2018–2023 are based on grant equivalent methodology, following changes in OECD reporting standards. Negative values reflect net loan repayments from recipient countries exceeding new disbursements in the given year.

Source: oECD DAC2A and OECD DAC1 Databases.

As illustrated in Table 1, Poland's geographically allocated bilateral ODA grew steadily from USD 120.26 million in 2013 to USD 292.61 million in 2021, with the ODA/GNI ratio remaining stable between 0.09% and 0.15%. The year 2022 marked a stark adjustment: bilateral ODA increased to USD 524.58 million, and ODA/GNI surged to 0.53%, before partially normalizing to 0.34% in 2023. Structurally, Polish ODA relies heavily on multilateral channels most notably the European Union although in 2022 and 2023, the bilateral share became dominant (OECD 2025, pp. 1–4). The regional concentration is equally pronounced: Europe consistently receives the largest share of bilateral ODA, while allocations to Africa declined sharply over the period, suggesting a possible crowding-out effect.

This is consistent with Poland's Multiannual Programme for Development Cooperation, which names the Eastern Partnership as the primary geographical priority, and explicitly links development to foreign policy objectives, including regional stability and institutional development (Ministry of Foreign Affairs of the Republic of Poland 2021, pp. 9–22). Recent development cooperation plans further emphasize Ukraine's positioning as the central recipient of Polish aid, particularly in the areas of reconstruction, institutional capacity, and humanitarian support (Ministry of Foreign Affairs of the Republic of Poland 2025, p. 3). Taken together, these trends indicate that Polish ODA has evolved towards an increasingly concentrated allocation pattern.

Against this background, this study examines the determinants of Poland's bilateral ODA per capita from 2013 to 2023. The ODA measure covers total bilateral official development assistance, including both development and humanitarian components, without distinguishing between the two. The analysis evaluates whether Poland's allocation patterns are shaped by recipient-need (RN) considerations, donor-interest (DI) motives, democracy promotion, or regional priorities, and whether the 2022 war in Ukraine altered these allocation patterns. The study tests four hypotheses:

Hypothesis 1: Poland provides higher ODA per capita to EaP countries compared to non-regional recipients, reflecting post-communist solidarity.

This hypothesis is grounded in Poland's historical ties to the region and its commitment to supporting EaP countries. Szent-Iványi (2012) provides evidence that geographic proximity, neighborhood foreign policy orientation, and pre-1989 historical ties as opposed to recipient needare the primary determinants of aid allocation in Central and Eastern European (CEE) donors (Szent-Iványi 2012, pp. 70–81). If confirmed for Poland, the hypothesis suggests that shared cultural bonds and historical solidarity play an important role in determining where Poland directs its aid, consistent with the "gift/reciprocity logic" (Drążkiewicz-Grodzicka 2013, pp. 68–71).

Hypothesis 2: Regarding the dual-track pattern DI for high-income recipients and RN for middle-income recipients Poland exhibits distinct allocation patterns across recipient groups. For EaP recipients, ODA allocation follows an RN pattern (negative income coefficient). For non-regional recipients, ODA follows a DI pattern (positive income coefficient), similar to South Korea.

This hypothesis tests whether Poland maintains different standards for different recipient groups, following humanitarian patterns in its immediate surroundings while pursuing strategic patterns in other regions. Opršal et al. (2020) find a middle-income effect in Polish aid allocation alongside a predominant post-Soviet neighborhood bias, suggesting that income-based allocation patterns operate differently depending on the recipient's regional proximity to Poland. Such findings would support the dual-track hypothesis.

Hypothesis 3: Poland's ODA is positively associated with democratizing regimes (Freedom House scores) as a result of its 1989 history.

Given Poland's history and its stated commitment to sharing transition know-how, it can be expected that Poland will reward countries making progress in democratic governance and civil liberties. Poland's mandate of democracy promotion is codified in official documentation, with both the Ministry of Foreign Affairs and the Multiannual Programme for Development Cooperation explicitly listing democratization, good governance, and civic society development among core priorities (Ministry of Foreign Affairs of the Republic of Poland 2019, p. 4; 2025, p. 10). Petrova (2014) argues that this orientation is rooted in Poland's own 1989 "negotiated transition," with Polish aid emphasizing civil society development as a reflection of its domestic democratization model. A positive relationship between democratic improvements and aid allocation would support the notion that Poland's own transition experience shapes its ODA priorities.

Hypothesis 4: The Ukraine war (2022–present) altered Poland's ODA behavior, increasing aid to Ukraine and strengthening regional solidarity.

Russia's invasion of Ukraine in 2022 marked a turning point for European security. Poland's response was immediate: the Act of 12 March 2022 on Assistance to Citizens of Ukraine set the foundations for a large-scale support framework whose associated expenditures were reported as in-donor refugee costs within Poland's ODA statistics (Republic of Poland 2022). This hypothesis posits that this geopolitical shock shifted Poland's aid toward countries affected by

the conflict, particularly Ukraine, while also strengthening its overall commitment to supporting EaP countries for security reasons.

By analyzing these hypotheses, the study contributes to the limited empirical literature on aid allocation among European donors. It assesses whether Poland aligns more closely with the behavior of traditional DAC donors or with emerging donors whose allocation patterns incorporate geopolitical and regional considerations. While Hypothesis 1 establishes a regional bias towards EaP countries, the study's primary contribution lies in assessing the magnitude and structure of this prioritization whether standard aid allocation variables (income, population, trade, democracy) operate differently within Poland's priority neighborhood than outside it. The study tests whether the dual-track framework is consistent across donor types and applies in a European post-accession context. Beyond hypothesis testing, the study incorporates a structural break analysis of the post-2022 period, providing evidence on how geopolitical shocks modify pre-existing allocation logics, and revisits the conceptual classification of Poland as a donor, as discussed in the literature review.

Literature Review

Research on the determinants of foreign aid allocation has traditionally been organized around two explanatory variables: RN and DI. Alesina and Dollar (2000) demonstrate that aid allocation by traditional donors reflects both humanitarian factors (such as poverty and governance) as well as strong political and strategic considerations. Subsequent work by Berthélemy and Tichit (2004) shows that both RN and DI variables systematically influence aid decisions, though the relative weight varies across donors. They find that the post-Cold War period decreased bias toward former colonies and increased the importance of trade relations, while donor attention to governance quality increased in the 1990s. Importantly, they reveal that aid becomes more "progressive" once large recipients such as China and India are excluded, suggesting that the distribution of aid depends on both recipient income structure and geopolitical relevance. Additionally, research on EU member states' bilateral aid has revealed differences between national interests and EU-level development norms. Hoekman and Shingal (2024) observed that bilateral aid from EU members tends to promote national exports, whereas EU-level aid aligns more closely with development goals. This suggests that even within the EU which emphasizes development policies individual member states advance aid programs that serve their national commercial and strategic interests.

While this literature primarily examines traditional donors, recent research has extended these frameworks to emerging donors, whose motives differ due to their dual identity as former recipients. Kim and Oh's (2012) analysis of South Korea shows that Korean aid demonstrates a "dual-track" structure, with a positive relationship between recipient income and aid for higher-income recipients, while exhibiting a negative relationship for middle-income recipients. This implies that Korea focuses on DI motives for higher-income developing countries but remains more receptive to RN among countries undergoing economic transitions. Similarly, Fuchs and Vadlamannati (2013) find that India's aid allocation is driven primarily by political and commercial motives (including voting affinity at the United Nations and access

to foreign markets). Their results underscore the argument that emerging donors despite claims of South–South solidarity often pursue self-interested objectives comparable to those of DAC donors. Additionally, when analyzing Türkiye's foreign aid patterns, Kavakli (2018) observes that Türkiye's aid allocation shifted significantly following its political turnover, with aid increasingly directed toward trade partners and culturally affiliated (Muslim-majority) countries after the rise of the AKP government. Dreher et al. (2018), analyzing China's official financing to Africa, demonstrate that concessional flows are primarily guided by foreign policy and diplomatic considerations, whereas less concessional flows follow more commercial interests such as investment opportunities.

A comparatively under-analyzed section of the literature concerns the CEE member states of the EU, whose place as former aid recipients turned donors gives them a distinct profile among DAC members. Lightfoot (2010) investigated the "Europeanization" of CEE development assistance following EU accession, finding that international factors were the primary catalysts for institutional transformation a term he refers to as a top-down process where CEE states aligned their legislative frameworks with EU development norms rather than developing aid policies based on domestic demand. This period is described as one of "adaptation and learning," in which national development architectures were built to satisfy external requirements (Zajaczkowski and Smolaga 2023), building on earlier analysis by Horký and Lightfoot (2012). Zajaczkowski and Smolaga (2023), drawing on OECD DAC data for 11 CEE EU members from 2004 to 2021, identify two main determinants of CEE aid behavior: national interests, which shape the direction of bilateral flows, and institutional factors, which drive overall volume. They find that between 65% and 90% of CEE ODA is channeled through multilateral institutions (primarily the EU), meaning that bilateral aid that represents genuine national policy choices remains a relatively small share of total ODA (Zajaczkowski and Smolaga 2023, p. 106). CEE donors direct their bilateral ODA primarily towards neighboring European recipients, with sub-Saharan Africa receiving comparatively minimal attention – a structural pattern they attribute to the link between "security and stability interests in the CEE region and the provision of aid" (Zajaczkowski and Smolaga 2023, p. 119).

The quantitative dimension of the aid allocation literature on individual CEE donors remains sparse. Szent-Iványi (2012) applied a regression-based approach, finding that post-communist donors prioritize political and security interests over poverty reduction, with the majority of bilateral aid directed towards the Commonwealth of Independent States (CIS) and neighboring countries. This challenges the predominantly humanitarian framing that CEE policymakers use to legitimize their aid programs. It does, however, align with Zajaczkowski and Smolaga's (2023) assessment that the implementation of "transition experience" often functions as a "rhetorical move," concealing the "pursuit of national interests". Opršal, Harmáček, and Syrovátka (2016) extend the quantitative analysis to Czechia. They find that historical communist-era ties are the predominant and statistically significant determinant of Czech ODA to Sub-Saharan Africa, while recipient economic level plays a secondary role.

The closest precedent to the present study is Opršal et al. (2020). It is the only quantitative study to comparatively analyze both Poland and Czechia, and it portrays their bilateral aid as a "mélange" of geopolitical and developmental objectives. This reflects the persistent tension between neighborhood-focused foreign policy and DAC development norms that neither country has fully

resolved since EU accession. More recently, in an analysis of aid allocation across the humanitaria n-development-peace nexus for 23 DAC donors, Yabe et al. (2024) deliberately exclude Poland from their dataset due to its post-2009 DAC accession a gap that motivates the donor-specific panel analyses carried out in this paper. Collectively, the aforementioned literature suggests that CEE donors operate according to a logic shaped by historical path-dependency, security interests, and geographical ties.

Throughout this study, we intentionally avoid the terms "emerging donor" and "new donor" when referring to Poland. While these terms have been widely used in the literature, their accuracy has declined in recent years. Poland has been an EU member since 2004, an OECD DAC member since 2013, and has maintained an active development cooperation program for over two decades a path that renders "emerging" both inaccurate and misleading. As Drążkiewicz-Grodzicka (2013) observes, the category of "emerging donor" is "more political than analytical," functioning primarily as a marker of Poland's attempts to reposition itself within post-Cold War global hierarchies rather than as an accurate description of its donor characteristics. Moreover, as Horký and Lightfoot (2012) note, these terms conflate decidedly distinct donor types: China, India, and South Korea have fundamentally different institutional and geopolitical positions from post-communist EU member states, and grouping them under a single label obscures more than it reveals. We therefore propose the term "post-accession donor" to describe states whose development cooperation systems were institutionalized primarily in response to EU and OECD DAC accession conditions, and whose aid allocation logic reflects the path dependencies, neighborhood orientations, and transitions created as a result of that accession process. This framing more accurately captures the distinctiveness of Poland's position neither a traditional DAC donor with decades of autonomous aid history, nor a non-DAC Southern donor operating outside Western development norms and provides a more long-lasting anchor for future comparative research on this donor group.

In essence, the literature indicates that DI and RN motives coexist across donor types, but the relative balance varies based on donors' history, domestic political institutions and experiences, and geopolitical priorities. Traditional donors demonstrate historical colonial patterns, whereas emerging donors exhibit region-specific preferences and sensitivity to political change. The aforementioned findings regarding South Korea, India, Türkiye, and China suggest that emerging donors do not entirely follow humanitarian "South–South cooperation" norms, raising questions about whether European post-accession donors such as Poland follow similar "dual-track" patterns. The existing literature provides a clear foundation but offers minimal empirical analysis of post-communist EU donors, underscoring the need for research on Poland's ODA allocation patterns.

Data and Methodology

This study utilizes panel data covering 127 recipient countries over the period from 2013 to 2023. This timeframe was chosen to reflect Poland's increasing engagement in international development cooperation following its accession to the OECD's DAC in 2013.

The dependent variable, *ODA per capita*, measures Poland's bilateral aid to each recipient. The disbursement data are obtained from the OECD DAC database and measured in US dollars at a constant price with the base year 2023. The ODA variable captures total bilateral official development assistance and does not distinguish between development-oriented and humanitarian assistance. As such, the measure includes all aid, including emergency humanitarian support and crisis-related expenditures. Addressing the potential for the dependent variable to contain many zero values, this study added one to each observation before log-transforming it, which allows us to avoid missing value-related problems. As a limitation, this will create a natural distortion, but its benefit will outweigh the cost given the improved quality of data analyses stemming from reduced missing values.

The analysis incorporates several core independent variables to capture both RN and DI considerations. These include *income*, measured as the recipient's per capita GDP, obtained from the World Bank's World Development Indicators (WDI). Additionally, the variable *income²* is employed to test the non-linear (dual-track) aid pattern utilized by Alesina and Dollar (2000) as well as Berthélemy and Tichit (2004). Furthermore, the recipient's population is included as the variable *pop*, also sourced from WDI. This variable controls for country size effects, as the size of a country may influence aid allocation. Another independent variable included is *trade*, which measures bilateral trade flows between Poland and recipient countries as a proxy for donor economic interests. These data are obtained from the International Monetary Fund. To capture political and humanitarian motivations, the variable *Democracy_Change* in recipient countries is included. This variable specifically represents the year-over-year change in Freedom House's Freedom in the World Score, which assesses political rights and civil liberties on a scale from 0 to 100, with higher scores indicating greater democratic freedom.

The analysis also incorporates two dummy variables to control for specific patterns in Poland's aid allocation. First, *Eastern_Partnership* is included as a dummy variable, coded as 1 for countries that are members of the EaP initiative (Ukraine, Belarus, Moldova, Georgia, Armenia, and Azerbaijan) and 0 for non-members. This variable examines whether Poland exhibits a geopolitical bias toward countries with which it shares historical, cultural, or security interests. Second, a *post-2022* dummy variable is included, where 1 represents years ≥ 2022 and 0 represents years before 2022. This variable captures the potential impact of the Ukraine War, which began in 2022, on Poland's aid allocation patterns. Based on the variables outlined above, the following model equation is defined as follows:

$$
\begin{aligned}
\ln\left(\mathrm{OD\,A_{PC}}\right)_{\mathrm{it}} = \beta_0 + \beta_1 \ln\left(\mathrm{Income}\right)_{\mathrm{it}-1} + \beta_2 \\
\left[\ln(\mathit{Income})_{\mathit{it}-1}\right]^2 + \beta_3 \ln\left(\mathrm{Pop}\right)_{\mathrm{it}-1} + \beta_4 \ln\left(\mathrm{Trade}\right)_{\mathrm{it}-1} \\
+\beta_5 \mathrm{Democracy\_Change}_{\mathrm{it}-1} + \beta_6 \mathrm{Eastern\_Partnership}_{\mathrm{i}} \\
+\beta_7 \left(\ln(\mathrm{Income})_{\mathrm{it}-1} \times \mathrm{Eastern\_Partnership}_{\mathrm{i}}\right) \\
+\beta_8 \left(\ln(\mathrm{Income})_{\mathrm{it}-1} \times \mathrm{Democracy\_Change}_{\mathrm{it}-1}\right) \\
+\beta_9 \mathrm{Post\,2022}_{\mathrm{t}} \times \mathrm{Eastern\_Partnership}_{\mathrm{i}} \\
+\alpha_{\mathrm{i}} + \gamma_{\mathrm{t}} + \varepsilon_{\mathrm{it}}.
\end{aligned}
$$

All variables, except *Democracy_Change* and the dummy variables, are log-transformed to account for skewness in their distribution, thereby reducing the influence of extreme values. Additionally, apart from the dummy variables, all independent variables are lagged by one year. This addresses potential endogeneity concerns and reflects the reality of aid budgeting, as donors typically rely on data from the previous year when making allocation decisions.

The study employs three complementary estimation models. First, a pooled ordinary least squares (OLS) regression model is used to capture the overall cross-country allocation pattern. Second, a fixed effects (FE) model is implemented to control for time-invariant and country-specific factors that may influence aid allocation. Third, a random effects (RE) model is employed for full-sample comparison, assuming uncorrelated country effects. To further test the hypotheses, subsample regressions are conducted. These include an analysis of EaP countries versus non-EaP countries to examine whether Poland applies different allocation criteria, consistent with the dual-track motive. Another subsample regression compares the pre-war (2012–2021) period with the post-war (2022–2023) period to assess whether the Ukraine War changed Poland's aid priorities and allocation patterns. Finally, interaction terms between key variables are included to test for conditional relationships. Accordingly, the interaction between *ln_income* and *Democracy_Change* is examined to evaluate whether Poland's response to democratic improvements differs across income levels. To test whether the income effect differs by region, an interaction model between *ln_income* and *Eastern_Partnership* is estimated.

Empirical Results

Overall Regression Results

Table 2 presents the results from the pooled OLS, FE, and RE models. Several patterns emerge regarding the determinants of Poland's bilateral ODA per capita across specifications.

Beginning with the pooled OLS models, the income variables show a clear non-linear pattern: *ln_income* is positive and significant in the basic model, while its squared term, ln_income^2, is significant with a negative sign. This implies that Poland's ODA allocation increases with a recipient's income but at a decreasing rate. This result is consistent with prior studies that incorporate quadratic income terms to capture diminishing marginal effects (Alesina and Dollar 2000, p. 8; Berthélemy and Tichit 2004, pp. 261–262). However, once the *Eastern_Partnership* dummy is introduced in the augmented OLS model, the income coefficients shrink dramatically and lose statistical significance ($\beta = -0.047$ for *ln_income*; $\beta = 0.001$ for ln_income^2). This suggests that much of the initial income effect is absorbed by Poland's strong regional targeting.

In contrast to the pooled OLS results, the FE and RE models do not exhibit strong support for income-driven allocation. When utilizing within-country variation over time, the income terms are small and statistically non-significant in the RE specifications and remain non-significant once the *Eastern_Partnership* dummy is included in the FE augmented model. This suggests that changes in recipient income from year to year do not significantly influence Poland's aid decisions. Instead, the relationship with income appears to reflect larger structural differences across countries, which are captured in the pooled OLS model but largely filtered

out in the panel specifications. These results imply that Poland's income-based allocation patterns are primarily cross-sectional and not highly responsive to short-run income changes within countries. This result is consistent with Kim and Oh's (2012) observation that the effects of DI often become clearer in aggregate comparisons than in panel models that emphasize within-country changes.

The population variable, *ln_pop*, consistently exhibits a negative and significant association with ODA per capita. Across pooled OLS, FE, and RE models, larger countries receive less aid per person. For example, the FE specifications show that a 10% increase in population is associated with a reduction in ODA per capita of approximately 3–4%, as indicated by the negative population elasticities (ranging from –0.293 to –0.399). The RE estimates follow these results with smaller magnitudes (–0.043 in the basic and –0.025 in the augmented model), confirming that the population bias is robust across specifications. This result aligns with the general literature on aid allocation, which frequently documents a population bias due to the budgetary implications of assisting large countries.

Trade flows provide evidence of DI motivations in Poland's ODA allocation. In the pooled OLS models, bilateral trade (*ln_trade*) is positive and significant, indicating that Poland allocates more aid to countries with which it has stronger commercial ties. This is consistent with previous findings that commercial connections constitute a key factor in the aid allocation of emerging donors. Dreher, Nunnenkamp, and Thiele (2011) demonstrate that trade ties often influence ODA flows among non-DAC donors. For instance, a 10% increase in trade is associated with roughly a 5% increase in ODA in the β-coefficient specification. However, this relationship weakens in the FE models, where *L.ln_trade* remains positive but remains small and statistically nonsignificant. In the RE specifications, however, *L.ln_trade* is positive and significant in both the basic (0.040, $p < 0.05$) and augmented (0.025, $p < 0.10$) models, suggesting that bilateral trade ties have a within-country effect on aid allocation when unobserved heterogeneity is modeled as random rather than fixed. This suggests that *ln_trade* is more important for explaining which countries Poland supports than for explaining changes in aid allocation within countries over time. This dynamic mirrors the case of South Korea, where *ln_trade* appeared as a strong cross-sectional determinant but demonstrated limited explanatory power within panels (Kim and Oh 2012, pp. 264–265).

Democracy_Change does not emerge as a significant predictor of ODA in any of the baseline models. Whether lagged or not, changes in political rights and civil liberties do not appear to influence Poland's aid allocation. This result contrasts with Poland's history of transitioning from authoritarianism to democracy in 1989 and suggests that democracy promotion is not a systematic determinant of Polish ODA within the baseline framework.

However, the *Eastern_Partnership* dummy displays one of the strongest and most consistent effects across all regressions. In the augmented pooled OLS model, *Eastern_Partnership* = 0.688*** ($p < 0.01$), and in the RE augmented model, it rises to 0.723*** ($p < 0.01$). These coefficients indicate that being an EaP country increases Poland's expected ODA per capita by a substantial margin of approximately 99% ($\exp(0.688) \approx 1.99$) in the OLS and 106% ($\exp(0.723) \approx 2.06$) in the RE model. This result underscores the importance of regional considerations in Poland's foreign aid strategy and emphasizes its historically rooted orientation toward the East. The magnitude

of the *Eastern_Partnership* effect suggests that regional prioritization is one of the most important determinants of Poland's ODA allocation.

Table 2. Regression Results for Poland's ODA Allocation: Pooled OLS, FE, and RE Estimates

	1. Pooled OLS models			2. Fixed effect models		3. Random effect models	
Variables	**Basic**	**β-coefficient**	**Augmented**	**Basic**	**Augmented**	**Basic**	**Augmented**
ln_income	0.324 (0.204)	1.015** (0.158)	−0.047 (0.165)				
ln_income²	−0.025* (0.014)	−1.229** (0.010)	0.001 (0.011)				
ln_pop	−0.075** (0.035)	−0.408*** (0.008)	−0.024 (0.023)				
ln_trade	0.072** (0.037)	0.512*** (0.006)	0.025 (0.021)				
Democracy_Change			−0.001 (0.003)				
Eastern_Partnership			0.688*** (0.227)				0.723*** (0.233)
L.ln_income				−1.069 (0.667)	−1.198* (0.713)	−0.149 (0.249)	−0.281 (0.202)
L.ln_income²				0.080* (0.045)	0.091* (0.049)	0.009 (0.016)	0.017 (0.013)
L.ln_pop				−0.293* (0.152)	−0.399** (0.170)	−0.043* (0.019)	−0.025* (0.015)
L.ln_trade				0.025 (0.017)	0.028 (0.018)	0.040** (0.020)	0.025* (0.014)
L.Democracy_Change					−0.000 (0.002)		0.001 (0.002)
Intercept	−13.763*** (0.907)	−13.763*** (0.633)	−13.201*** (0.612)	−5.621 (3.800)	−3.551 (4.143)	−12.588*** (0.924)	−12.339** (0.728)
Number of observations	946	946	874	879	806	879	806

*** p < .01, ** p < .05, * p < .1

Note: Numbers in parentheses are standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. White-corrected standard errors were calculated to minimize heteroskedasticity issues. In the fixed effect and random effect analyses, *ln_income*, *ln_pop*, *ln_trade*, *ln_income²*, and *Democracy_Change* are lagged by one year to address endogeneity concerns.

Source: oDA data are obtained from the OECD DAC database, income and population data from the World Bank World Development Indicators, bilateral trade data from the IMF, and democracy measures from Freedom House's Freedom in the World dataset.

Overall, the baseline regression results indicate that Poland's ODA allocation is influenced by a combination of DI and regional strategic considerations. Income effects in pooled OLS suggest interest-based behavior, whereas strong *Eastern_Partnership* coefficients reveal a clear neighborhood focus consistent with Poland's foreign policy orientation. The consistently negative population

coefficients reflect standard aid allocation tendencies, and the limited significance of *Democracy_Change* suggests that political reform in recipient countries is not a major factor in Poland's aid decisions. These patterns collectively support findings in the literature on emerging donors, where structural interest and geopolitical priorities often coexist with weaker responsiveness to short-term changes in recipient characteristics.

Eastern Partnership Versus Non-Eastern Partnership Recipients

Table 3 presents separate regressions for EaP and non-EaP recipients and highlights the stark differences in the determinants of Poland's ODA allocation between the two groups. The contrast between the two models reveals Poland's dual allocation logic: a strongly regionally driven pattern for EaP countries and a DI-oriented pattern for non-EaP recipients.

For EaP countries, the income terms indicate a non-linear, inverted-U relationship with ODA. The lagged income coefficient (*L.ln_income*) is large and positive, while its squared term (*L.ln_income*^{2}) is negative and significant. This combination implies that Poland increases support as EaP countries transition from low- to middle-income status but reduces it at higher income levels. The magnitude of these coefficients is substantially larger than in any of the baseline models, indicating that income effects increase within the EaP region. This pattern is consistent with earlier studies demonstrating that donors often target middle-income neighbors for strategic or transition-sharing purposes, as found in South Korea's differentiated aid strategy toward countries at intermediate income levels (Kim and Oh 2012, pp. 265–267). These results suggest that ODA allocation within Poland's priority neighborhood is most responsive at income levels characteristic of transitioning post-Soviet economies.

The population variable in the EaP sample shows a strong negative effect (*L.ln_pop* = –3.603, $p < 0.05$), indicating that even within Poland's strategic region, larger countries receive less ODA per capita. A 10% increase in population reduces ODA per capita by approximately 36%, reflecting a stronger population bias than in the full-sample FE models. Trade flows (*L.ln_trade* = 0.408, $p < 0.10$) are also positively and significantly associated with ODA within the EaP group, suggesting that commercial links reinforce Poland's regional motives. This result is consistent with the emerging-donor literature, which suggests that economic and geopolitical motivations overlap rather than operate independently.

Table 3. Eastern Partnership Versus Non-Eastern Partnership Countries

Variables	Eastern Partnership Countries	Non-Eastern Partnership Countries
L.ln_income	18.243*	−0.972
	(7.771)	(0.697)
L.ln_income^2	−1.206*	0.069
	(0.490)	(0.047)
L.ln_pop	−3.603**	−0.758***
	(1.275)	(0.261)

Variables	Eastern Partnership Countries	Non-Eastern Partnership Countries
L.ln_trade	0.408*	0.002
	(0.181)	(0.012)
L.Democracy_Change	0.003	0.001
	(0.015)	(0.001)
Year		
2016	0.053	0.019
	(0.082)	(0.012)
2017	0.211	0.035**
	(0.122)	(0.016)
2018	0.247**	0.058***
	(0.070)	(0.021)
2019	0.313**	0.066***
	(0.095)	(0.022)
2020	0.385*	0.091***
	(0.175)	(0.028)
2021	0.437**	0.110***
	(0.155)	(0.035)
2022	0.860**	0.110***
	(0.274)	(0.034)
2023	0.439**	0.092***
	(0.138)	(0.035)
Intercept	−27.178	2.046
	(35.575)	(6.091)
Number of observations	54	752

*** p < .01, ** p < .05, * p < .1

Note: Numbers in parentheses are standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. White-corrected standard errors were calculated to minimize heteroskedasticity issues. Coefficients represent lagged independent variables (L.) to address potential endogeneity. All continuous variables are in logarithmic form, except Democracy_Change. The Eastern Partnership group includes Ukraine, Belarus, Moldova, Georgia, Armenia, and Azerbaijan. As a main caveat, the Eastern Partnership subsample analysis relies on a small number of countries, making the result sensitive to particular countries (e.g. Ukraine after 2022), which could be re-examined in further studies.

Source: oDA data are obtained from the OECD DAC database, income and population data from the World Bank World Development Indicators, bilateral trade data from the IMF, and democracy measures from Freedom House's Freedom in the World dataset.

Examining the non-EaP sample, income behaves very differently. The lagged income coefficient (*L.ln_income*) is small and negative (–0.972), and its squared term ($L.ln\_income^2$) turns positive (0.069), but neither is statistically significant. This indicates that outside the EaP region, Poland does not allocate ODA systematically according to recipient income. In contrast to the EaP model, where income strongly predicts aid levels, income among non-EaP countries

plays almost no role. This distinction provides empirical support for the dual-track logic: Poland's income-sensitive aid pattern applies primarily within its strategic neighborhood.

Population continues to remain negative and statistically significant among non-EaP recipients (*L.ln_pop* = −0.758*, $p < 0.01$), though the effect is less steep than for EaP countries. Furthermore, trade flows (*L.ln_trade*) are nonsignificant in the non-EaP sample (0.002, $p > 0.10$), indicating that commercial relationships meaningfully shape Poland's aid only within its prioritized regional area.

The year dummies included in the sample provide additional insight into how aid patterns evolved over time. For EaP countries, the post-2018 period shows a consistent upward trend, with year FE rising from 0.247 in 2018 ($p < 0.05$) to 0.860 in 2022 ($p < 0.05$). This substantial increase captures the rise in Poland's regional engagement following the escalation of tensions in Eastern Europe, culminating in the Russian invasion of Ukraine in 2022. Comparable patterns are observed in Türkiye's aid behavior, where geopolitical shocks and regional crises strongly increased aid flows to neighboring countries, as demonstrated by Kavakli (2018). For non-EaP countries, the year effects are positive but considerably smaller, suggesting that while Poland's total ODA rose globally, the increase was disproportionately concentrated in its EaP neighbors.

It is important to note that the aggregate nature of the ODA variable which includes both development and humanitarian assistance affects the interpretation of the post-2022 results. Given that the analysis does not differentiate between the two components, a portion of the substantially larger coefficients for EaP countries may reflect emergency humanitarian assistance directed toward Ukraine following the Russian invasion, rather than a sudden increase in traditional, long-term development aid. Consequently, the post-2022 effects should be interpreted with caution.

There are various signals that a significant portion of the post-2022 increase reflects crisis-driven mobilization rather than a strategic reorientation of aid policy. Poland's ODA/GNI ratio surged from 0.15% in 2021 to 0.53% in 2022, a level the OECD (2023) primarily attributes to in-donor refugee hosting costs and emergency expenditures affiliated with the reception of Ukrainian refugees. Nevertheless, the post-2022 shift is not purely reactive Poland's Multiannual Development Cooperation Programme already designated the Eastern Partnership as the primary geographic priority prior to the invasion of Ukraine (Ministry of Foreign Affairs of the Republic of Poland 2021, pp. 9–22). This suggests that the war intensified a pre-existing orientation rather than creating a new one. Nonetheless, given the short post-2022 time window in the dataset, it is not possible to ascertain whether this increase demonstrates a temporary crisis-driven response or a longer-term structural reorientation of Poland's development policy.

Overall, the EaP versus non-EaP regressions reveal different allocation patterns. Within the EaP, Poland's ODA is strongly shaped by a non-linear income relationship that favors middle-income recipients, trade connections, and significant year-on-year increases tied to the Ukraine war. Outside the EaP region, these determinants weaken, leaving the population effect as the only remaining factor. This divergence provides clear evidence for a regionally segmented aid strategy, in which Poland behaves as a strategic, neighborhood-focused donor for its closest partners but adopts a more neutral or diffuse allocation logic for the rest of the world.

Interaction Effects

As shown in Table 4, the interaction models test whether the effect of income on Poland's ODA per capita differs by regional affiliation (EaP) or by democratization. Across specifications, the results confirm that Poland's income–ODA relationship is strongly influenced by regional status rather than by shifts in political liberalization.

In the model examining income interacting with EaP, the main effect of lagged income is negative and statistically non-significant (*L.ln_income* = –0.690, SE = 0.757). However, the interaction term *Eastern_Partnership* × *L.ln_income* is positive (β = 0.381, SE = 0.583), suggesting that the marginal effect of income is more favorable for EaP countries. Although the interaction does not reach high significance levels, the direction and magnitude align with the earlier EaP-only regressions, where income had large and significant coefficients. The quadratic interaction term (*L.ln_income* × *L.ln_income* = 0.046, SE = 0.053) provides additional evidence for a curvature in the income effect among EaP neighbors. Evidently, income plays a qualitatively different role inside Poland's strategic neighborhood than outside.

Population effects remain robust in the interaction models, with coefficients of –1.410*** and –1.464*** across the two specifications. These values imply that even after accounting for regional interactions, a 10% increase in recipient population reduces ODA per capita by approximately 14–15%, reinforcing the negative effects observed in the EaP and non-EaP regressions. Trade remains small and statistically non-significant (β = 0.004), consistent with the FE results in the full-sample models, where bilateral trade was not significant. While the RE specifications and the EaP-only sample suggest that trade does have some within-country influence on aid allocation, this effect does not survive once income–region interactions are introduced. Democracy change also shows no significant moderating effect. In the income × democracy change model, the interaction term *L.ln_income* × *L.Democracy_Change* is almost zero (β = –0.000, SE = 0.001), reinforcing the conclusion that Poland does not reward democratizing countries with additional ODA, even when controlling for income levels.

The year dummies demonstrate a clear upward trajectory across both models. Coefficients rise steadily from 0.025* in 2016 to 0.219*** in 2022, reflecting a continuous increase in Poland's ODA disbursements over time. The substantial rise in 2022 is consistent with Poland's intensified aid engagement following the outbreak of the Ukraine war.

Table 4. Interaction Effects of Income with Eastern Partnership Status and Democracy Change

Variables	Income × Eastern Partnership	Income × Democracy Change
L.ln_income	−0.690	−0.756
	(0.757)	(0.771)
Eastern_Partnership x L.ln_income	0.381	
	(0.583)	
L.ln_income²	0.046	0.052
	(0.053)	(0.053)

Variables	Income × Eastern Partnership	Income × Democracy Change
L.ln_pop	−1.410***	−1.464***
	(0.449)	(0.420)
L.ln_trade	0.004	0.004
	(0.014)	(0.014)
L.Democracy_Change	0.000	0.003
	(0.002)	(0.011)
Year		
2016	0.025*	0.025*
	(0.013)	(0.013)
2017	0.062***	0.063***
	(0.023)	(0.022)
2018	0.097***	0.099***
	(0.031)	(0.029)
2019	0.119***	0.122***
	(0.041)	(0.038)
2020	0.153***	0.158***
	(0.049)	(0.045)
2021	0.185***	0.192***
	(0.051)	(0.047)
2022	0.219***	0.226***
	(0.069)	(0.067)
2023	0.193***	0.201***
	(0.071)	(0.065)
L.ln_income x *L.Democracy_Change*		−0.000
		(0.001)
Intercept	11.846	13.104*
	(7.959)	(7.289)
Number of observations	806	806

*** p < .01, ** p < .05, * p < .1

Note: Numbers in parentheses are standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. White-corrected standard errors were calculated to minimize heteroskedasticity issues. All continuous variables are expressed in logarithmic form and lagged by one year to mitigate endogeneity concerns. Interaction terms capture how the marginal effect of income varies across (1) Eastern Partnership recipients and (2) changes in political rights and civil liberties. Year fixed effects are included.

Source: oDA data are obtained from the OECD DAC database, income and population data from the World Bank World Development Indicators, bilateral trade data from the IMF, and democracy measures from Freedom House's Freedom in the World dataset.

Marginal Effects of Income

Figure 1 displays the marginal effects of income on predicted ODA per capita, differentiating between EaP and non-EaP countries. The plotted lines reveal that the relationship between income and aid differs not only in magnitude but also in slope across the two groups. For non-EaP countries (green line), the slope is shallow but generally positive, indicating a weak tendency for higher-income recipients to receive slightly more ODA a pattern consistent with DI behavior observed among many non-DAC donors.

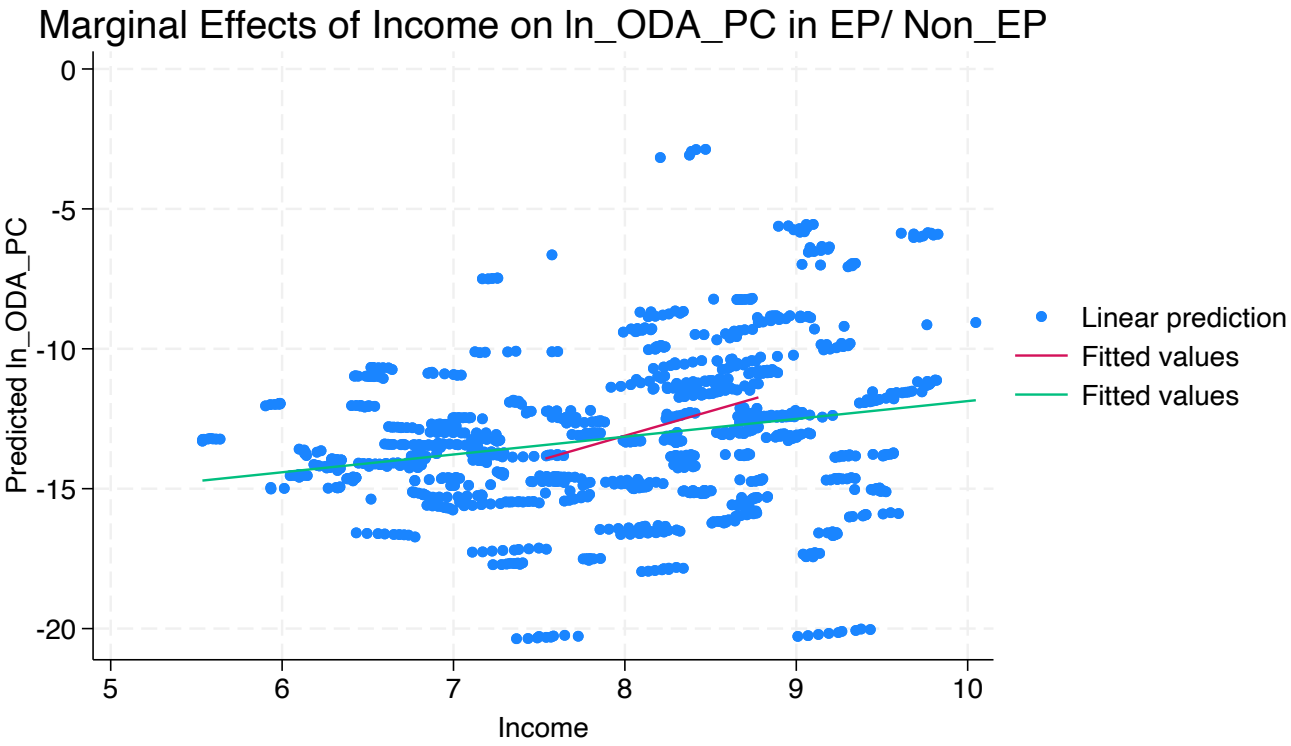

Figure 1. Marginal Effects of Income on Poland's ODA per Capita for EaP & Non-EaP Countries

Note: The red fitted line represents the marginal effect of income on ln(ODA per capita) for Eastern Partnership countries, while the green fitted line represents the corresponding effect for Non-Eastern Partnership countries. Income is measured as the natural logarithm of GDP per capita, and blue points indicate individual predicted values across all observations.

Source: The figure is based on regression estimates using bilateral ODA data from the OECD DAC database, GDP per capita and population data from the World Bank World Development Indicators, bilateral trade data from the IMF, and democracy indicators from Freedom House's Freedom in the World dataset.

For EaP countries (red line), the slope is visibly steeper, confirming that income plays a stronger role in shaping Poland's ODA allocation within its strategic neighborhood. The red line's upward trajectory at mid-income levels corresponds with the large income coefficients observed in the EaP-only regressions. At lower income levels, the EaP and non-EaP marginal predictions intersect, but beginning around *ln_income* = 7.5–8.0, the EaP prediction line rises more sharply. This suggests that Poland allocates relatively more aid to middle-income EaP countries those whose development trajectories most closely resemble Poland's own historical transition experience.

The interaction results and marginal effects graph jointly support the conclusion that Poland's ODA allocation follows a region-based allocation pattern. Income is more significant for EaP countries

than for other recipients, while *Democracy_Change* has no moderating influence. The visualized marginal effects demonstrate that Poland's aid behavior cannot be understood solely through global determinants: the income–aid relationship is fundamentally different inside Poland's geopolitical neighborhood, with mid-income EaP states receiving the strongest marginal increases.

Conclusion

This study analyzed Poland's bilateral ODA allocation and tested whether Poland, as a post-accession donor with its own experience of receiving aid, exhibits allocation patterns similar to traditional Western donors or emerging Asian donors. In doing so, this study bridges the literature on traditional DAC donors and emerging non-Western donors, specifically examining Poland, a European transition economy that occupies an intermediate position between the two. Using panel data covering 127 recipient countries from 2013 to 2023, this study employed multiple regression techniques, including pooled OLS, FE, and RE models, along with subsample analysis, to test four key hypotheses regarding regional preferences, dual-track allocation patterns, democracy promotion, and the impact of the war in Ukraine.

Our findings provide strong support for regional solidarity, as Poland allocates significantly higher ODA per capita to EaP countries compared to non-regional recipients. This regional bias predates the Ukraine war, reflecting Poland's long-standing historical and cultural ties, as well as strategic engagement with its eastern neighborhood. However, it has become significantly stronger after 2022, suggesting that geopolitical shocks in this case, the Russian invasion of Ukraine can greatly reinforce pre-existing regional allocation priorities.

Additionally, the dual-track pattern is only partially supported. Initially, Poland's aid behavior differed significantly between EaP and non-EaP countries. However, after the war in Ukraine began, Poland shifted its support toward wealthier, more strategically important partners within the EaP. These results indicate a reorientation from a recipient-need (RN) to a donor-interest (DI) allocation of aid, likely driven by security concerns and the imperative to support countries most threatened by the ongoing war.

Furthermore, *Democracy_Change* does not predict ODA allocation in any of the specifications, remaining statistically non-significant across all models. This finding does not imply that Poland is indifferent to sharing transition know-how and supporting democratic reforms. Instead, it suggests that short-term changes in political rights and civil liberties, as captured by Freedom House's Freedom in the World Score, do not influence aid allocation decisions.

Finally, the findings indicate that Poland is shifting toward a more crisis-driven, security-aligned donor profile following Russia's invasion of Ukraine in 2022. As the ODA measure includes both development and humanitarian assistance, part of this shift may reflect short-term crisis response rather than a permanent change in Poland's aid allocation strategy. However, whether this shift reflects a permanent transformation or a temporary response remains an open question.

Beyond hypothesis testing, this study reveals several additional patterns. First, population (*ln_pop*) consistently demonstrates a strong negative relationship with per capita ODA across all

models. This suggests that Poland maintains a systematic preference for supporting smaller countries, in which aid can achieve greater per capita impact. Second, trade flows (*ln_trade*) show a positive association with aid allocation in the pooled OLS and RE models, but weaken in the FE models. This pattern suggests that commercial connections help explain both cross-country differences in aid allocation and aggregate within-country variation, even if year-to-year shifts within individual countries are not strongly trade-driven.

Collectively, the findings in this study align with recent literature on emerging donors. They are consistent with Kim and Oh (2012) and Fuchs and Vadlamannati (2013), who both find that emerging donors often combine need-based allocations with strategic and geopolitical objectives, rather than adhering to purely humanitarian logic. Moreover, Poland's post-2022 shift toward security-driven and regionally concentrated aid aligns closely with Dreher et al.'s (2018) concept of "strategic state financing," in which concessional flows serve regional stability goals in an increasingly deliberate manner over time. Poland's post-war aid also reflects a broader trend within EU member states, where, although the EU collectively promotes development effectiveness, bilateral ODA is frequently employed as a foreign policy instrument, with strategic interests shaping allocation decisions (Hoekman and Shingal 2024, pp. 5–6).

The shift from the RN to the DI approach in aid allocation within the EaP after 2022 raises questions about the sustainability and development impact of Poland's aid. As security concerns increasingly shape allocation decisions, there is a risk that aid may be redirected from promoting poverty reduction and long-term development toward short-term stabilization and political support. This growing tension between security concerns and long-term development objectives illustrates a broader challenge for donors operating in conflict-affected regions.

The post-2022 reorientation toward Ukraine and the broader EaP region also raises questions about implications for other recipients. As shown in Table 1, geographically allocated bilateral ODA to Africa declined from USD 47.66 million in 2013 to USD 8.34 million in 2023, while Poland's four remaining non-EaP priority countries Palestine, Lebanon, Tanzania, and Ethiopia received a combined USD 12.1 million in 2023, compared to USD 249.7 million for Ukraine (Ministry of Foreign Affairs of the Republic of Poland 2023). This structural imbalance is consistent with broader concerns in the literature that the post-2022 Ukraine response has crowded out allocations to lower-income regions among European donors, raising the question of how sustainable Poland's development commitments are beyond its immediate neighborhood (Kiel Institute for the World Economy 2025).

Polish public opinion has shifted toward more pragmatic and nationalist interpretations of aid, partly due to the high costs of supporting Ukraine and rising domestic skepticism (Jasiecki 2024, pp. 30–33). While not directly tested in this study, this shift in public opinion may reinforce the government's approach of using aid in the national interests rather than humanitarian solidarity, potentially reducing support to non-strategic regions. However, given that this study covers only the period from 2013 to 2023, it has several limitations. Most notably, given the recency of the war in Ukraine, the post-war data are restricted to two years, limiting the ability to distinguish between short-term crisis response and long-term structural change. As additional post-2022 data become available, future research can assess

whether Poland's reorientation persists or gradually normalizes. Furthermore, this study did not consider the influence of domestic political changes on foreign aid allocation, such as shifts in the Polish government. Additional research could incorporate variables that capture government dynamics or differentiate political from geopolitical factors.

Moreover, Poland allocates both bilaterally and through EU frameworks, creating an important distinction between its own national interests and motives that are driven by the EU. Further studies could analyze EU allocation rules, compare national versus EU-driven motives, or separate EU-managed ODA from national bilateral ODA. Future research could also examine whether other CEE DAC members exhibit similar allocation patterns. Comparing Poland to neighbors such as Czechia, Slovakia, and Slovenia would reveal whether Poland's EaP focus represents a national strategy or regional approach among post-communist EU donors.

Ultimately, Poland's ODA behavior reflects neither purely humanitarian nor predominantly commercial motives. Instead, it illustrates how donor identity and allocation strategy are shaped by historical solidarity, geographic proximity, and security context. The Polish case suggests that history as an aid recipient does not ensure need-based aid allocation as a donor.

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Determinanty pomocy zagranicznej: przypadek Polski

W artykule poddano analizie determinanty bilateralnej oficjalnej pomocy rozwojowej (ODA) *per capita*, przyznawanej przez Polskę w latach 2013–2023 na rzecz 127 krajów-beneficjentów. Wykorzystując dane panelowe oraz modele regresji wielokrotnej, zbadano, czy Polska – jako kraj Unii Europejskiej z doświadczeniem transformacji postkomunistycznej, będący po akcesji dawcą pomocy – alokuje pomoc przede wszystkim na podstawie potrzeb beneficjentów czy też interesów dawcy. Wyniki wskazują, że Polska przeznacza istotnie wyższą pomoc *per capita* dla krajów Partnerstwa Wschodniego, co odzwierciedla silną solidarność regionalną zakorzenioną w więziach historycznych. W ramach tego kontekstu regionalnego alokacja pomocy wykazuje nieliniowy wzorzec dochodowy, przy czym kraje o średnich dochodach otrzymują największe wsparcie. Z kolei wśród krajów nienależących do Partnerstwa Wschodniego poziom dochodu odgrywa minimalną lub wręcz znikomą rolę w decyzjach Polski dotyczących alokacji pomocy. Relacje handlowe mają znaczenie w ujęciu regionalnym, natomiast promowanie demokracji nie wykazuje istotnego wpływu na alokację pomocy. Analiza ujawniła ponadto, że inwazja Rosji na Ukrainę miała istotny wpływ na alokację polskiej pomocy dla krajów Partnerstwa Wschodniego. Ogółem wyniki te częściowo potwierdzają hipotezę podwójnej ścieżki, identyfikowaną w literaturze dotyczącej wschodzących azjatyckich dawców pomocy. Rezultaty sugerują, że polska oficjalna pomoc rozwojowa realizuje strategię skoncentrowaną regionalnie, łączącą uwarunkowania geopolityczne z solidarnością transformacyjną, zamiast być determinowaną względami humanitarnymi lub komercyjnymi.

Słowa kluczowe: determinanty ODA, Polska, poakcesyjny dawca pomocy, Partnerstwo Wschodnie