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Does the European Green Deal Reach Microenterprises? Repeated Cross-Sectional Evidence on Resource Efficiency Adoption and Firm-Size Convergence Among EU SMEs

Almudena Recio-Román ¹, Manuel Recio-Menéndez ^{2,*}, and María Victoria Román-González ²

¹ Research Group SEJ-324, University of Almería, 04120 Almería, Spain; recioalmudena@gmail.com

² Department of Economics and Business, University of Almería, 04120 Almería, Spain; mvroman@ual.es

* Correspondence: mrecio@ual.es

Abstract

Small and medium-sized enterprises (SMEs) represent the majority of EU businesses and a disproportionate share of its environmental impact, yet longitudinal evidence on their resource efficiency behaviour remains scarce. This study examines whether SME adoption of resource efficiency practices increased between 2017 and 2024 and whether the size gradient changed across a period spanning several major and concurrent institutional and economic events: the European Green Deal (2019), the Circular Economy Action Plan (2020), the COVID-19 pandemic and its economic aftermath (2020–2021), the energy price shock that intensified in 2021 and was amplified by the Russia–Ukraine conflict in 2022, and the early implementation phase of the Corporate Sustainability Reporting Directive (2022–2024). These events overlapped substantially in time and cannot be disentangled with the present empirical design. Using microdata from three Flash Eurobarometer waves ($N = 38,165$; EU27), we construct a harmonised eight-item adoption index and estimate a weighted Poisson regression with cluster-robust standard errors and wave $\times$ firm-size interactions. Adoption increased substantially: SMEs reporting no resource efficiency action fell from 10.5% to 4.2%, and renewable energy use more than doubled (+15.3 pp). More substantively, the population-level gap in resource efficiency adoption between medium-sized enterprises (50–249 employees) and microenterprises (1–9 employees) narrowed by 81%, from +0.89 practices in 2017 (out of a maximum of 8) to a statistically non-significant +0.13 and +0.17 practices in 2021 and 2024 respectively (interaction IRR ≈ 0.81 – 0.82 , $p < 0.001$ in both waves), robust to nine checks. The size gradient in environmental behaviour appears not to be structural but a dynamic feature of the institutional landscape, one that narrowed substantially over a period coinciding with intensifying regulatory ambition and energy price shock—though the present repeated cross-sectional design cannot establish which mechanisms drove this compression.

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1. Introduction

Small and medium-sized enterprises (SMEs) occupy a paradoxical position in Europe's green transition. They account for approximately 99% of all businesses in the European Union, generate around 50% of GDP, and are responsible for a substantial and

often underestimated share of total environmental impact—estimates consistently place their contribution to industrial greenhouse gas emissions, water consumption, and waste generation between 60% and 70% of the business sector total [1,2]. Yet environmental policy has historically been designed around the compliance capacity of large firms: mandatory environmental reporting, supply-chain due diligence obligations, and green public procurement criteria have tended to impose thresholds that leave the vast majority of SMEs formally outside their scope, even as those same SMEs feel the indirect pressure through customer requirements, rising input costs, and regulatory spillovers from their larger counterparts [3,4].

The past decade has altered this dynamic considerably. The European Green Deal [5], the Circular Economy Action Plan [6], and above all the Corporate Sustainability Reporting Directive [7] have collectively shifted the regulatory frontier towards SMEs: either directly, through value-chain reporting requirements that cascade from large firms to their suppliers, or indirectly, through the broader signalling effect of an EU-level commitment to a resource-efficient economy [8,9]. At the same time, the energy price shock—which intensified in the second half of 2021 as natural gas reserves fell and energy market volatility increased, and was sharply amplified by the Russian invasion of Ukraine in February 2022—created conditions that may have strengthened the economic incentive for resource efficiency adoption, particularly among energy-intensive small firms, reframing what had previously been a largely environmental discourse into one of operational resilience and cost control [10]. This window also encompassed the COVID-19 pandemic, whose economic aftermath through 2021 shaped SME operational priorities in ways that cannot be separated from those of the regulatory sequence within the present design. Whether these regulatory and economic forces have in fact translated into measurable changes in SME behaviour—and whether they have done so equally across the heterogeneous SME population—remains an open empirical question. While the present study does not employ a causal identification strategy capable of isolating the effect of any single policy intervention, the temporal coincidence of observed behavioural changes with this regulatory sequence provides a theoretically motivated interpretive framework.

Existing research provides a rich theoretical and empirical foundation for understanding resource efficiency adoption in SMEs [3,11–13]. The dominant methodology is the single cross-sectional survey: representative studies by Hillary [12], Revell and Blackburn [14], Revell et al. [13], Testa et al. [8], and Bos-Brouwers [9] all capture adoption rates at one point in time, as does the Eurobarometer-based analysis by Carfora et al. [15], which uses the same 2017 survey wave as the present study. The study by Aragón-Correa et al. [3] and the critical review by Lepoutre and Heene [16] confirm that cross-sectional evidence predominates across the SME environmental management literature. This concentration of single-point evidence creates two systematic limitations.

First, while longitudinal and panel-based studies on SME environmental behaviour exist—including repeated cross-sectional designs using the Community Innovation Survey [4,17], national panel surveys of energy efficiency investment in Germany and the Netherlands, and regular SME eco-innovation monitoring by the European Commission—they are predominantly national in scope, sector-specific (concentrated in manufacturing and energy-intensive industries), or focused on a single dimension of environmental behaviour such as eco-innovation output, energy efficiency investment, or ISO 14001 certification. The specific combination of EU27 coverage, cross-sector representativeness, repeated population-weighted microdata, and multidimensional practice measurement that is required to answer the present study's research question has not previously been achieved in the literature.

Second, and more specifically, the temporal dynamics of the size gradient in resource efficiency adoption have not been studied at EU27 scale. The longitudinal studies

available do not examine whether the size effect in multi-practice adoption changes across periods at the level of the EU27 SME population. Studies that include firm size as a predictor—including Carfora et al. [15], Frondel et al. [18], and the cross-national comparisons reviewed by Aragón-Correa et al. [3]—treat it as a stable moderator in a static cross-sectional framework, with no wave-to-wave comparison that could reveal whether the size effect is changing. The few studies that do use multiple time points or quasi-longitudinal designs either focus on specific sectors such as manufacturing [4] or construction [14], are limited to single countries such as the United Kingdom [13] or Italy [8], or capture adoption of a single practice—energy efficiency or ISO 14001 certification—rather than a multidimensional portfolio of resource efficiency behaviours [18]. None provides a population-weighted, EU27-level estimate of whether the size gradient in multi-practice adoption has shifted over the period of the Green Deal’s introduction.

This paper addresses both limitations directly. We use the microdata from three waves of the Flash Eurobarometer survey on SMEs, Resource Efficiency and Green Markets—conducted in September 2017 (Flash EB 456, ZA6917), November–December 2021 (Flash EB 498, ZA7806), and June 2024 (Flash EB 549, ZA8869)—to construct a repeated cross-sectional dataset of 38,165 SME observations spanning 27 EU Member States and a seven-year period that bridges the pre-Green Deal era, the energy crisis, and the early implementation phase of the CSRD. The three survey waves share a nearly identical questionnaire structure, allowing us to build a comparable index of resource efficiency adoption across eight practices (saving water, saving energy, renewable energy use, saving materials, minimising waste, selling residues, recycling, and designing for repairability) that we verify at the item level against the official bilingual questionnaires archived in GESIS.

Our main findings can be summarised as follows. First, resource efficiency adoption increased substantially over the period, with the sharpest gains in practices that were least common at baseline, such as renewable energy use. Second, this increase was not uniform across firm sizes: medium-sized enterprises held a significant adoption advantage over microenterprises in 2017 that narrowed to a statistically non-significant residual by 2024, a pattern robust across nine pre-specified sensitivity analyses. Third, the temporal pattern of adoption differs across dimensions, with investment intensity, the offer of green products or services, and perceived barriers to adoption each following a distinct trajectory over the period—a pattern we interpret as reflecting growing ambition rather than stagnating capacity. Full statistical detail supporting each of these findings is reported in Section 4.

Because the design relies on independently drawn cross-sections rather than a longitudinal panel, this narrowing reflects changes in population distributions across size classes rather than within-firm behavioural change; the micro-level processes underlying this population-level pattern—whether genuine firm-level adoption, compositional change in the microenterprise stratum, or cohort replacement—cannot be determined from the present data.

These findings make three contributions, the primary one being empirical. Empirically, we provide the first harmonised, population-weighted, repeated cross-sectional analysis of resource efficiency adoption using Flash Eurobarometer microdata across three waves (FE-456, FE-498, FE-549), documenting a substantial and robust compression of the size gradient in environmental behaviour—a pattern not previously documented at EU27 scale—and we address the methodological challenges of cross-wave comparability (item-level wording changes, the absence of a pre-computed EU27 population weight in two of the three wave files, and the asymmetric availability of variables across waves) in a way that can serve as a methodological reference for future users of this data infrastructure. Theoretically, this empirical finding challenges the implicit assumption—common

to Resource-Based View accounts of environmental management and to models of organisational environmentalism [19] and of the diffusion of environmental innovations [17,20]—that capability gaps between firm size classes are stable moderators across institutional contexts; it suggests instead that such gaps are contingent on the strength of prevailing institutional pressure, a characterisation that the temporal pattern we document supports but that remains to be confirmed by designs capable of identifying firm-level mechanisms. For policy, the convergence result carries a nuanced message: microenterprises have been catching up, but the process is gradual and still incomplete; the stabilisation of green market offer between 2021 and 2024 suggests that the demand-side conditions for SME greening—customer pull, public procurement, consumer awareness—have not yet matched the pace of supply-side adoption of internal practices; and the sensitivity of the aggregate temporal trend to the weighting scheme warrants caution in treating the EU27-level increase as definitively established.

The remainder of the paper is organised as follows. Section 2 reviews the theoretical background and derives the paper's hypotheses. Section 3 describes the data, the construction of the survey-harmonised dataset, and the analytical strategy. Section 4 presents the descriptive and multivariate results. Section 5 discusses the findings in light of the theoretical framework and the policy context, acknowledges the study's limitations, and outlines an agenda for future research. Section 6 concludes.

2. Theoretical Background and Hypotheses

2.1. Resource Efficiency Adoption in SMEs: Barriers and Drivers

Research on environmental management in SMEs has consistently documented a pattern in which adoption of resource efficiency practices—broadly defined as actions that reduce the consumption of energy, water, materials, or other natural resources per unit of output—is lower, more incremental, and more reactive than in large firms [3,12,13]. Throughout this paper, we distinguish three firm-size strata within the SME population, following the European Commission's definition: microenterprises (1–9 employees), small enterprises (10–49 employees), and medium-sized enterprises (50–249 employees). This pattern has been theorised through several complementary lenses.

From a resource-based perspective [21,22], resource efficiency adoption requires the prior existence of organisational capabilities—managerial attention, technical expertise, monitoring systems—that SMEs are less likely to possess due to their smaller scale and narrower functional specialisation. The so-called “liability of smallness” [23] translates into environmental management as a chronic scarcity of the financial slack, human capital, and information-processing capacity needed to identify, evaluate, and implement efficiency improvements [11,24]. Survey evidence consistently finds that SME managers cite cost, lack of expertise, and administrative complexity as their primary barriers to environmental action [2,14], a pattern documented across national contexts and sector types in both EU and non-EU settings [13,18].

The RBV thus predicts a persistent and structurally stable size gradient in environmental adoption, because the resource constraints that generate it are intrinsic properties of firm scale rather than products of the institutional environment. This stability assumption has rarely been tested longitudinally. If capability-based disadvantages of smallness are structural constants, the size gradient in adoption should remain broadly stable across institutional contexts regardless of what regulatory pressures are applied. A substantial compression of that gradient over a period of intensifying institutional pressure would therefore challenge this assumption, suggesting that capability gaps between firm size classes are better characterised as boundary conditions whose magnitude depends on the intensity and reach of prevailing institutional pressures—a possibility that H3 allows us to assess.

From an institutional theory perspective [25,26], resource efficiency adoption is also shaped by normative and coercive pressures that vary in their reach and intensity across firm types. Large firms face stronger external isomorphic pressure—from investors, auditors, customers, and regulators—to signal environmental commitment [8,19]. SMEs, by contrast, operate in a lower-visibility institutional environment: they are rarely the direct targets of mandatory environmental reporting, their green credentials are seldom scrutinised by capital markets, and their individual environmental footprints are too small to attract regulatory enforcement attention [4,16]. This reduced institutional pressure is theoretically consistent with lower average adoption rates, but it also implies that when external pressure does reach SMEs—through supply-chain requirements, rising energy prices, or broadened regulatory scope—the potential for adoption gains may be proportionally larger than in firms where institutional pressures were already high.

Institutional Theory thus predicts that increasing regulatory intensity should produce convergence in environmental behaviour across the firm population, but does not specify whether this convergence should be proportional across firm sizes or disproportionately concentrated among those furthest below the institutionally defined norm. The value-chain cascade mechanism described in Section 2.3 generates a specific directional prediction: convergence should be driven by upward catch-up among the smallest firms, not by a parallel shift across the size distribution. This is a theoretically distinguishable prediction that our repeated cross-sectional design can assess.

From a diffusion of innovations perspective [17,20], resource efficiency practices follow an S-shaped diffusion curve through the firm population, with adoption typically beginning among larger, better-resourced early adopters before spreading to smaller firms as information, costs, and technical standards become more accessible. If this framework applies, we would expect the aggregate adoption rate across the SME population to follow a positive temporal trend as the diffusion frontier advances—a prediction that can be tested with repeated cross-sectional microdata spanning multiple survey waves.

Rogers' framework predicts catch-up by late adopters as diffusion matures but does not generate size-specific predictions about the rate at which firm-size heterogeneity in adoption speed should diminish over time. The implicit assumption in most applications is that firm size moderates adoption speed in a stable way—that is, that larger firms will always adopt faster by a roughly constant margin. If the size gradient in adoption speed is itself subject to temporal compression, this would extend the diffusion framework by showing that firm-size heterogeneity is not a fixed parameter of the diffusion model but an evolving feature of the institutional context in which diffusion occurs.

Testing this hypothesis is important for two reasons. First, EU sustainability policy—including the Green Deal and its SME Strategy—is predicated on the assumption that a broad-based improvement in SME resource efficiency is achievable and measurable, yet no population-weighted EU27 evidence confirms that such an improvement has in fact occurred over the Green Deal period. Second, while the theoretical frameworks reviewed above all predict a positive temporal trend, whether that trend is driven by genuine new adoption or by compositional change in the firm population cannot be determined from cross-sectional evidence alone. The existing empirical literature does not provide a reliable answer to this question at EU27 scale: the available longitudinal evidence is national in scope (e.g., [13,14]), sector-specific (e.g., [4]), or focused on a single practice dimension (e.g., energy efficiency or ISO certification), and the Eurobarometer-based analyses by Carfora et al. [15] and comparable studies use a single survey wave and therefore provide no temporal comparison. The present study provides the first EU27-scale, population-weighted, multi-practice test of a temporal trend in SME resource efficiency adoption.

These three frameworks generate cross-sectional predictions—explaining why some firms adopt more than others at a given point in time—but they also yield temporal

predictions when the institutional context changes systematically across the study period. Under the RBV, declining costs of resource efficiency technologies and growing availability of information reduce the capability barriers that previously confined adoption to better-resourced firms, expanding the range of firms for whom the cost-benefit calculation favours action; the aggregate adoption rate should therefore rise over time as the resource threshold required for adoption falls. Under Institutional Theory, the intensification of coercive and normative pressures during the 2017–2024 period—through the Green Deal, the CSRD, and supply-chain requirements cascading from regulated large firms—raises the institutional cost of non-adoption for a broader segment of the SME population, drawing firms previously below the institutional visibility threshold into the adopting pool. Under Innovation Diffusion Theory, the S-curve structure predicts that the rate of adoption is highest in the intermediate diffusion phase, before the early-majority threshold is reached; the period 2017–2024 may represent precisely this steep portion of the curve for practices previously adopted by a minority. All three frameworks therefore predict a positive temporal trend in aggregate adoption. Within the paper's hypothesis structure, H1 serves as a necessary prerequisite verification rather than the paper's central theoretical contribution: establishing that aggregate adoption increased is required before asking whether that increase was uniform across firm size classes (H2) or convergent (H3). If H1 were disconfirmed, the compression of the size gradient documented in H3 would lack a substantive interpretation. H1 is therefore positioned as a prerequisite check that anchors the more theoretically consequential tests that follow.

Confirmation of H1 requires that the increase be broad—observed across the majority of the eight practices and across size strata—and robust to alternative weighting schemes. An increase confined to one or two practices, concentrated exclusively in one size class, or sensitive to the choice of weighting would not constitute confirmation even if the wave dummy coefficients reach statistical significance. Considering the theoretical arguments above, it seems appropriate to formulate the following hypothesis:

H1. (*Upward trend in adoption*): *The average number of resource efficiency practices adopted by EU SMEs increased substantially and broadly between 2017 and 2024, across the majority of the eight measured practices and across all three firm-size strata.*

2.2. The Role of Firm Size in Environmental Behaviour

Firm size is one of the most robust predictors of environmental management adoption in the SME literature, documented across national contexts, sectors, and measurement approaches [3,13,15,18]. The theoretical mechanisms linking size to adoption are multiple and mutually reinforcing.

Larger SMEs have greater financial resources to absorb the upfront costs of energy audits, equipment retrofits, or waste management systems [11,24]. They are more likely to have a dedicated manager or department responsible for environmental issues, providing the organisational attention and internal expertise that resource efficiency improvements require [16,27]. They are more frequently embedded in supply chains where large customers impose environmental standards on their suppliers, creating a coercive pressure that does not typically reach the smallest enterprises [4,9]. And they face stronger reputational incentives to demonstrate environmental commitment to a broader set of stakeholders, including local communities, prospective employees, and credit providers [8,19].

The empirical literature consistently finds that this size effect operates along the full spectrum of the SME size distribution—not merely at the threshold between SMEs and large firms. Carfora et al. [15], using Flash Eurobarometer 456 (the same 2017 wave used in the present study), find that the number of green jobs in a firm and its size category are

among the strongest predictors of resource efficiency adoption, with medium-sized enterprises (50–249 employees) significantly outperforming microenterprises (1–9 employees) even within the SME population. This EU-level finding corroborates the national-level evidence reviewed by Aragón-Correa et al. [3] and Lepoutre and Heene [16], establishing the size gradient as one of the most consistent empirical regularities in the SME environmental management literature.

Testing H2 in the present study serves a specific purpose beyond replicating prior findings: it establishes the 2017 baseline size gradient in the same dataset and with the same operationalisation that is used to test H3. This internal replication is methodologically necessary because any claim that the gradient narrowed over time requires a reliable estimate of where it stood at the start of the period. Prior literature documents a size effect consistently [3,13,15,16], but those estimates derive from different datasets, different countries, different practice definitions, and different model specifications. A reliable test using the same EU27 population-weighted microdata and the same eight-item index that will be used for H3 has not previously been conducted. In addition, testing H2 confirms that the present sample replicates the size gradient found in prior cross-national studies, providing external validity for the analytical framework before the longitudinal test in H3 is introduced.

H2. (*Size gradient*): Medium-sized enterprises (50–249 employees) adopt more resource efficiency practices than microenterprises (1–9 employees), controlling for sector and turnover.

2.3. Regulatory Context as a Time-Varying Moderator: From the Circular Economy Action Plan to the CSRD

While H1 and H2 describe the baseline levels and trends expected from established theory, the key theoretical innovation of this paper concerns the interaction between the temporal trend and the size gradient. We argue that the period 2017–2024 represents a qualitatively distinct regulatory and economic window that should have produced a differential increase in adoption rates across firm sizes—and specifically, a faster rate of adoption among smaller firms relative to their medium counterparts.

The following mechanisms are presented as theoretically motivated contextual interpretations of the observed temporal patterns rather than as causal claims that the empirical design can establish directly.

Three mechanisms support this argument.

- **Regulatory cascade via value chains:** The most direct channel through which the Green Deal and CSRD affect SMEs is indirect: large firms covered by mandatory sustainability reporting requirements are compelled to collect environmental data from their suppliers, imposing de facto reporting and improvement obligations on SMEs that are formally outside the regulatory perimeter [7,8]. This cascade effect is inherently size-graduated: because the largest SMEs are more likely to supply regulated large firms directly, they were already subject to this indirect pressure before 2021. The expansion of CSRD scope in 2022 extended the cascade further down the supply chain, reaching smaller and less-connected firms for the first time. The net effect of this regulatory deepening should be a proportionally larger increase in adoption rates among the smallest firms—precisely those where the previous baseline of institutional pressure was lowest—narrowing the size gradient.
- **Energy price shock as a size-equalising catalyst:** The energy price shock that intensified throughout 2021 and was sharply amplified by the Russian invasion of Ukraine in February 2022 introduced an exogenous economic incentive to reduce energy consumption that operated independently of firm size, regulatory compliance capacity, or environmental awareness. For microenterprises, which typically operate on

tighter margins and have less hedging capacity than medium-sized firms, the energy cost increase represented a particularly acute pressure that may have prompted the adoption of energy-saving measures that had previously been deferred on cost grounds [10]. An abrupt fall in the proportion of EU SMEs investing nothing in resource efficiency over this period would be consistent with a widespread, size-undifferentiated response to this shock (a pattern assessed descriptively in Section 4.1.2). To the extent that the smallest firms had the most room to reduce their “nothing” investment share (given their higher baseline of non-investment), the shock should again have compressed the size gradient.

- Diffusion dynamics and catch-up: A third mechanism operates via the diffusion logic outlined in Section 2.1. If microenterprises began the period with a lower baseline of adopted practices, diffusion theory predicts a faster rate of subsequent adoption among this group as information, costs, and technical standards become more accessible—producing an upward catch-up dynamic that compresses the size gradient over time. Although a mechanical ceiling effect (bounded index, maximum 8 practices) could in principle produce apparent convergence without any genuine catch-up, this mechanical explanation can be empirically assessed using fractional-response models, item-level specifications, and predicted margins that explicitly account for the upper bound of the scale—analyses we conduct in Section 4.4 to distinguish substantive from mechanical convergence.

All three mechanisms point in the same direction: faster relative growth in adoption among microenterprises than medium-sized enterprises between 2017 and 2024, producing a compression of the size gradient. H3 is the central and most theoretically consequential hypothesis of the paper. Its importance derives from two sources. Theoretically, it tests whether the size gradient in environmental adoption is a structural constant—as the RBV and institutional theory accounts implicitly assume, given their cross-sectional grounding—or whether it is a dynamic feature of the institutional landscape that responds to changes in external pressure. No study has tested this assumption of stability at the EU27 scale: the longitudinal and quasi-longitudinal studies available do not examine whether the size effect in multi-practice resource efficiency adoption changes over the Green Deal period, and single-country studies (e.g., [14,18]) cannot be generalised to the EU27 population. For policy, the answer to H3 directly determines the targeting logic of SME green support instruments: if the gap is narrowing spontaneously, policy resources are better directed at accelerating diffusion among laggards; if it is stable, structural capability interventions remain necessary. The present study provides the first reliable test of this hypothesis using three-wave EU27 population-weighted microdata.

H3. (Convergence): *The gap in resource efficiency adoption between medium-sized enterprises and microenterprises narrowed significantly between 2017 and 2021, and remained narrower in 2024 relative to the 2017 baseline.*

Note that H3 does not predict full convergence—nor does the theory require it. The resource-based and institutional mechanisms that generate the size advantage (financial resources, managerial capacity, supply-chain pressure) remain present even after the regulatory deepening of the Green Deal era; what changes is the marginal intensity of the external driver reaching smaller firms. We therefore expect a significant but partial compression of the gap, with medium-sized enterprises retaining some advantage in 2024 relative to microenterprises, but a substantially smaller one than in 2017.

2.4. Barriers and Adoption: A Paradox with a Theoretical Resolution

A fourth empirical pattern—one that repeated cross-sectional surveys of SME environmental behaviour have documented in multiple national contexts [13,18] and that our design allows us to verify at EU27 scale—requires theoretical attention: the co-movement of resource efficiency adoption rates and perceived barriers to that adoption. If adoption is rising, why should barriers be increasing at the same time? This apparent paradox can be resolved through two complementary mechanisms documented in the organisational environmental management literature.

First, and most straightforwardly, the pool of firms attempting to adopt resource efficiency practices is itself growing. If previously non-adopting firms begin attempting implementation—which is precisely what H1 predicts—they will encounter barriers that were simply not relevant to them before, because barriers to adoption are only perceived by firms that are actively trying to adopt. This selection effect means that as the frontier of adoption expands outwards to less-experienced, resource-constrained firms (disproportionately microenterprises, consistent with H3), the aggregate level of reported barriers in the SME population should increase even if the barriers faced by any individual firm remain constant [13,28].

Second, the regulatory and technological landscape itself has become more complex over the period. The survey instrument itself reflects this evolution: the official questionnaires document that the list of barriers was expanded between waves to include “complexity associated with environmental labelling and certification” (new in 2021) and “complex environmental reporting requirements” (new in 2024)—the latter added precisely as the CSRD disclosure requirements began to materialise as a concrete concern for SME managers. This questionnaire evidence mirrors a broader pattern: as the regulatory environment grows more demanding, the range of perceived obstacles to compliance grows commensurately [4,8].

Together, these two mechanisms predict that perceived barriers and adoption rates should co-move positively over the study period—a dynamic that, far from constituting a contradiction, is a theoretically expected signature of a population undergoing active but uneven diffusion of environmental practices.

Documenting this co-movement is important because it has direct implications for interpreting survey evidence on SME environmental behaviour: if barriers increase alongside adoption, this pattern would be misread as policy failure or deteriorating conditions unless the theoretical resolution is made explicit. The existing literature has proposed the selection mechanism theoretically [13,28] but has not documented the co-movement pattern systematically at EU27 scale or confirmed it across multiple survey waves. Without this documentation, the simultaneous rise in adoption rates and barrier reports that appears in EU Eurobarometer data risks being dismissed as inconsistent or measurement error rather than recognised as a theoretically predicted and empirically replicable signature of active diffusion. The present three-wave design provides the first repeated documentation of this pattern at EU27 scale, allowing us to confirm whether the co-movement is consistent across the 2017–2021 and 2021–2024 intervals.

Observation 1. (*Barrier-adoption co-movement*): As resource efficiency adoption expands across the SME population, the share of adopting firms reporting perceived barriers is expected to increase, reflecting both the entry of less-prepared firms into the adopting pool and the growing complexity of the regulatory environment. Rather than a hypothesis subject to causal testing, this expected co-movement constitutes a theoretically motivated descriptive expectation against which the survey evidence is assessed.

The four expectations are summarised below.

Hypothesis	Core Claim	Operationalisation
H1	Substantial and broad-based upward trend	Positive and significant Wave dummies (2021, 2024) in main model; confirmed if the trend is observed across the majority of practices, across all size strata, and robust to the within-country weighting scheme (Sensitivity S2)
H2	Size gradient: medium > micro	Positive and significant Size 50-249 coefficient in baseline year (2017)
H3	Size gap narrows over time	Negative and significant Wave × Size 50-249 interaction terms
Obs. 1	Barriers expected to increase alongside adoption rates	Q7 barrier index compared descriptively across waves for adopting sub-population

H3 is the central, theoretically distinctive hypothesis of the paper; H1 and H2 serve as necessary conditions whose confirmation validates the baseline from which convergence is measured, while Observation 1 provides a theoretically grounded interpretation of an otherwise counterintuitive descriptive finding. H1, H2, and H3 are tested in the empirical analysis reported in Section 4.2; Observation 1 is assessed descriptively in Section 4.1.2.

3. Data and Methods

3.1. Data Source: Flash Eurobarometer Repeated Cross-Sections

This study uses the microdata from three waves of the Flash Eurobarometer survey on SMEs, Resource Efficiency and Green Markets, commissioned by the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs of the European Commission and deposited at GESIS—Leibniz Institute for the Social Sciences:

- Flash Eurobarometer 456 (FE-456; fieldwork: 11–26 September 2017; GESIS study number ZA6917; conducted by TNS Political & Social) [29].
- Flash Eurobarometer 498 (FE-498; fieldwork: 8 November–10 December 2021; GESIS study number ZA7806; conducted by Ipsos European Public Affairs) [30].
- Flash Eurobarometer 549 (FE-549; fieldwork: 3–28 June 2024; GESIS study number ZA8869; conducted by Ipsos European Public Affairs) [31].

All three waves were administered via Computer-Assisted Telephone Interviewing (CATI), with interviews conducted with a person holding decision-making responsibility in the firm (managing director, CEO, financial director, commercial manager, or legal officer). Coverage is restricted to businesses employing at least one person, operating across the industry, retail, and services sectors as defined by NACE Rev. 2 sections B through M (excluding public administration). The analytical grouping of these sections into the three regression categories used throughout the paper is described in Section 3.3.2. The use of repeated cross-sections—Independently drawn samples from the same target population at three points in time—is appropriate for the research design, which seeks to identify population-level trends in adoption behaviour rather than tracking individual firms over time. Because each wave represents a fresh random draw from the SME population, temporal comparisons reflect changes in the distribution of practices across the population rather than within-firm learning trajectories.

The three waves share a highly stable questionnaire structure. We verified cross-wave comparability at the item level through systematic review of the three official bilingual questionnaires archived alongside the microdata files at GESIS (ZA6917_bq, ZA7806_bq, ZA8869_bq) [32–34]. Each questionnaire explicitly labels each item with its origin in the previous wave (e.g., “FL498–Q1”, “FL549–NEW”, “FL498–Q7 MODIFIED”), allowing exact

identification of which items are strictly comparable across all three waves, which changed wording between 2017 and 2021 but were stable thereafter, and which were introduced in 2021 or 2024 and are therefore not usable for a full three-wave trend comparison. A detailed item-level equivalence table is available in Appendix A.

3.2. Sample and Weighting Procedure

3.2.1. Sample Definition

The analysis is restricted to SMEs (1–249 employees) located in the 27 EU Member States (EU27). FE-456 was conducted with EU28 coverage, including the United Kingdom (then still an EU member), while FE-498 and FE-549 cover EU27. To ensure strict geographic comparability across the three waves, the analysis is restricted to the 27 EU Member States in all three waves. Although FE-456 was conducted with EU28 coverage and includes United Kingdom observations ($n = 501$), these are excluded from the main analytical sample. The robustness of the results to the inclusion of the United Kingdom is assessed in Appendix C (Sensitivity S5, Table A11), where the EU28-inclusive sample is retained and results are shown to be substantively unchanged. The SME size classification follows the consolidated categorical size variable derived by the survey organisation from the directly reported employee count: micro (1–9 employees, scr10t codes 1 in FE-456; scr10 code 1 in FE-498/549), small (10–49, codes 2), and medium (50–249, codes 3). Respondents who could not estimate their employee count and were assigned a ‘don’t know’ code are retained in the descriptive analyses (Tables 1–5), where firm size is not required to compute the adoption index or the barrier measures, to maintain consistency with the weighting denominator used by the official reports. These respondents are excluded from the regression estimation sample (Section 4.2), because firm size category is a required component of the wave $\times$ size interaction terms. The number of such respondents is small: 45 in FE-456, 21 in FE-498, and 8 in FE-549 (74 in total, 0.19% of the pooled EU27 bruto sample). A further 5187 respondents (13.6% of the pooled EU27 sample) are excluded from the regression estimation sample because their annual turnover bracket is missing; the complete flow is documented in Appendix A.8. A complete sample-flow table documenting retention and exclusion at each step, disaggregated by wave and exclusion criterion, together with the wave $\times$ size composition of the estimation sample, is provided in Appendix A.8. Large firms (250+ employees), which were included in the FE-498 and FE-549 samples but not in FE-456, are excluded from all analyses.

Final sample sizes after application of these restrictions are 11,690 SMEs in 2017, 13,343 in 2021, and 13,132 in 2024, yielding a pooled repeated cross-sectional dataset of $N = 38,165$ observations.

3.2.2. Weighting Procedure

EU-level aggregate estimates require probability weights that account for the disproportionate sampling design of the Flash Eurobarometer (each country receives a roughly equal sample size regardless of its share of the EU SME population, so unweighted estimates over-represent small countries and under-represent large ones).

For FE-456, the microdata file includes a pre-computed EU28 weight variable (w23, “WEIGHT EU-28”) that rebalances the national samples according to each country’s share of the total EU28 SME population. We use this weight directly. Its validity was confirmed by comparing weighted estimates from our microdata against the published aggregate figures in the official report: deviations were below 0.6 percentage points for all checked indicators.

For FE-498 and FE-549, the microdata files do not contain a pre-computed EU27-specific weight for the SME sub-sample in isolation. The closest available variable in FE-549 (w113_sme) aggregates EU27 with all non-EU countries covered by the survey, making it

unsuitable for an EU27-only aggregate. The post-stratification weight included in both files (*w1_sme*) corrects for within-country imbalances in sector and size composition but does not rescale the relative contribution of each country to the EU27 aggregate, producing systematic deviations of 5–6 percentage points relative to published figures when used for cross-country aggregation.

We therefore construct a country-rebalancing weight that replicates the methodology declared in the official technical notes: “EU27 averages are weighted according to the size of the SME population of each EU Member State” (Flash Eurobarometer 498, technical specifications). The weight assigned to each SME respondent from country c is:

$$w_{EU27}(i) = \frac{s_c/100}{n_c} \quad (1)$$

where s_c is the percentage of the EU27 SME universe accounted for by country c (drawn from the “% of EU27 universe” column of the official technical specifications table, itself derived from Eurostat Structural Business Statistics and Business Demography), and n_c is the number of SME interviews conducted in country c in that wave. This weight ensures that the contribution of each country to the EU27 aggregate is proportional to its actual SME population share, replicating the same logic that produces the pre-computed *w23* weight in FE-456 (confirmed empirically: Italy, France, Spain, and Germany, the countries with the largest SME populations, carry the highest aggregate weight in *w23*, not the countries with the largest interview samples).

The resulting reconstructed weights were validated against published aggregate figures for FE-498 and FE-549, yielding mean absolute deviations of 2.1 and 2.3 percentage points, respectively, across the nine Q1 items with available published benchmarks. One item—“selling residues and waste to another company”—shows a larger discrepancy (approximately 8 percentage points in FE-498 even before weighting), which we attribute to a wording change between FE-456 (“selling your scrap material”) and FE-498/549 (“selling your residues and waste”) that broadens the operational definition of the practice; weighted estimates for this item should be interpreted with caution and are excluded from the trend comparison discussed in Section 5.5. For all other items and for the composite adoption index, the reconstructed weight produces estimates within the expected range of the official published figures. Since the same weighting logic is applied consistently across all three waves, any remaining systematic bias should affect all three time points similarly, attenuating its impact on temporal comparisons. A robustness check using *w1_sme* without cross-country rebalancing (Sensitivity S2, Table A7) reveals an important differential: while the Wave $\times$ Medium interaction terms remain negative and statistically significant under this specification (Wave2021 $\times$ Medium: IRR = 0.818, p = 0.002; Wave2024 $\times$ Medium: IRR = 0.849, p = 0.005), the wave main effects lose statistical significance (Wave2021: p = 0.975; Wave2024: p = 0.365), indicating that the aggregate EU27 temporal trend estimated in the main model is sensitive to the cross-country rebalancing of the weight. The convergence finding is therefore more robustly supported by the data than the aggregate trend finding, and this differential should be borne in mind when interpreting H1.

3.3. Measures

3.3.1. Dependent Variable: Resource Efficiency Adoption Index

The dependent variable is a count of the number of resource efficiency practices currently adopted by the firm, constructed from survey question Q1: “What actions is your company undertaking to be more resource efficient?” (multiple response). Respondents are presented with a list of practices and asked to select all that apply.

Cross-wave item-level comparison of the official questionnaires reveals that nine substantive response options were available in FE-498 and FE-549, but only eight in FE-

456, because the item “switching to greener suppliers of materials” was introduced as a new item in FE-498 (explicitly labelled “(N)” in the questionnaire) and did not exist in FE-456. To ensure strict comparability across all three waves, the adoption index is constructed by summing the eight items present in all three waves:

1. Saving water
2. Saving energy
3. Using predominantly renewable energy
4. Saving materials
5. Minimising waste
6. Selling residues/waste to another company
7. Recycling (reusing material or waste within the company)
8. Designing products that are easier to maintain, repair, or reuse

The resulting index ranges from 0 to 8. The equal-weighting assumption reflects the conceptual operationalisation of the index as a measure of adoption breadth—the number of distinct organisational domains in which a resource efficiency decision has been made—rather than a measure of environmental impact or investment intensity. Two measurement limitations follow from this design. First, the binary coding does not distinguish between marginal and comprehensive implementation within each category: a firm that has replaced one piece of equipment with a more efficient model and a firm that has achieved full thermal modernisation receive the same score on the ‘saving energy’ item. The REAI is therefore more sensitive to the extensive margin of adoption—whether a firm acts in each domain—than to the intensive margin—how thoroughly it does so. Second, the questions ask whether the firm currently engages in each practice, not when it first adopted it. The observed change in adoption prevalence between survey waves therefore reflects the change in the stock of current adopters, not the flow of new adopters during the inter-wave period. A firm adopting in 2024 may have adopted the relevant practice in 2016 rather than in response to any post-2017 regulatory change. Both limitations are discussed further in Section 5.5. At the level of the binary adoption decision, all eight practices are commensurate: each represents a distinct managerial choice. Differential weighting by environmental impact, implementation cost, or technological complexity would require domain-specific assumptions external to the survey data. The internal consistency and dimensionality of the index, and the robustness of the central finding to PCA-derived weighting, are assessed in Appendix A.9 and Appendix C.12, respectively. Each item is coded 1 if the respondent selected it and 0 otherwise; respondents who selected “none” or “don’t know” at the question level are assigned a score of 0 on all items. This coding treats uncertainty or non-response as equivalent to confirmed non-adoption. Because ‘don’t know’ is an exclusive response option in the questionnaire—respondents either select it or indicate specific practices, but not both—there are no item-level missing values for non-DK respondents; pure DK respondents (205 across all waves, 0.62% of the EU27-strict estimation sample; 0.54% of the pooled analytical sample) receive index scores of zero under this assumption. Three sensitivity analyses examining the robustness of the convergence finding to alternative DK treatments are reported in Appendix C.8. The “switching to greener suppliers” item is retained as an auxiliary variable for analysis within the 2021 and 2024 waves separately, but is excluded from all cross-wave comparisons.

One additional item warrants a note. The item on selling residues changed its wording between FE-456 (‘selling your scrap material to another company’) and FE-498/549 (‘selling your residues and waste to another company’), potentially broadening the set of behaviours captured. This item is included in the index to maintain the full eight-item structure, but results involving this item individually should be interpreted as

approximate rather than strictly comparable trend estimates. A sensitivity analysis re-estimating the main model on a seven-item index excluding this practice (Sensitivity S7, Appendix C.9, Table A14) confirms that the convergence result is unchanged: Wave2021 $\times$ Medium = -0.195 (IRR = 0.823, $p < 0.001$); Wave2024 $\times$ Medium = -0.182 (IRR = 0.834, $p < 0.001$).

3.3.2. Control Variables

All control variables were verified for item-level comparability across the three questionnaires before inclusion. The selection of control variables was constrained by two criteria: theoretical relevance to the adoption decision and availability as a comparably measured item across all three survey waves. Firm age, export orientation, and direct financial condition indicators—variables that are theoretically relevant [3,11,24]—were not available in a form that is comparably measured across FE-456, FE-498, and FE-549, and were therefore not included. Annual turnover serves as a partial proxy for financial capacity, given that the ability to absorb the upfront costs of resource efficiency improvements is one of the most consistently documented determinants of environmental management adoption in the SME literature [11,24]. NACE sector controls for between-sector heterogeneity in environmental pressure, supply-chain dependencies, and regulatory exposure. These two controls are the minimum set necessary to ensure that the estimated wave $\times$ size interactions are not confounded by cross-sector compositional differences or by the systematic correlation between firm size and turnover. Their inclusion does not exhaust the set of theoretically relevant confounders; the limitations section (Section 5.5) discusses the omitted variables that future designs with richer firm-level data could address.

Firm size is the primary moderating variable and is measured as a three-category classification: micro (1–9 full-time equivalent employees), small (10–49), and medium (50–249). The classification uses the consolidated categorical variable derived by the survey organisation from the directly reported employee count (scr10t in FE-456; scr10 in FE-498 and FE-549), which combines the open numeric response (SCR10a) and the bracketed follow-up (SCR10b) into a single harmonised category—an approach confirmed in the official codebook and verified against the raw employee count distributions.

Sector of activity (NACE section) is derived from the sector variable common to all three waves (nace_a) and grouped into three categories of our own choosing for parsimony: an industry/other reference category (NACE sections B, C, D, E, and F—mining, manufacturing, energy, water/waste, and construction—together with section J, information and communication), a retail category (NACE sections G and I—wholesale/retail trade and accommodation/food—together with section H, transportation and storage), and a services category restricted to sections K, L, and M (financial, real estate, and professional/technical activities). This grouping does not follow NACE section boundaries strictly: transportation and storage is grouped with retail rather than services, and information/communication is grouped with the reference category rather than services. Throughout the paper, this reference category is reported as ‘industry/other (NACE B–F and J)’ in table notes. Note that the survey sampling frame distinguishes manufacturing (NACE C) from the remaining industry strata (NACE B, D, E, F); these are combined in the regression model given small individual cell sizes within the SME sub-sample. A sensitivity with manufacturing as a separate category is reported in Appendix C.10. The questionnaire confirms that the NACE classification scheme is identical across all three waves. Sector is included as a control because SMEs operating in manufacturing, industry, and energy-intensive supply chains face systematically different levels of environmental pressure—from large-firm customers, regulators, and input cost structures—than those in retail or services [4,9]. Failing to control for sector would conflate the size effect with a sector

composition effect, since medium-sized enterprises are disproportionately concentrated in manufacturing and industry relative to microenterprises.

Annual turnover is used as a proxy for financial resources and is measured in six harmonised categories. FE-456 uses a coarser scale (six brackets from “ $\leq$ €100,000” to “ $>$ €50 million”) while FE-498 and FE-549 use a finer scale (nine brackets from “ $<$ €25,000” to “ $>$ €50 million”). The nine-bracket scale of FE-498 and FE-549 is collapsed to six categories matching the FE-456 brackets, with the three brackets genuinely below €100,000 (‘ $<$ €25,000’, ‘€25,000–€50,000’, and ‘€50,000–€100,000’) assigned to the ‘ $\leq$ €100,000’ reference category, and the two brackets between €100,000 and €500,000 (‘€100,000–€250,000’ and ‘€250,000–€500,000’) assigned to the ‘€100,000–€500,000’ second category. An error in the original pipeline erroneously placed the ‘€100,000–€250,000’ bracket in the reference category; this has been corrected and all reported estimates reflect the corrected mapping. A sensitivity using a broader $\leq$ €500,000 reference category immune to any residual bracket ambiguity is reported in Appendix C.11. This harmonisation preserves the comparability of the upper brackets, which are the most relevant for the size-adoption gradient of interest. Turnover is included as a proxy for financial capacity: the ability to absorb the upfront costs of resource efficiency investments—energy audits, equipment retrofits, waste management systems—is one of the strongest and most consistently replicated predictors of environmental management adoption in the SME literature [11,24]. More precise financial condition indicators (cash flow, debt-to-equity ratio, profitability) would be preferable theoretically but are not available in the Flash Eurobarometer microdata. Turnover captures the size-of-firm dimension of financial capacity while remaining distinct from the employee count variable that defines the main predictor of interest.

Firm age was considered as a control but is excluded from the main model because the bracket structure of the age variable (scr12b/scr12) shifts across waves as the calendar reference points are updated (e.g., “before 2010” in FE-456, “before 2014” in FE-498, “before 2016” in FE-549), making cross-wave comparisons on a harmonised age category unreliable without strong assumptions about the age distribution of the SME population. It is retained as a control in single-wave cross-sectional analyses where applicable.

Given the theoretical relationship between firm size and annual turnover—larger SMEs systematically tend to have higher revenues—we verified that their joint inclusion does not produce estimation problems due to multicollinearity. Variance Inflation Factor (VIF) statistics for all 15 predictors in the main model are reported in Appendix A.10. No predictor exceeds the conventional moderate-concern threshold of $VIF > 5$, and all are far below the severe multicollinearity threshold of $VIF > 10$. The maximum VIF is 4.409 for the Medium (50–249) size dummy, followed by Small (10–49) at 4.236. These values reflect a structural property of any specification that includes both main effects and their interaction terms—the firm size dummies share variance with the wave $\times$ size interactions that are their products, a form of essential collinearity that does not bias the interaction coefficients or distort inference. The elevated VIF for the size dummies also partly reflects the empirical correlation between size category and annual turnover. However, this correlation does not approach problematic levels: the turnover bracket dummies themselves show very low VIF values (1.168–1.909), confirming that turnover and size are correlated but not substitutable. The two variables capture conceptually distinct dimensions of firm capacity—size reflects organisational capacity (management depth, internal expertise, administrative infrastructure) while turnover proxies financial capacity (ability to absorb upfront investment costs)—and their joint inclusion is both theoretically justified and empirically tractable at the VIF levels observed. The central convergence estimands, Wave2021 $\times$ Medium and Wave2024 $\times$ Medium, have VIF values of 2.727 and 2.780, respectively, both well within acceptable bounds. Sector variables show very low VIF values

(1.123–1.129), confirming that the compositional overlap between sector and firm size does not create estimation problems.

3.3.3. Auxiliary Outcome Variables

Three additional outcome variables are used in the descriptive analysis (Section 4.1) and discussed in Section 5, but are not included as dependent variables in the main regression model:

- Investment intensity (Q4): ordinal variable recording the proportion of annual turnover invested in resource efficiency over the past two years, in six categories from “nothing” to “>30%”. Verified as strictly identical across all three waves at the item level.
- Green product/service offer (Q9): binary indicator (1 = currently offers green products or services; 0 = does not, with or without plans to do so). Verified as identical across all three waves.
- Perceived barriers (Q7): count of the number of barriers to resource efficiency adoption reported by the respondent, constructed from the eight items present in all three waves (items 1–8). Two additional items were introduced in subsequent waves—“complexity associated with environmental labelling and certification” (new in FE-498) and “complex environmental reporting requirements” (new in FE-549)—and are excluded from the cross-wave barrier index but retained as auxiliary variables for single-wave analyses in 2021 and 2024.

3.4. Analytical Strategy

The empirical strategy unfolds in two stages.

Stage 1: Descriptive analysis. Weighted percentages and means are computed separately for each wave and compared across time. These descriptive estimates are weighted using the EU27 weights described in Section 3.2, restricted to SMEs only, and presented for the EU27 aggregate as well as disaggregated by firm size category. The descriptive stage corresponds directly to the assessment of H1 (general trend) and of the descriptive expectation formulated in Observation 1 (barrier-adoption co-movement), neither of which requires parametric assumptions.

Stage 2: Multivariate regression. To test H2 (size gradient) and H3 (convergence of the size gradient), we estimate a Poisson regression model with the adoption index as the dependent variable. The Poisson specification is appropriate for count outcomes and imposes the constraint that $\text{Var}(Y) = E(Y)$ (equidispersion). This assumption was verified through a Negative Binomial sensitivity check (S3, Appendix C, Table A8), which estimated a dispersion parameter of $\alpha = 0.105$, indicating low overdispersion and confirming that the Poisson specification is adequate for these data. All coefficients are interpreted as incidence rate ratios ($\text{IRR} = \exp(\hat{\beta})$), representing the multiplicative change in expected adoption count associated with a unit change in the predictor.

The model specification is:

$$\log(E[Y_i]) = \beta_0 + \beta_1 W_{2021} + \beta_2 W_{2024} + \beta_3 S_{10-49} + \beta_4 S_{50-249} + \gamma' Z_i + \delta_1 (W_{2021} \times S_{50-249}) + \delta_2 (W_{2024} \times S_{50-249}) + \delta_3 (W_{2021} \times S_{10-49}) + \delta_4 (W_{2024} \times S_{10-49}) \quad (2)$$

where W_{2021} and W_{2024} are survey wave dummies (reference: 2017), S_{10-49} and S_{50-249} are firm size dummies (reference: micro, 1–9 employees), and Z_i is a vector of controls including NACE sector group dummies (reference: industry) and turnover bracket dummies (reference: $\leq \text{€}100\text{k}$). The interaction terms δ_1 – δ_4 are the quantities of central theoretical interest: a negative δ_2 or δ_1 indicates that the adoption advantage of medium-sized (or small) enterprises over microenterprises narrowed between 2017 and the

corresponding later wave. It should be noted that the wave $\times$ size interaction terms in this model estimate changes in size-class conditional means across independently drawn cross-sectional samples rather than within-firm trajectories over time. The coefficient on Wave2021 $\times$ Medium, for instance, estimates the difference between the 2021 and 2017 waves in the expected adoption count of medium-sized relative to micro enterprises, under the assumption that the three cross-sections are comparable population samples. It does not observe whether any individual firm adopted new practices between waves.

Standard errors are cluster-robust (sandwich estimator), clustered at the country level ($G = 27$ clusters, corresponding to the 27 EU Member States). Country-level clustering accounts for within-country correlations in resource efficiency behaviour driven by shared regulatory environments, economic conditions, and industrial structures. With $G = 27$ clusters and $N = 32,904$ observations, the sandwich estimator is consistent and is applied with the finite-sample correction factor $\frac{G}{G-1} \cdot \frac{N-1}{N-p}$ [35]. The model is estimated using weighted maximum likelihood with the EU27 weights from Section 3.2.

Nine pre-specified sensitivity analyses assess the robustness of the main findings to alternative analytical choices, reported in full in Appendix C and summarised in Section 4.3: (S1) replacement of the wave dummies with a continuous year variable; (S2) use of the within-country post-stratification weight ($w1_sme$) in place of the reconstructed EU27 weight; (S3) re-estimation under a Negative Binomial distribution; (S4) a country-level jackknife in which each of the 27 country clusters is excluded in turn; (S5) re-estimation on the EU28-inclusive sample retaining United Kingdom observations in the 2017 wave; (S7) re-estimation on a seven-item adoption index excluding the ‘selling residues/waste’ item, whose wording changed between FE-456 and FE-498/549 (Table A14); (S8) re-estimation with manufacturing (NACE C) as a separate sector category; (S9) re-estimation with a broader $\leq \text{€}500,000$ turnover reference category immune to bracket misclassification; and (S10) re-estimation on a PCA-weighted adoption index (Table A17). A further battery of four checks addressing the upper bound of the adoption index constitutes Sensitivity S6 (Section 4.4, Table A12). Three additional diagnostics address the coding of ‘don’t know’ responses (Appendix C.8).

4. Results

4.1. Descriptive Trends (2017–2024)

4.1.1. Resource Efficiency Practices: A Broad-Based Upward Shift

Table 1 presents the weighted prevalence of each of the eight resource efficiency practices in the common index, plus the “greener suppliers” item available only from 2021 onwards, for EU SMEs in each of the three survey waves.

Table 1. Weighted percentage of EU SMEs undertaking each resource efficiency practice, by survey wave (Q1, multiple response; EU27 weighted estimates).

Practice	2017	2021	2024	Δ 2017–2024
Minimising waste	65.3%	67.1%	70.2%	+4.8 pp
Saving energy	63.0%	64.5%	68.4%	+5.5 pp
Saving materials	56.8%	59.0%	59.5%	+2.8 pp
Saving water	47.0%	46.7%	50.6%	+3.6 pp
Recycling (internal)	41.6%	48.7%	50.7%	+9.1 pp
Designing for repairability	25.3%	27.7%	30.5%	+5.1 pp
Selling residues/waste †	21.0%	32.7%	30.8%	+9.8 pp †
Using renewable energy	13.8%	22.8%	29.1%	+15.3 pp
Greener suppliers (2021+ only)	n/a	35.2%	37.1%	n/a
None of the above	10.5%	6.6%	4.2%	−6.4 pp

† The wording of this item changed between 2017 (“selling your scrap material”) and 2021/2024 (“selling your residues and waste”), which may partly account for the apparent jump between those two waves. The 2017 estimate for this item should be interpreted with caution; see Section 3.3.1.

The data reveal a broad-based upward shift across all eight practices over the seven-year period. All seven practices with stable wording across waves increased in prevalence between 2017 and 2024. The eighth item, ‘selling residues/waste’, also records a net increase, but its wording changed between FE-456 (‘selling your scrap material’) and FE-498/549 (‘selling your residues and waste’); the anomalously large 2017–2021 jump (+11.7 pp) likely reflects the broader definition rather than genuine behavioural change, and the item declined slightly between 2021 and 2024 (32.7% → 30.8%). For the remaining seven items, the increase between 2017 and 2024 is unambiguous and monotone. The share of SMEs reporting no resource efficiency action fell by more than half—from 10.5% to 4.2%—a reduction of 60% in relative terms. This constitutes preliminary evidence in support of H1.

The magnitude of change varies considerably across practices; however, the pattern is not monotonic. Renewable energy adoption exhibited the largest absolute gain (+15.3 percentage points, from 13.8% to 29.1%), more than doubling over the period. Recycling also showed a substantial increase (+9.1 pp), driven primarily by the jump between 2017 and 2021. The two historically most common practices—minimising waste and saving energy—grew more modestly in absolute terms (+4.8 and +5.5 pp, respectively), consistent with an approaching saturation effect among practices that were already adopted by nearly two-thirds of SMEs in 2017. Saving materials and saving water—both in the 47–57% range in 2017—showed intermediate growth of 2.8–3.6 pp.

Renewable energy adoption grew strongly in both intervals, though at a decelerating rate (+9.0 pp in 2017–2021 vs. +6.3 pp in 2021–2024); recycling grew faster in the first interval (+7.1 vs. +2.0 pp), whereas energy saving and waste minimisation accelerated in the second (+1.5 vs. +3.9 pp and +1.8 vs. +3.1 pp, respectively). The aggregate index confirms this pattern: the mean weighted adoption count increased by 0.35 practices between 2017 and 2021 and by a further 0.21 practices between 2021 and 2024, with the slightly faster growth in the first interval coinciding with the early phase of the energy price shock, which was already driving European gas prices significantly higher by late 2021 when FE-498 was collected (Table 2).

Table 2. Distribution of the Resource Efficiency Adoption Index (0–8 common practices), by survey wave (EU27 weighted estimates, SMEs only).

	2017	2021	2024
Weighted mean	3.34	3.69	3.90
Median	3.0	4.0	4.0
Standard deviation	2.20	2.13	2.05
% scoring 0 (no actions)	10.5%	6.6%	4.2%
% scoring 1–3	33.8%	28.6%	25.3%
% scoring 4–6	36.5%	40.3%	42.6%
% scoring 7–8	19.2%	24.5%	27.9%

This slightly faster growth in the 2017–2021 interval is consistent with multiple concurrent forces—including the early diffusion of practices stimulated by the Green Deal framework, supply-chain reconfiguration in response to the COVID-19 pandemic and its economic aftermath, and the onset of the energy price shock in the second half of 2021—none of which can be separately attributed on the basis of the present data.

The distribution is shifting upward and compressing. The standard deviation of the index falls progressively from 2.20 to 2.05, and the proportion of SMEs scoring in the

upper range (7–8 practices) grows from 19.2% to 27.9%, while those in the lower range (0–3) decline from 44.3% to 29.5%. This rightward shift with decreasing variance is a signature of upward convergence within the SME population: a growing share of firms is approaching the practical ceiling of the index while the tail of non-adopters shrinks.

Table 3 disaggregates the adoption index by firm size. The descriptive gap between medium-sized enterprises and microenterprises narrows from 1.26 practices in 2017 (4.44 versus 3.18) to 0.56 practices in 2024 (4.21 versus 3.65), while the share of firms undertaking at least one practice rises in every size class and most markedly among microenterprises (87.3% to 92.1%). These are unadjusted contrasts that control for neither sector nor turnover; the population-level test of this convergence is presented in Section 4.2.4.

Table 3. Weighted Resource Efficiency Adoption Index and Share of Adopters, by Wave and Firm-Size Category (EU27-Strict Descriptive Sample).

Firm Size	Weighted Mean Adoption Index (0–8)			Weighted % with ≥ 1 Practice		
	2017	2021	2024	2017	2021	2024
Micro (1–9)	3.18	3.49	3.65	87.3%	88.5%	92.1%
Small (10–49)	3.54	3.70	4.00	89.7%	92.0%	94.8%
Medium (50–249)	4.44	4.09	4.21	94.9%	94.6%	96.6%

Note. N = 38,165 (EU27-strict; United Kingdom excluded from all three waves); EU27 population weights. ‘ ≥ 1 practice’ = weighted share of firms reporting at least one of the eight resource efficiency practices (i.e., not selecting ‘none’). Descriptive statistics; not adjusted for sector, turnover, or country composition (cf. the model-based predicted margins in Table A12, row 4, which control for these covariates and therefore show a smaller and more strictly monotone gap). The weighted mean index for medium-sized enterprises is not strictly monotonic across waves (4.44 $\rightarrow$ 4.09 $\rightarrow$ 4.21): it falls between 2017 and 2021 before partially recovering by 2024, remaining below its 2017 level. The share of adopters (≥ 1 practice), by contrast, is non-decreasing across all three size strata over the full period.

4.1.2. Investment Intensity, Green Market Offer, and Perceived Barriers

Investment in resource efficiency (Table 4) shows a sharp discontinuity between 2017 and 2021: the proportion of SMEs reporting zero investment fell from 30.6% to 18.7%—a drop of nearly 12 percentage points in a single inter-wave period—before stabilising at 19.7% in 2024. The proportion investing between 1% and 5% of annual turnover rose correspondingly (25.3% in 2017 to 30.7% in 2021). After 2021, the zero-investment rate plateaued, but growth in the higher investment tiers continued: the proportion investing more than 5% of turnover grew from 9.6% in 2017 to 12.9% in 2021 and 14.4% in 2024, with the share investing more than 30% nearly tripling over the full period (0.7% to 2.0%).

Table 4. Investment in resource efficiency as a proportion of annual turnover (Q4), by survey wave (EU27 weighted estimates, SMEs only).

Investment Level	2017	2021	2024
Nothing	30.6%	18.7%	19.7%
Less than 1% of turnover	24.7%	22.8%	23.0%
1–5% of turnover	25.3%	30.7%	29.9%
6–10% of turnover	7.0%	8.5%	9.0%
11–30% of turnover	1.9%	3.0%	3.4%
More than 30% of turnover	0.7%	1.4%	2.0%
Don’t know/not applicable	9.8%	14.9%	13.0%

Green product and service offer (Table 5) shows a large jump between 2017 and 2021 (+9.1 percentage points, from 24.5% to 33.6%) followed by a near- complete plateau

between 2021 and 2024 (33.2%). The proportion planning to offer green products in the next two years grew modestly (8.7% to 12.0%), while those with no plans declined substantially (62.7% to 50.8%). The gap between current adoption and planned adoption may foreshadow a new growth phase after 2024.

Table 5. Offer of green products or services (Q9), by survey wave (EU27 weighted estimates, SMEs only).

Response	2017	2021	2024
Yes, currently	24.5%	33.6%	33.2%
No, but planning to in next 2 years	8.7%	11.6%	12.0%
No, and not planning to	62.7%	50.9%	50.8%
Don't know	4.1%	3.9%	4.0%

Perceived barriers (Table 6) exhibit a pattern that runs counter to the adoption trend: the mean number of barriers reported by EU SMEs increased steadily from 1.69 in 2017 to 1.94 in 2021 and 2.09 in 2024, while the proportion reporting at least one barrier rose from 58.1% to 69.2% over the same period. This co-movement of adoption and barriers—consistent with the theoretically motivated expectation in Observation 1—is discussed in detail in Section 5.4.

Table 6. Perceived barriers to resource efficiency adoption (Q7, common 8-item index), by survey wave (EU27 weighted estimates, SMEs that have undertaken at least one resource efficiency action).

	2017	2021	2024
Mean number of barriers (0–8)	1.69	1.94	2.09
% reporting at least one barrier	58.1%	66.0%	69.2%
% citing administrative/legal complexity	26.1%	33.7%	35.2%
% citing cost of environmental actions	20.5%	24.3%	28.4%
% citing lack of environmental expertise	16.4%	19.8%	21.1%

Table 6 reports perceived barriers among SMEs that have already undertaken at least one resource efficiency action. This restriction is intentional: it isolates the sub-population whose direct experience of barriers during implementation is relevant to the theoretical mechanism. It should be noted that the broader adopting population expanded substantially over the period—from 89.5% of EU SMEs in 2017 to 95.8% in 2024—meaning that the composition of this sub-population changed as previously non-adopting firms entered the pool.

4.1.3. Composition of the Estimation Sample by Wave

Table 7 reports the distribution of the three independent variables—firm size category, sector, and turnover bracket—in the regression estimation sample ($N = 32,904$), disaggregated by wave. The table serves two purposes: it allows verification of compositional stability across waves, and it provides the numerical baseline against which the regression coefficients in Table 8 should be interpreted.

Table 7. Distribution of Independent Variables in the Regression Estimation Sample, by Wave (EU27-Strict, Corrected Turnover Harmonisation; Unweighted Counts and Column Percentages).

	2017 (N = 10,080)	2021 (N = 11,448)	2024 (N = 11,376)
Firm Size			
Micro (1–9 employees)	4458 (44.2%)	4965 (43.4%)	5033 (44.2%)
Small (10–49 employees)	3572 (35.4%)	4403 (38.5%)	4204 (37.0%)
Medium (50–249 employees)	2050 (20.3%)	2080 (18.2%)	2139 (18.8%)

	Sector		
Industry/other (NACE B–F, J)	3852 (38.2%)	4327 (37.8%)	4206 (37.0%)
Retail & hospitality (NACE G, H, I)	2622 (26.0%)	2958 (25.8%)	3035 (26.7%)
Services (NACE K–M)	3606 (35.8%)	4163 (36.4%)	4135 (36.3%)
	Annual Turnover		
≤€100,000	3145 (31.2%)	3307 (28.9%)	3162 (27.8%)
€100,000–€500,000	3032 (30.1%)	3446 (30.1%)	3446 (30.3%)
€500,000–€2M	2016 (20.0%)	2233 (19.5%)	2220 (19.5%)
€2M–€10M	1261 (12.5%)	1681 (14.7%)	1716 (15.1%)
€10M–€50M	481 (4.8%)	601 (5.2%)	629 (5.5%)
>€50M	145 (1.4%)	180 (1.6%)	203 (1.8%)

Note. Unweighted counts; column percentages in parentheses. Totals by wave: 2017 N = 10,080; 2021 N = 11,448; 2024 N = 11,376; pooled N = 32,904. The size-class composition is highly stable across waves (micro: 43.4–44.2%; small: 35.4–38.5%; medium: 18.2–20.3%), confirming that the wave × size interaction estimates are not driven by compositional change in size-class membership. Sector distribution is also stable across waves. The turnover distribution shows a modest shift toward higher brackets over the period (≤€100k share: 31.2% → 27.8%), consistent with nominal revenue growth in the SME population. The wave × size composition is also reported in Appendix A.8 Table A1 Panel B with EU27 population-weighted estimates. Sector categories are analytical groupings of our own choosing for regression parsimony rather than a partition specified in the survey’s sampling frame; the ‘Retail & hospitality’ category additionally includes transportation and storage, and the ‘Industry/other’ category additionally includes information and communication (see Section 3.3.2 for the exact NACE composition and rationale).

The size-class composition is highly stable: the micro share ranges from 43.4% to 44.2% across waves (a variation of 0.8 percentage points), the small share from 35.4% to 38.5% (3.1 pp), and the medium share from 18.2% to 20.3% (2.1 pp). This stability confirms that the wave × size interaction estimates are not driven by compositional change in size-class membership between waves.

The sector distribution is also broadly stable across waves, with industry/manufacturing accounting for approximately 37–39% of the estimation sample, retail and hospitality for 25–27%, and services for 35–37%. Minor wave-to-wave variation reflects sampling rather than structural change in the EU SME sector composition.

The turnover distribution shows a modest shift toward higher brackets over the study period: the share of firms in the ≤€100,000 reference category falls from 31.2% in 2017 to 27.8% in 2024, while the share in the two upper brackets (>€10M) increases slightly. This upward shift is consistent with nominal revenue growth in the SME population over the period and does not represent compositional selection of a qualitatively different sample.

4.2. Main Model: Poisson Regression Results

4.2.1. Full Model Estimates

Table 8 presents the estimates of the Poisson regression model described in Section 3.4 (a full coefficient table with all turnover brackets and 95% confidence intervals is in Appendix B). The model is estimated on N = 32,904 observations (the 38,165 pooled observations minus 74 respondents with unknown employee count, who are retained in the descriptive analyses but excluded here as firm size is a required regressor, and minus 5187 respondents with missing turnover category; NACE sector information is complete across all three waves with zero missing) across G = 27 country clusters. Coefficients are reported alongside cluster-robust standard errors, z-statistics, two-tailed p-values, and incidence rate ratios (IRR = $\exp(\beta)$).

Table 8. Weighted Poisson Regression of the Resource Efficiency Adoption Index on Wave, Firm Size, Sector, Turnover, and Wave $\times$ Firm-Size Interactions (EU27-Strict Main Specification).

Predictor	β	Cluster SE	z	p	IRR
Intercept	1.100	0.053	20.63	<0.001	3.004 ***
Wave2021	0.081	0.070	1.15	0.249	1.084
Wave2024	0.104	0.045	2.29	0.022	1.109 *
Small (10–49)	0.052	0.037	1.42	0.154	1.053
Medium (50–249)	0.243	0.071	3.44	<0.001	1.275 ***
Sector: Retail	−0.008	0.023	−0.33	0.740	0.992
Sector: Services	−0.168	0.050	−3.34	<0.001	0.846 ***
Turnover €100k–500k	0.132	0.039	3.36	<0.001	1.141 ***
Turnover €500k–2M	0.189	0.049	3.88	<0.001	1.208 ***
Turnover €2M–10M	0.167	0.059	2.83	0.005	1.182 **
Turnover €10M–50M	0.396	0.119	3.33	<0.001	1.487 ***
Turnover >€50M	0.045	0.149	0.30	0.765	1.046
Wave2021 $\times$ Small	−0.057	0.041	−1.39	0.165	0.945
Wave2021 $\times$ Medium	−0.208	0.059	−3.55	<0.001	0.812 ***
Wave2024 $\times$ Small	−0.022	0.041	−0.55	0.584	0.978
Wave2024 $\times$ Medium	−0.197	0.044	−4.50	<0.001	0.821 ***

Note. N = 32,904; G = 27 country clusters (EU27-strict; United Kingdom excluded from all three waves). Weighted Poisson regression (log link); EU27 population weights (official w23 for FE-456; reconstructed from Eurostat SME population shares for FE-498 and FE-549); cluster-robust standard errors by country with finite-sample correction (G−1 degrees of freedom). Turnover brackets corrected: the ‘€100,000–€250,000’ bracket of FE-498 and FE-549 has been reassigned from the reference category to the ‘€100,000–€500,000’ category; all estimates reflect this corrected harmonisation. IRR = incidence-rate ratio = $\exp(\beta)$. Bold rows are the central convergence estimates. Weighted log-likelihood = −21,785.92. Reference categories: firm size = micro (1–9 employees); wave = 2017; sector = industry/other (NACE B–F and J); turnover = $\leq$ €100,000. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

4.2.2. Testing H1: General Upward Trend

The wave dummy coefficients capture the temporal trend in resource efficiency adoption for the reference firm (micro-sized, industry sector, $\leq$ €100k turnover). The Wave2021 coefficient is positive ($\beta = 0.081$, IRR = 1.084) but does not reach conventional significance thresholds ($p = 0.249$), indicating that the adoption increase among microenterprises between 2017 and 2021 was modest relative to between-country variability. The Wave2024 coefficient, however, is positive and significant ($\beta = 0.104$, IRR = 1.109, $p = 0.022$), indicating that by 2024 the expected adoption count for a reference microenterprise was 10.9% higher than in 2017. The descriptive evidence in Table 1 corroborates this: all eight common practices show higher prevalence in 2024 than in 2017, and the “none” category halved from 10.5% to 4.2%.

H1 is therefore partially supported: the trend reaches statistical significance in the model only over the full seven-year span (2017 to 2024), not at the intermediate 2021 wave for the smallest reference firms, and—as detailed below—its model-based confirmation does not survive the within-country weighting criterion specified in Section 2. Disaggregated by firm size (Table 3), the descriptive evidence is similarly mixed: the weighted share of firms adopting at least one practice rose in all three size strata, but the raw weighted mean index for medium-sized enterprises did not increase monotonically, falling from 2017 to 2021 before only partially recovering by 2024.

A second and more fundamental qualification is warranted regarding the sensitivity of this finding to the weighting scheme. As documented in Section 3.2.2 and confirmed in Sensitivity S2 (Table A7), the wave main effects lose statistical significance when the within-country post-stratification weight ($w1_sme$) is substituted for the reconstructed EU27 population weight. H1 should therefore be interpreted as indicative rather than confirmatory: the descriptive evidence of a broad-based upward shift across all eight practices (Table 1) is robust and unambiguous, but the model-based test of aggregate temporal significance depends on a weighting choice that is not fully resolved by the available micro-data infrastructure.

4.2.3. Testing H2: Size Gradient

The coefficients on the size dummies in the 2017 reference year confirm the existence of a significant positive size gradient in resource efficiency adoption. Medium-sized enterprises adopted 27.5% more practices than comparable microenterprises in 2017 ($IRR = 1.275$, $p < 0.001$). The advantage of small enterprises (10–49 employees) over microenterprises is smaller ($IRR = 1.053$) and not statistically significant ($p = 0.155$). Both the sign and significance of these effects replicate findings from the existing literature and validate the 2017 cross-sectional baseline of our panel.

The positive gradient for turnover is also consistent with expectations: firms with annual revenues above €100k adopt more practices than otherwise identical firms below that threshold, with the gradient broadly increasing—though not strictly monotone—across revenue brackets, peaking at an IRR of 1.487 for firms with revenues between €10M and €50M. The services sector penalty is significant and substantively meaningful ($IRR = 0.846$, $p < 0.001$), confirming that resource-intensive practices such as water and material saving, waste minimisation, and recycling are inherently less applicable to service firms than to manufacturers.

H2 is confirmed.

4.2.4. Testing H3: Population-Level Convergence of the Size Gradient

The interaction terms between wave dummies and size categories are the central estimates of the paper. Both interactions between medium-sized enterprises and the later survey waves are negative, statistically significant, and of similar magnitude:

Wave2021 $\times$ Medium: $\beta = -0.208$, $IRR = 0.812$, $p < 0.001$

Wave2024 $\times$ Medium: $\beta = -0.197$, $IRR = 0.821$, $p < 0.001$

These coefficients indicate that the adoption advantage of medium-sized enterprises over microenterprises shrank significantly between 2017 and 2021 and remained comparably compressed in 2024. To interpret the magnitude in substantive terms: in 2017, the expected adoption count for a medium-sized firm was 27.5% higher than for an otherwise identical microenterprise ($IRR = 1.275$). By 2021 and 2024, that combined effect (main size effect $\times$ interaction) amounts to:

$$IRR_{medium,2021} = \exp(0.243 - 0.208) = \exp(0.035) = 1.036 \quad (3)$$

$$IRR_{medium,2024} = \exp(0.243 - 0.197) = \exp(0.046) = 1.047 \quad (4)$$

The size gap in resource efficiency adoption thus narrowed from +0.89 practices in 2017—measured as the model-predicted difference in adoption between size categories at the population-weighted means of the remaining covariates (Table A12, row 4)—to a statistically non-significant +0.13 practices in 2021 and +0.17 practices in 2024, a reduction of 81% relative to the original gap. Expressed in model-estimated multiplicative terms, the IRR for medium-sized enterprises relative to microenterprises narrowed from 1.275 in 2017 to a statistically non-significant 1.036 in 2021 (95% CI [0.939, 1.144], $p = 0.482$) and

1.047 in 2024 (95% CI [0.946, 1.159], $p = 0.374$) (Table A5). Medium-sized firms retain a small residual advantage over microenterprises, but it is no longer statistically distinguishable from zero at conventional significance levels.

The parallel interactions for small enterprises (10–49 employees) are not significant in either wave (Wave2021 $\times$ Small: $p = 0.165$; Wave2024 $\times$ Small: $p = 0.584$). This indicates that small enterprises followed the same temporal trajectory as microenterprises, with no significant compression of their—already modest and marginally significant—size advantage relative to microfirms.

H3 is confirmed for medium-sized enterprises and not supported for small enterprises.

4.3. Robustness Checks

The robustness checks reported in this section assess the statistical stability of the estimated coefficients across alternative model specifications, distributional assumptions, weighting schemes, and sample compositions. They establish that the Wave $\times$ Medium interaction estimates are not artefacts of specific methodological choices. They do not, and are not designed to, validate the causal interpretation of the temporal patterns: distinguishing the effects of the Green Deal, the CSRD, and the energy shock from one another and from secular diffusion trends would require an identification strategy—such as firm-level measures of regulatory exposure, country-level variation in policy implementation intensity, or a quasi-experimental design—that the Flash Eurobarometer data do not support. This limitation is discussed in Section 5.5.

Table 9 summarises the key interaction coefficients across the main sensitivity analyses described in Section 3.4; the complete set is reported in Appendix C (S1–S5 and S7–S10 summarised in Table A10; S6 in Table A12).

Table 9. Key interaction coefficients under alternative specifications (Wave $\times$ Medium size; reference: microenterprises in 2017).

Specification	Wave2021 $\times$ Medium	p	Wave2024 $\times$ Medium	p
Base model (EU27-strict)	−0.208	<0.001	−0.197	<0.001
S1: Continuous year trend †	—	—	−0.237 ‡	<0.001
S2: Within-country weight (w1_sme)	−0.202	0.002	−0.164	0.005
S3: Negative Binomial 2	−0.208	<0.001	−0.198	<0.001
S4: Jackknife max (excl. Germany)	−0.164	0.015	−0.169	0.004
S5: EU28-inclusive (UK in 2017)	−0.208	<0.001	−0.197	<0.001

Note. † In S1, wave dummies are replaced by a continuous year variable scaled to [0, 1]; the coefficient reported is year_c $\times$ Medium (−0.237, IRR = 0.789), capturing the linear compression of the size gap over the full 2017–2024 span. ‡ Single coefficient capturing both periods jointly. The S4 row reports the leave-one-out specification excluding Germany, the country producing the maximum deviation from the base model ($\Delta = 0.044$). Full tables, including S6–S10, are reported in Appendix C (summary in Table A10).

The main findings are highly consistent across the five specifications summarised in Table 9 (the full set S1–S10 is reported in Appendix C). The Wave $\times$ Medium interaction is negative and statistically significant ($p \leq 0.015$) in every model. The magnitude varies only moderately across specifications. In S5 (EU28-inclusive, UK retained in 2017), the interaction estimates are identical to the main model (Wave2021 $\times$ Medium: −0.208; Wave2024 $\times$ Medium: −0.197); after correcting the turnover bracket harmonisation, the apparent discrepancy between the EU27-strict and EU28-inclusive specifications disappears entirely, confirming that it was an artefact of the miscoding rather than a genuine effect of UK inclusion. S1 (continuous year trend) yields a single interaction coefficient of −0.237

(IRR = 0.789, $p < 0.001$), capturing the full 2017–2024 linear compression of the size gap. S2 (within-country weight without cross-country rebalancing) reveals a differential pattern: the Wave $\times$ Medium interaction coefficients remain negative and significant (Wave2021 $\times$ Medium: IRR = 0.818, $p = 0.002$; Wave2024 $\times$ Medium: IRR = 0.849, $p = 0.005$), confirming the robustness of the convergence finding. The wave main effects, however, lose statistical significance under this specification (Wave2021: $p = 0.975$; Wave2024: $p = 0.365$), indicating that the aggregate temporal trend in adoption is sensitive to the cross-country rebalancing embedded in the reconstructed EU27 weight. This asymmetry reflects the fact that the *w1_sme* weight gives greater relative influence to smaller EU member states, whose adoption trajectories differ from those of the large-population countries (Germany, France, Italy, Spain) that dominate the EU27 aggregate under the main weighting scheme. S3 confirms that the equidispersion assumption of the Poisson model is not binding: the Negative Binomial estimates are virtually identical to the Poisson baseline, with a dispersion parameter of $\hat{\alpha} = 0.105$ that lies close to zero. S4 establishes that no single country is driving the result: The maximum shift in the interaction coefficients when any country is excluded from the sample is 0.044 points (when Germany is excluded), and even in that extreme case both interactions remain negative and significant ($p = 0.015$ and $p = 0.004$); both interactions are significant at $p < 0.05$ in all 27 leave-one-out specifications; at $p < 0.01$, 25 of 27 reach significance, with Germany and Spain—the two countries producing the largest shifts—being the only exceptions. The stability of the size-class composition of the estimation sample across waves—documented in Appendix A.8 Table A1 Panel B, where the micro share varies by at most 0.8 percentage points across the three waves—rules out compositional change in size-class membership as a driver of the observed wave $\times$ size interaction pattern.

An additional sensitivity including wave $\times$ sector interaction terms—testing whether the aggregate temporal increase in adoption differed systematically across the three sector groups—yields non-significant wave $\times$ sector interactions, indicating that the temporal trend does not vary materially by broad sector category. Detailed results are available from the corresponding author upon reasonable request.

The population-level gap compression between medium-sized enterprises and microenterprises in resource efficiency adoption is therefore a robust empirical finding, not an artefact of the analytical choices made in the main specification.

4.4. Robustness to the Upper Bound of the Adoption Index

The bounded nature of the Resource Efficiency Adoption Index (range 0–8) raises the possibility that the observed narrowing of the medium–micro gap is a mechanical artefact of the scale rather than a substantive convergence process. We address this concern with four complementary checks (Sensitivity S6), reported in Table A12.

First, rescaling the index to the $[0, 1]$ interval (index / 8) leaves the interaction estimates unchanged—Wave2021 $\times$ Medium = -0.208 (IRR = 0.81) and Wave2024 $\times$ Medium = -0.197 (IRR = 0.82)—as expected from the scale-invariance of the log-link Poisson model. Second, a bounded fractional-response model (Papke–Wooldridge, GLM with Binomial family and logit link) that explicitly constrains the conditional mean within $[0, 1]$ yields negative and significant average marginal effects for both interactions (Wave2021 $\times$ Medium: AME = -0.096 , 95% CI $[-0.152, -0.041]$; Wave2024 $\times$ Medium: AME = -0.089 , 95% CI $[-0.136, -0.043]$), ruling out a mechanical ceiling as the driver of the result. Third, item-level logistic regressions estimated separately for each of the eight binary practices show negative wave $\times$ medium interactions for all eight practices in both waves, with five of eight reaching $p < 0.05$ in 2021 and four of eight in 2024; convergence is broadly distributed rather than concentrated in near-saturated items. Fourth, predicted margins from the base model show that the expected medium – micro gap in absolute units falls from +0.89

practices in 2017 to +0.13 in 2021 and +0.17 in 2024—a reduction of 81%—while the expected adoption count for medium-sized firms never exceeds 5.3 of the 8 possible practices, confirming that substantial headroom remained throughout the period.

Taken together, these checks establish that the convergence is substantive rather than mechanical. Medium-sized enterprises began the period at 51.5% of the maximum index value (4.12 of 8 practices in 2017), well below any reasonable saturation threshold, and the narrowing of the size gap persists under all specifications that account for the bounded nature of the outcome.

5. Discussion

5.1. A Generalised Upward Trend in Resource Efficiency Adoption

The first and most straightforward finding of this study is that resource efficiency adoption among European SMEs increased substantially between 2017 and 2024. The share of EU SMEs undertaking no resource efficiency action at all fell from 10.5% to 4.2%—a compression of the non-adopter tail that is difficult to attribute to measurement artefact, given that the item-level wording of the ‘none’ response option is identical across all three waves and the directional consistency extends to all seven practices with stable wording (the eighth item, selling residues/waste, also shows a net increase, but its 2017 wording change precludes a strict trend comparison; Section 3.3.1. This finding is broadly consistent with the diffusion of innovations framework [20]: the SME population is traversing an S-curve of environmental practice adoption, and the period 2017–2024 appears to coincide with the steepest portion of that curve for practices that were previously confined to a minority of firms (renewable energy, recycling, designing for repairability), while the most established practices (minimising waste, saving energy) are approaching saturation with more modest marginal gains. This pattern of broad-based upward trend is consistent with, but stronger than, the cross-sectional benchmarks available from prior EU studies. Carfora et al. [15], using the same FE-456 2017 wave that serves as our baseline, documented adoption patterns consistent with our weighted 2017 estimates, under which 89.5% of EU SMEs report at least one resource efficiency action. The near-doubling of renewable energy adoption (from 13.8% to 29.1%) is broadly consistent with the rapid deployment trends documented by the IEA [10] and IRENA [36] for the residential and commercial small-scale sector, though direct comparisons are complicated by differences in measurement. What the present study adds beyond these benchmarks is a longitudinal dimension: the cross-sectional studies establish what the baseline was, but cannot tell us whether the aggregate level was rising or stable; our three-wave design shows clearly that the 2017 baseline was not a steady state but a point on a steeply rising trend.

The temporal profile of change, however, is not uniform and suggests that more than a single mechanism is at work. The sharpest discontinuity in investment intensity occurs between 2017 and 2021—the proportion of SMEs investing nothing in resource efficiency fell by nearly 12 percentage points in that interval, compared to a near-plateau thereafter—while practice adoption continued to increase at a broadly comparable rate in both inter-wave periods. This asymmetry is consistent with the interpretation that the early phase of the energy price shock—already underway by late 2021 when FE-498 was collected, and subsequently amplified by the Russian invasion of Ukraine in February 2022 and the 2022 price peak—acted as a catalyst for investment decisions that had previously been deferred, without necessarily translating into a proportional acceleration of actual practice change (which may follow investment with a lag). The IEA [10] documented that small businesses in Europe faced disproportionate exposure to spot energy prices relative to large firms with longer-term hedging contracts, making energy cost management suddenly financially urgent for firms that had previously treated it as a secondary concern. The abrupt change in investment behaviour we observe between 2017 and 2021 is

consistent with this reading, although our cross-sectional design does not permit causal attribution.

Renewable energy adoption stands out as the fastest-growing practice over the full period (+15.3 pp, from 13.8% to 29.1%), with both inter-wave intervals contributing substantially (+9.0 pp between 2017 and 2021, +6.3 pp between 2021 and 2024). This growth is likely associated with the convergence of multiple forces: falling costs of solar photovoltaic technology [36], national subsidy schemes associated with the REPowerEU plan, and the broader reputational and commercial incentive to signal green credentials to customers and public procurement bodies. The fact that renewable energy started from the lowest baseline (13.8%) among all eight practices in 2017 also means it had the most headroom for absolute growth, consistent with the diffusion argument.

5.2. The Narrowing Size Gap: Microenterprises Catching Up

The central finding of this study—that the resource efficiency adoption gap between medium-sized and microenterprises compressed by 81% between 2017 and 2024 (from a model-predicted advantage of 0.89 practices for medium-sized firms to a statistically non-significant residual of +0.13 practices in 2021 and +0.17 practices in 2024; Table A12)—merits careful interpretation, both as to its mechanisms and its boundary conditions. The empirical design identifies that this population-level gap compression occurred but cannot establish which mechanisms produced it: the survey contains no firm-level measures of supply-chain pressure, financing constraints, managerial capabilities, or policy awareness, and the repeated cross-sectional structure does not permit causal attribution to any specific channel. The three mechanisms discussed below—regulatory cascade, energy price incentive, and diffusion catch-up—should therefore be read as theoretically motivated interpretations consistent with the observed temporal pattern rather than as conclusions the data confirm.

The theoretical framework advanced in Section 2.3 identified three mechanisms that should produce this convergence. Our data allow a partial, indirect evaluation of each.

Before examining each mechanism, it is worth situating the central finding—an over-80% compression of the medium-micro adoption gap—in the context of what prior studies established about the size gradient. Carfora et al. [15] found that firm size category was among the two strongest predictors of resource efficiency adoption in the 2017 Flash Eurobarometer, with medium-sized enterprises significantly outperforming microenterprises after controlling for sector, country, and green job intensity. Our 2017 baseline replicates this finding directly: medium-sized enterprises adopted 27.5% more practices than microenterprises ($IRR = 1.275, p < 0.001$), equivalent to a model-predicted gap of 0.89 practices (Table A12). Aragón-Correa et al. [3] and Lepoutre and Heene [16] reviewed the broader SME environmental management literature and consistently found that larger SMEs outperform smaller ones, documenting effects that these authors attributed to differences in financial resources, managerial capacity, and regulatory exposure. The RBV and institutional theory frameworks underlying those reviews would predict that such gaps are persistent—driven by structural properties of firm scale—rather than subject to rapid compression under external pressure. Our finding that the gap essentially closed to statistical non-significance by 2021 (combined $IRR = 1.036, p = 0.482$) and remained closed in 2024 ($IRR = 1.047, p = 0.374$) constitutes a direct empirical challenge to the structural stability assumption implicit in those cross-sectional accounts.

The regulatory cascade mechanism predicts that the extension of sustainability reporting requirements down the supply chain—via the CSRD and related Green Deal instruments—should have disproportionately increased adoption pressure on smaller firms that were previously below the regulatory radar. This mechanism is consistent with the timing of convergence: the gap narrows sharply between 2017 and 2021, just as the

European Green Deal (2019) and the Circular Economy Action Plan (2020) were being embedded into national policy frameworks and supply-chain pressure on SME suppliers was beginning to be anticipated, and it remains compressed (rather than reverting) in 2024, when the CSRD's first reporting obligations were beginning to materialise. It is also consistent with the sector pattern in our data: the services sector—where supply chain dependencies are typically shorter and value chain pressure from large regulated firms is less direct—shows a significantly lower adoption level overall (IRR = 0.846), a pattern consistent with—though not conclusive for—the cascade mechanism operating through manufacturing and retail supply chains rather than primarily through service sector dependencies. We emphasise that this consistency is correlational: the data cannot rule out that the same temporal pattern would have occurred absent the Green Deal, driven instead by secular diffusion dynamics, by COVID-19-related operational reconfiguration, or by other concurrent forces.

Two pieces of indirect mechanism-relevant evidence can be extracted from the available data, though neither constitutes a test of the underlying mechanism. First, if the regulatory cascade were operating primarily through supply-chain pressure confined to manufacturing and industry sectors—where value-chain dependencies on large regulated firms are most intense—the convergence should be more pronounced in the industry stratum than in services. The sector coefficients in Table 8 confirm that services SMEs have substantially lower baseline adoption (IRR = 0.846, $p < 0.001$), but the wave $\times$ size interaction terms do not show materially different convergence patterns across sector groups, suggesting that if a cascade mechanism is operating, it extends beyond manufacturing supply chains. Second, the barrier evolution documented in Section 4.1.2 provides indirect evidence on the capability mechanism. If the convergence were primarily driven by microenterprises overcoming structural capability deficits, we would expect expertise-related barriers to decline most rapidly. Instead, the most rapidly growing barriers are administrative and legal complexity (+9.1 pp) and cost of environmental actions (+7.9 pp), while lack of expertise grew more modestly (+4.7 pp). This pattern is more consistent with a growing regulatory burden generating new compliance requirements than with a closing of intrinsic capability gaps between size classes. Both observations are consistent with the cascade and regulatory burden mechanisms but cannot confirm or rule out alternative explanations.

The investment data are consistent with the energy price shock mechanism. The jump in investment between 2017 and 2021 is concentrated at the lower end of the investment distribution: the proportion investing nothing fell by 12 pp, while the upper tail grew more modestly. If the shock affected microenterprises with greater urgency—due to their typically lower hedging capacity and higher reliance on direct energy inputs, as documented by the IEA [10]—the expected first response would be precisely what we observe—a shift from 'zero investment' to 'some investment' in the most basic energy-saving measures. This remains a theoretical inference rather than an empirical finding of the present study. The investment discontinuity is consistent with this mechanism even though the two most prevalent practices (minimising waste and saving energy) recorded their larger absolute gains in the 2021–2024 interval (+3.1 and +3.9 pp, versus +1.8 and +1.5 pp in 2017–2021)—a lag pattern compatible with investment decisions taken during the early phase of the price rise translating into reported practice change only by the subsequent wave, although the present design cannot verify this sequencing at the firm level.

The diffusion catch-up mechanism receives support from the data, but not through a ceiling effect operating mechanically on the bounded index. A dedicated battery of robustness checks (Section 4.4, Table A12) confirms that medium-sized enterprises began the period at approximately 52% of the maximum index value—well below any saturation threshold—and that the convergence persists under four specifications that explicitly

account for the upper bound of the scale. The catch-up is therefore substantive: microenterprises adopted practices faster in absolute terms not because medium-sized firms were running out of room, but because the diffusion frontier was advancing more rapidly among the smaller, previously less-engaged segment of the SME population. This interpretation is consistent with the item-level evidence: the convergence is broadly distributed across all eight practices rather than concentrated in those where medium-sized firms were near-saturated.

Disentangling these three mechanisms with the available data is not possible, and this constitutes one of the study's principal limitations (see Section 5.5). What the data do establish is the net result: a robust, substantial, and temporally stable compression of the size gradient that is consistent with all three mechanisms operating simultaneously rather than being driven by any one of them in isolation.

An important boundary condition concerns the small enterprise category (10–49 employees). The interaction terms for Wave $\times$ Small are not statistically significant in either period (Wave2021 $\times$ Small: $p = 0.165$; Wave2024 $\times$ Small: $p = 0.584$), indicating that small firms followed essentially the same temporal trajectory as microenterprises rather than converging from a separate position. This null finding is itself informative: it suggests that the convergence dynamic is specifically a medium-to-micro phenomenon, and that the 10–49 employee segment—which already occupied an intermediate position between micros and mediums in 2017, with only a modest and statistically non-significant advantage (IRR = 1.053, $p = 0.155$)—did not undergo differential acceleration. One possible interpretation is that small enterprises already face many of the same institutional pressures as medium-sized ones (for instance, they are more likely than microenterprises to participate in formal supply chains and to be subject to customer environmental audits), but this remains speculative without firm-level panel data to identify the specific pressure channels.

5.3. Investment and Green Market Offer: Different Temporal Structures

Two of our auxiliary outcome variables exhibit temporal patterns that diverge from the main adoption index in theoretically interesting ways.

Investment in resource efficiency (Q4) follows a threshold-and-plateau pattern: the most dramatic change occurs between 2017 and 2021 (the “nothing” category falls from 30.6% to 18.7%), with only marginal further change in the “nothing” category between 2021 and 2024 (18.7% to 19.7%). This discontinuity is the sharpest temporal break we observe in any outcome variable and maps most directly onto the period of the energy price shock, suggesting that the shock converted a large cohort of non-investing firms into investors in a single inter-wave period. After 2021, the growth in investment is concentrated in the upper tail (investment $>5\%$ of turnover grows from 12.9% to 14.4%), suggesting that the easy gains—the conversion of non-investors—have been largely exhausted, and that continued growth in aggregate investment intensity now depends on deepening investment among firms already committed to resource efficiency. This distinction between extensive margin (more firms investing at all) and intensive margin (existing investors investing more) has implications for policy design: instruments targeting the extensive margin (awareness raising, subsidies with low entry thresholds, energy audits) appear most relevant before 2021, while instruments targeting the intensive margin (investment tax credits, access to green finance, technical assistance for scaling up) may be more impactful in the current phase.

Green product and service offer (Q9) follows a structurally different pattern: a large jump between 2017 and 2021 (+9.1 pp, from 24.5% to 33.6%) followed by near-complete stabilisation between 2021 and 2024 (33.2%). This plateau is notable given that internal resource efficiency practices continued to grow over the same period. One possible interpretation is that the offer of green products is more demand-constrained than the adoption

of internal practices: a firm can implement energy-saving or waste-reduction measures without needing a corresponding change in its customer base, but offering a green product requires confident anticipation of market demand for it. The stabilisation of green product offer between 2021 and 2024 may therefore reflect the limits of current consumer demand and public procurement capacity for green SME products, rather than a supply-side constraint on SMEs themselves. The growing proportion of SMEs “planning” to offer green products (from 8.7% in 2017 to 12.0% in 2024) is consistent with a pipeline that may translate into another wave of adoption once demand conditions improve—an interpretation that future waves of the Eurobarometer survey will be able to test.

5.4. Rising Barriers Alongside Rising Adoption: A Paradox Explained

The simultaneous increase in resource efficiency adoption and perceived barriers over 2017–2024 requires explanation, as it superficially appears contradictory: if SMEs are adopting more practices, why do they report more obstacles to doing so?

The evidence is consistent with the two-mechanism theoretical resolution advanced in Section 2.4. The first mechanism—selection into the barrier-perception population—implies that barriers are only visible to firms actively attempting to adopt, so an expanding adoption frontier mechanically increases aggregate barrier reports. The second mechanism—regulatory complexity growth—implies that the set of obstacles SMEs face has itself expanded, coinciding with new reporting and certification requirements. Both mechanisms receive empirical support.

The selection mechanism is evidenced by the composition of barrier reporters: in all three waves, firms reporting at least one barrier overlap almost entirely with firms that have also adopted at least one practice (the Q7 barrier question is routed to firms that responded affirmatively to at least one item in Q1). As the proportion of adopting firms grows from 89.5% (2017) to 95.8% (2024), the denominator for barrier perception grows correspondingly. Even if the conditional probability of encountering a barrier given that one is attempting to adopt remained constant, the unconditional prevalence of barrier reports in the full SME population would increase.

The evolution of the survey instrument itself is consistent with a genuine expansion of regulatory complexity: the questionnaire added ‘complexity associated with environmental labelling and certification’ as a new barrier item in 2021, and ‘complex environmental reporting requirements’ in 2024. The fact that the European Commission’s research unit deemed these additions necessary in successive waves suggests that regulatory burden was expanding in ways that respondents were encountering in practice, though this inference rests on the instrument’s design decisions rather than on the survey responses themselves. Consistent with this, the most rapidly growing specific barriers in our data are administrative/legal complexity (+9.1 pp, from 26.1% to 35.2%) and cost of environmental actions (+7.9 pp, from 20.5% to 28.4%), while the more “structural” barriers such as lack of expertise grew more modestly (+4.7 pp). This pattern is consistent with growing regulatory load rather than a decline in intrinsic organisational capacity. This interpretation aligns with findings from Revell et al. [13] and Testa et al. [8], who documented that SMEs frequently cite administrative complexity and cost as primary barriers to environmental action and noted that the barrier landscape tends to expand as regulatory requirements evolve. However, those studies were conducted in single-country contexts (the UK and Italy, respectively) and at a single point in time, making it impossible to assess whether barriers were growing or stable. Our three-wave data provide the first repeated cross-sectional evidence that the aggregate barrier burden—measured consistently across all EU27 member states—grew systematically over the 2017–2024 period, with the largest increases concentrated in the administrative complexity category rather than in capability or finance barriers.

Taken together, these results suggest that the Green Deal regulatory environment has simultaneously accelerated adoption—by raising the reputational and commercial costs of non-adoption and by transmitting urgency through supply chains—and increased perceived friction—by adding new compliance requirements on top of those already in place. This dual dynamic is not unique to SMEs: the same interplay between expanding regulatory ambition and growing compliance burden has been documented in the context of large-firm environmental management [4,8]. What distinguishes SMEs is the proportionally higher cost of compliance relative to organisational capacity, which makes the barrier-adoption co-movement sharper and politically more significant.

5.5. Limitations

Several limitations constrain the inferences that can be drawn from this study.

Cross-sectional identification. The repeated cross-sections design, while adequate for documenting population-level trends, does not permit causal identification of the mechanisms driving convergence. In particular, we cannot distinguish whether the compression of the size gap reflects genuine within-firm learning and catch-up among microenterprises, composition effects (the exit of non-adopting microenterprises and entry of greener ones changing the mean adoption in that size category without any individual firm improving), or cohort replacement. Specifically, the observed narrowing of the size gap is observationally consistent with at least three distinct micro-level processes that the design cannot separate: (a) genuine within-firm adoption by microenterprises that were not adopting in 2017 but were doing so by 2021 or 2024; (b) compositional change in the microenterprise stratum, whereby lower-adoption firms exited and were replaced by higher-adoption entrants between waves; and (c) cohort replacement, whereby a new generation of microenterprises with higher baseline environmental engagement entered the population over the period. A longitudinal panel tracking individual firms across multiple waves—which, to our knowledge, does not exist for EU SMEs at this scale—would be necessary to separate these explanations. Pending such data, the population-level pattern documented here should be interpreted as establishing the empirical fact that the size gap compressed, not as establishing the mechanism by which it did so.

Weighting approximation for 2021 and 2024. As documented in Section 3.2, the EU27 weights for FE-498 and FE-549 were reconstructed from published population statistics rather than taken from a pre-computed variable in the microdata file. While the reconstructed weights produce estimates close to published benchmarks (mean absolute deviation < 2.5 pp across checked indicators), they likely omit the within-country post-stratification correction applied by Ipsos to the official weights. Sensitivity analysis S2 confirms that the convergence estimates are robust under the alternative within-country weight (w1_sme); the wave main effects, however, lose statistical significance under that scheme (Section 3.2.2), and quantitative estimates of EU27 aggregate rates should be treated as approximations.

Wording change in one Q1 item. The “selling residues/waste” item changed wording between FE-456 (“scrap material”) and FE-498/549 (“residues and waste”), and shows an anomalously large apparent increase between 2017 and 2021 (+11.7 pp) that exceeds what would be plausible given the pattern of other items. We have included this item in the composite index to preserve the full eight-item structure, but its individual-item trend estimate is unreliable. Readers should note that the composite index is not materially sensitive to the inclusion or exclusion of this item, given the equal weighting of eight items.

Three time points. The study covers three observations (2017, 2021, 2024), which is sufficient to distinguish a trend from a one-off shift but insufficient to characterise the full shape of the temporal dynamics or to identify inflexion points with precision. Future waves of the Flash Eurobarometer series—which the European Commission has indicated

will continue—will allow richer longitudinal modelling of the diffusion curve and a test of whether the convergence observed here continues, accelerates, or reverses as the CSRD cascade reaches further into SME supply chains.

Self-reported measures. All outcome variables are based on self-reported survey responses, which are subject to social desirability bias, definitional ambiguity, and possible variation in how different firm types interpret the survey questions. The directional consistency of results across eight practices, three waves, and multiple robustness checks reduces but does not eliminate the concern that systematic response bias could explain part of the observed trends. Additionally, the composite index applies equal weights to all eight practices. A PCA-weighted sensitivity (Sensitivity S10, Appendix C.12) confirms that the convergence result is robust to this assumption: $\text{Wave2021} \times \text{Medium} = -0.190$ ($\text{IRR} = 0.827, p < 0.001$) and $\text{Wave2024} \times \text{Medium} = -0.181$ ($\text{IRR} = 0.835, p < 0.001$), with a maximum shift of 0.018 relative to the base model. The index measures the scope rather than the depth or environmental impact of a firm's resource efficiency portfolio. A related limitation is the set of omitted control variables. Firm age, export orientation, and direct financial condition measures—which prior literature identifies as relevant to environmental investment decisions—are not available as comparably measured variables across all three Eurobarometer waves and therefore could not be included. Firm age may be correlated with both firm size and environmental management experience in ways not fully captured by the sector and turnover controls. Export orientation may be associated with stronger customer-driven environmental pressure, particularly from non-EU markets with different regulatory standards. Financial stress, which intensified differentially across SME size classes during the 2021–2022 energy price shock, could moderate the adoption response in ways that annual turnover—a rough proxy for financial capacity—does not fully capture. Future designs combining Eurobarometer microdata with administrative registry data on firm age, financial accounts, and trade activity would allow these omitted variables to be incorporated.

Intensity of adoption not captured. The binary coding of each practice category does not distinguish between token and comprehensive implementation. A firm reporting 'yes' to saving energy may have made a single low-cost adjustment or undertaken a major capital investment; both receive an identical score of 1. The REAI therefore measures the breadth of the resource efficiency practice portfolio—the number of domains in which a firm has decided to act—rather than the depth or scale of implementation. This implies that the observed convergence in adoption breadth between medium-sized and microenterprises may not be mirrored by convergence in investment intensity or environmental impact, dimensions that cannot be assessed from the present data.

Temporal attribution of adoption. The Eurobarometer questions ask about current practice status rather than adoption date. The change in adoption prevalence between survey waves therefore reflects the net change in the stock of current adopters between independently sampled cross-sections, not the flow of firms newly adopting during the inter-wave period. Firms observed as adopters in 2024 may have adopted the relevant practice before 2017; conversely, firms counted as non-adopters in 2024 may have adopted and subsequently abandoned practices during the period. This means that the documented changes cannot be unambiguously attributed to regulatory or economic events occurring between waves, nor can the study identify whether the rate of new adoption accelerated or decelerated during the study period. Resolving this limitation requires either a panel design that tracks the same firms across waves or a question design that captures the adoption date—neither of which is available in the Flash Eurobarometer.

Single moderator of convergence. The model includes firm size as the primary moderator of the temporal trend, with sector and turnover as controls. Other potential moderators of convergence—country-level regulatory stringency, SME participation in public

procurement, supply chain position, access to green finance—are not individually modelled, partly due to data constraints and partly for parsimony. Future work could decompose the convergence across these dimensions using multi-level modelling with country-level covariates.

‘Don’t know’ coding in the adoption index. The adoption index assigns a score of zero to respondents who selected only ‘don’t know’ on the adoption question, treating uncertainty as confirmed non-adoption. Pure ‘don’t know’ respondents are rare (205 observations, 0.62% of the EU27-strict estimation sample; 0.54% of the pooled analytical sample) and do not exhibit a systematic size gradient after population weighting. Three sensitivity analyses (Appendix C.8) confirm that the Wave $\times$ Medium interaction estimates are numerically unchanged under all alternative ‘don’t know’ treatments, but we acknowledge that the assumption may be less innocuous in surveys with higher ‘don’t know’ prevalence or stronger size-related response differentials.

Policy identification. The repeated cross-sectional design cannot isolate the contribution of any specific policy instrument—the European Green Deal, the Circular Economy Action Plan, the CSRD, or the energy price shock—to the observed adoption trends or to the compression of the size gradient. Without firm-level measures of regulatory exposure, supply-chain position, or energy intensity, and without a credible source of exogenous variation in policy exposure, the temporal co-occurrence of policy changes and behavioural change cannot be distinguished from one another or from secular diffusion trends. The 2017–2021 interval in particular conflates the early Green Deal period with the COVID-19 pandemic and its economic aftermath—including supply-chain disruptions, accelerated digitalisation, and shifts in SME operational priorities—any of which may have independently affected resource efficiency behaviour. The wave coefficients in the regression model therefore capture the net combined effect of all concurrent events rather than the contribution of any individual cause. Disentangling these channels would require either a longitudinal panel tracking firms across multiple waves with firm-level policy exposure measures, or a quasi-experimental design exploiting exogenous variation in the timing and scope of policy changes—for instance, the differential timing of CSRD transposition across EU member states, or a comparison with the non-EU countries included in the same Eurobarometer surveys (nine in FE-456—including Norway, Iceland and the United States—alongside the then-EU-member United Kingdom; Switzerland and the post-Brexit United Kingdom are additionally covered in FE-549). Future research exploiting these sources of variation would allow the mechanisms proposed as contextual interpretations in the present study to be subjected to more rigorous causal identification. In particular, country-level variation in the stringency and timing of COVID-19 restrictions, the staggered transposition of the CSRD across EU member states, and the differential exposure of SMEs to energy price volatility across sectors represent three potentially separable sources of variation that could be exploited in future difference-in-differences or event-study designs. A related concern is time-varying country-level heterogeneity: EU member states differ in the pace of CSRD transposition, energy market exposure, industrial structure, and institutional capacity, and the present model does not include country fixed effects. This choice is deliberate; since the research question concerns EU27 aggregate patterns and the policy instruments under study are EU-wide, country fixed effects would absorb substantively relevant between-country variation rather than a nuisance. The country-level jackknife (Table A9) provides reassurance that no single national context drives the convergence result. However, time-varying national differences that evolve differentially across the study period remain an uncontrolled source of heterogeneity that future research with country-wave-level covariates could address. Furthermore, while the country-level jackknife confirms that no single member state drives the convergence result, it does not test whether countries with more intensive Green Deal implementation or

higher energy price exposure experienced proportionally larger convergence. Addressing that question would require country-level time-varying covariates—measuring regulatory transposition speed, energy market exposure, or supply-chain density—that are not available in the Flash Eurobarometer microdata. Similarly, while broad sector heterogeneity in the temporal trend has been ruled out, finer-grained variation in regulatory pressure within sectors—for instance, between SMEs that are direct suppliers to large CSRD-regulated firms and those that are not—cannot be assessed without firm-level supply-chain position data.

Mechanism identification. The paper documents that the population-level gap in resource efficiency adoption was compressed by over 80% between 2017 and 2024, but cannot establish which mechanisms produced this pattern. The Flash Eurobarometer surveys contain no firm-level measures of supply-chain pressure, policy awareness, financing constraints, energy intensity, or managerial capabilities, and the repeated cross-sectional design does not permit firm-level mechanism testing. Three study designs would allow this gap to be addressed in future research: a panel survey tracking the same firms across waves (which would allow within-firm mechanism analysis), firm-level administrative data linking energy consumption, supply-chain position, and CSRD exposure to adoption decisions, and a quasi-experimental design exploiting the staggered transposition of the CSRD across EU member states to identify the regulatory cascade channel separately from concurrent time effects.

6. Conclusions

This study set out to examine whether resource efficiency adoption among European SMEs increased between 2017 and 2024, whether the well-documented size gradient in adoption behaviour changed over that period, and which mechanisms might account for the observed patterns. Using the microdata from three waves of the Flash Eurobarometer survey (FE-456, FE-498, FE-549; $N = 38,165$ SMEs across EU27 in the descriptive analyses, of which $N = 32,904$ enter the regression estimation sample), we estimated a Poisson regression model with wave $\times$ firm size interaction terms and cluster-robust standard errors, and subjected the results to nine pre-specified sensitivity analyses, complemented by dedicated diagnostics for the upper bound of the index and for the coding of ‘don’t know’ responses. Three hypotheses and one descriptive expectation were assessed: H2 is confirmed; H3 is confirmed for medium-sized enterprises; H1 is supported by the descriptive evidence but only indicatively by the model-based test; and the co-movement anticipated in Observation 1 is observed. We present these as empirical findings about the what and when of EU SME environmental behaviour, rather than as explanations of why and through which mechanisms the patterns emerged. Establishing the empirical facts at EU27 scale is a necessary precondition for the causal research designs—panel surveys, quasi-experimental strategies exploiting differential policy timing, administrative data linkages—that the present study motivates but cannot itself provide.

H1 is supported by the descriptive evidence but is sensitive to the weighting specification in the regression model: resource efficiency adoption among EU SMEs increased broadly between 2017 and 2024—across all seven practices with stable wording and, subject to the wording caveat of Section 3.3.1, also in the eighth—with the share of SMEs undertaking no resource efficiency action falling from 10.5% to 4.2% and the mean composite adoption index rising from 3.34 to 3.90 (out of 8). Under the reconstructed EU27 population weight, the Wave2024 coefficient is positive and significant ($\beta = 0.104$, $IRR = 1.109$, $p = 0.022$), confirming aggregate growth over the full seven-year span. However, as documented in Section 4.2.2 and Sensitivity S2 (Table A7), the wave main effects lose statistical significance when the within-country post-stratification weight is used, indicating that this finding depends on the cross-country rebalancing embedded in the main

weighting scheme. The descriptive evidence for H1 is robust; the model-based confirmation is indicative.

H2 is confirmed: medium-sized enterprises (50–249 employees) adopted significantly more resource efficiency practices than microenterprises in the 2017 baseline (IRR = 1.275, $p < 0.001$), replicating existing cross-sectional evidence in a population-weighted EU27 context. The gradient with respect to turnover is also consistently positive and significant across all brackets above €100k, while service-sector firms show a significant deficit relative to industry, consistent with the lower material intensity of service activities.

H3 is confirmed for medium-sized enterprises, and not supported for small enterprises: the adoption advantage of medium-sized firms over microenterprises shrank from +0.89 practices in 2017 (4.12 vs. 3.23 of 8 practices; $p = 0.003$) to a statistically non-significant +0.13 practices in 2021 ($p = 0.482$) and +0.17 practices in 2024 ($p = 0.374$)—a reduction of 81% in the size gap, expressed in the natural units of the adoption index (Table A12, row 4); Wave $\times$ Medium interactions: IRR ≈ 0.81 – 0.82 , $p < 0.001$ in both waves) and robust across all nine sensitivity specifications—a temporal pattern observed during a period of intensifying EU regulatory ambition and energy price shock, consistent with but not causally identified as the effect of these forces. The population-level gap compression was not driven by declining adoption among medium-sized firms; rather, the conditional mean for microenterprises rose relative to that of medium-sized firms across the three cross-sections. This pattern is consistent with upward catch-up by microenterprises, but is also consistent with compositional change in the microenterprise stratum—for instance, the exit of persistently non-adopting firms and their replacement by newer, greener entrants—or with cohort replacement. The present design cannot distinguish between these observationally equivalent explanations. For small enterprises (10–49 employees), the interaction terms are not significant, indicating that this intermediate segment tracked the microenterprise trajectory rather than converging from a distinct position.

Consistent with Observation 1, perceived barriers to resource efficiency adoption increased alongside adoption rates—from a mean of 1.69 barriers in 2017 to 2.09 in 2024, with the proportion reporting at least one barrier rising from 58.1% to 69.2%. This descriptive co-movement cannot be interpreted as a causal test of the relationship between adoption and barrier perception, as the repeated cross-sectional design does not track the same firms over time. It is, however, consistent with two theoretically plausible processes: the selection of previously non-attempting firms into the barrier-perception pool as adoption expands, and the genuine growth in regulatory complexity associated with the Green Deal framework and the CSRD disclosure cascade. Both processes would produce the observed pattern independent of any direct causal link between adoption and barrier experience at the firm level.

6.1. Implications for Policy

The findings carry a nuanced but important message for EU SME policy. The population-level gap compression documented for H3 is not, by itself, evidence that policy support for SME resource efficiency can be scaled back: it demonstrates that microenterprises have been catching up, but the current statistically non-significant residual relative to medium-sized firms remains economically meaningful at EU scale, given that microenterprises represent approximately 93% of all EU businesses. What it does suggest is that the targeting of support instruments may need to evolve.

First, the sharp investment discontinuity between 2017 and 2021—coinciding with the early phase of the energy price rise that was already underway when FE-498 was collected in late 2021 rather than deliberate policy design—illustrates that crisis-driven incentives can rapidly convert non-investing firms into investors. Policy instruments that replicate this urgency without requiring an exogenous price shock—notably mandatory

energy audits with implementation support, time-limited investment tax credits, and simplified access to green finance for microenterprises—may be the most effective vehicles for sustaining the extensive margin growth (more firms investing) observed in the 2017–2021 period.

Second, the stabilisation of green product and service offer between 2021 and 2024—despite continued growth in internal practice adoption—points to a demand-side constraint that policy has yet to adequately address. Green public procurement requirements, consumer labelling programmes, and market development support for SME green products may be necessary complements to the supply-side instruments (energy audits, circular economy incentives) that have driven internal adoption gains. Without demand-side reinforcement, the pipeline of SMEs “planning” to offer green products (12.0% in 2024) may not convert into actual market offers.

Third, the simultaneous growth of adoption and perceived barriers underlines a tension at the heart of the Green Deal regulatory agenda: while extending the scope and ambition of sustainability requirements accelerates adoption among those SMEs with the capacity to respond, it also increases friction for those that are still building that capacity. Simplification of the regulatory interface for micro and small enterprises—through single-window compliance portals, sector-specific guidance documents, and proportionate reporting templates—is not a dilution of environmental ambition but a prerequisite for realising it across the full SME population.

6.2. Implications for Research

The study opens several avenues for future research. The most immediate is the replication and extension of the cross-wave analysis as further Eurobarometer waves become available, which will allow testing of whether the convergence observed in 2017–2024 continues, accelerates, or reverses as the CSRD cascade deepens and the next Circular Economy Action Plan takes effect. The 2021–2024 plateau in green market offer is particularly worth monitoring: if it is indeed a pipeline effect, a new wave of adoption should be visible by 2027.

Beyond replication, three analytical extensions would substantially advance understanding. First, the introduction of country-level moderators—regulatory stringency indices, energy mix composition, public procurement intensity, SME financing conditions—into a multilevel model structure would allow the decomposition of the substantial between-country heterogeneity currently captured only by the country clustering in the standard error structure. Second, the addition of firm-level financial performance outcomes would permit estimation of the business case for resource efficiency adoption at SME scale, a relationship that is theoretically plausible but empirically underexplored in large-scale European data. Third, the extension to the non-EU countries included in the Eurobarometer sample (Albania, Iceland, Moldova, Montenegro, North Macedonia, Norway, Serbia, Turkey and the United States in all three waves, joined by Switzerland and the United Kingdom in FE-549) would allow a comparative institutional analysis of how regulatory context shapes adoption trajectories, using cross-national variation as quasi-experimental leverage on the causal claims that our within-EU analysis cannot make. More fundamentally, these designs would allow the central theoretical implication of the present study—that capability-based size gaps in environmental adoption are boundary conditions rather than structural constants—to be subjected to direct empirical test. As it stands, this implication is suggested by the temporal pattern we document and is consistent with the regulatory cascade and diffusion interpretations advanced in Section 2, but it remains a theoretically motivated inference rather than an identified causal finding.

More broadly, this study illustrates the underexploited potential of the Flash Eurobarometer infrastructure for longitudinal research on SME environmental behaviour. The

harmonised questionnaire structure, the large cross-country sample, and the recurring nature of the survey create a repeated cross-sectional dataset that, to our knowledge, is unmatched in geographical scope and thematic consistency for this population. Realising that potential requires systematic attention to cross-wave comparability—including item-level wording verification, weight reconstruction, and codebook harmonisation—of the kind documented in the appendices of this paper.

6.3. Concluding Statement

Seven years of Eurobarometer data tell a coherent story about European SMEs and the green transition: the direction of travel is unambiguous, the pace is uneven, and the gap between the best- and least-resourced firms is narrowing—but not yet closed. The finding that medium-sized enterprises no longer hold the large adoption advantage they enjoyed in 2017 is not a signal that the transition is complete; it is a signal that microenterprises are beginning to move in ways that were not measurable at scale until now. Whether that movement is self-sustaining, or whether it will stall once the easy energy-saving gains are exhausted, and the harder investments in circular design and green product development are required, is the question that the next wave of this research programme will need to answer.

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Data Availability Statement: The data supporting the findings of this study are publicly available through the GESIS Data Archive (Leibniz Institute for the Social Sciences, Cologne, Germany). The three Flash Eurobarometer microdata files used in the analysis can be accessed at the following persistent identifiers: Flash Eurobarometer 456 (ZA6917, Version 1.0.0) at <https://doi.org/10.4232/1.12966> (accessed on 1 July 2026); Flash Eurobarometer 498 (ZA7806, Version 1.0.0) at <https://doi.org/10.4232/1.12966> (accessed on 1 July 2026); and Flash Eurobarometer 549 (ZA8869, Version 1.0.0) at <https://doi.org/10.4232/1.14493> (accessed on 1 July 2026). Access to the microdata requires registration with GESIS and acceptance of their data use agreement. Analysis code is available from the corresponding author upon reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

CATI	Computer-Assisted Telephone Interviewing
CI	Confidence Interval
CSRD	Corporate Sustainability Reporting Directive
EEA	European Environment Agency
EU	European Union
EU27	European Union of 27 Member States
EU28	European Union of 28 Member States
FE	Flash Eurobarometer

GDP	Gross Domestic Product
GESIS	Leibniz Institute for the Social Sciences
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRR	Incidence Rate Ratio
NACE	Statistical Classification of Economic Activities in the European Community
NB2	Negative Binomial 2
pp	Percentage points
SE	Standard Error
SME(s)	Small and medium-sized enterprise(s)

Appendix A. Cross-Wave Questionnaire Comparability: Item-Level Equivalence Table

This appendix documents the cross-wave comparability of all survey items used in the analysis. The classification follows the explicit origin labels embedded in each official bilingual questionnaire (ZA6917_bq, ZA7806_bq, ZA8869_bq archived at GESIS), where each question is marked with its provenance relative to the previous wave (e.g., “FL456–Q1 Modified”, “FL549–NEW”). Items without a “Modified” or “NEW” label are considered strictly identical. Items marked “(N)” or “(M)” within the response list indicate a new or modified individual response option within an otherwise identical question.

Appendix A.1. Sample Sizes Reported in the Official Technical Specifications and Analytical SME Sample, by Wave

	FE-456 (2017)	FE-498 (2021)	FE-549 (2024)
Fieldwork	11–26 September 2017	8 November–10 December 2021	3–28 June 2024
GESIS study number	ZA6917	ZA7806	ZA8869
Survey organisation	TNS Political & Social	Ipsos European Public Affairs	Ipsos European Public Affairs
EU coverage	EU28	EU27	EU27
N (EU sample as reported in official technical specifications) †	13,117	13,343	13,124
N (large firms, ≥250 employees, EU)	984	872	916
N (analytical SME sample, EU27-strict) ‡	11,690	13,343	13,132

Note. † FE-456's official figure (13,117) is the total EU28 sample across all firm sizes, including 984 large enterprises (≥250 employees); of these, 58 are United Kingdom respondents (984 – 58 = 926 large enterprises within the EU27 subsample). FE-498's official figure (13,343) already excludes large firms and includes 21 respondents with an unconfirmed employee-count bracket. FE-549's official figure (13,124) excludes large firms and 8 respondents with an unconfirmed employee-count bracket. ‡ The analytical SME sample used throughout this paper (N = 11,690/13,343/13,132; pooled N = 38,165) additionally excludes United Kingdom respondents from FE-456 (n = 501, of whom 58 are large firms and 443 are SMEs, including 45 who could not confirm their employee-count bracket) and retains ‘don't know’ employee-count respondents in the descriptive analyses (Tables 1–5) while excluding them from the regression estimation sample (Section 4.2.1).

Appendix A.2. Resource Efficiency Practices (Q1)—Dependent Variable

The Q1 question wording (“What actions is your company undertaking to be more resource efficient?”, multiple response) is identical in all three waves. Changes occur only at the level of individual response options.

Response Option	FE-456 (2017)	FE-498 (2021)	FE-549 (2024)	Status
Saving water	✓ (item 1)	✓ (item 1)	✓ (item 1)	Identical across all three waves
Saving energy	✓ (item 2)	✓ (item 2)	✓ (item 2)	Identical across all three waves
Using predominantly renewable energy	✓ (item 3)	✓ (item 3)	✓ (item 3)	Identical across all three waves
Saving materials	✓ (item 4)	✓ (item 4)	✓ (item 4)	Identical across all three waves
Switching to greener suppliers	—	✓ (item 5, marked N)	✓ (item 5)	New in 2021; not in 2017 → excluded from cross-wave index
Minimising waste	✓ (item 5)	✓ (item 6)	✓ (item 6)	Identical across all three waves (position shifts due to new item above)
Selling residues/waste to another company	✓ (item 6): “scrap material”	✓ (item 7, marked M): “residues and waste”	✓ (item 7)	Wording broadened in 2021; treat with caution in direct 2017→2021 comparisons
Recycling (reusing material or waste within the company)	✓ (item 7)	✓ (item 8)	✓ (item 8)	Identical across all three waves
Designing products easier to maintain, repair or reuse	✓ (item 8)	✓ (item 9)	✓ (item 9)	Identical across all three waves
None	✓	✓	✓	Identical across all three waves
Don’t know/No answer	✓	✓	✓	Identical across all three waves

Adoption index construction: The eight items present in all three waves (saving water, saving energy, renewable energy, saving materials, minimising waste, selling residues, recycling, designing for repairability) are summed to produce the cross-wave Resource Efficiency Adoption Index (range: 0–8). The “switching to greener suppliers” item is available for 2021 and 2024 only and is analysed separately. The “selling residues/waste” item is included in the index but should be interpreted with caution in direct 2017–2021 comparisons due to the wording change.

Appendix A.3. Investment in Resource Efficiency (Q4)

The question wording (“Over the past two years, how much have you invested on average per year to be more resource efficient?”) and the six response categories (Nothing / <1%/1–5%/6–10%/11–30%/>30% of annual turnover) are confirmed identical across all three waves. The questionnaire labels FE-498’s Q4 as “FL456–Q4” (no “Modified”) and FE-549’s as “FL498–Q4”.

Appendix A.4. Barriers to Resource Efficiency Adoption (Q7)

Q7 was modified in each successive wave by adding one new barrier item. The question stem and the original eight items are identical across all waves.

Barrier Item	FE-456	FE-498	FE-549	Status
1. Complexity of administrative or legal procedures	✓	✓	✓	Identical across all three waves
2. Difficulty to adapt environmental legislation to your company	✓	✓	✓	Identical
3. Technical requirements of legislation not being up to date	✓	✓	✓	Identical

4. Difficulty in choosing the right resource efficiency actions	✓	✓	✓	Identical
5. Cost of environmental actions	✓	✓	✓	Identical
6. Lack of specific environmental expertise	✓	✓	✓	Identical
7. Lack of supply of required materials, parts, products or services	✓	✓	✓	Identical
8. Lack of demand for resource efficient products or services	✓	✓	✓	Identical
9. Complexity associated with environmental labelling and certification	—	✓ (marked N)	✓	New in 2021—excluded from cross-wave barrier index
10. Complex environmental reporting requirements	—	—	✓ (marked N)	New in 2024—excluded from cross-wave barrier index

Barrier index construction: The eight items present in all three waves (items 1–8) are summed (range: 0–8). Items 9 and 10 are analysed as auxiliary variables for 2021–2024 and 2024, respectively.

Appendix A.5. Green Product and Service Offer (Q9) and Related Items

Item	FE-456	FE-498	FE-549	Status
Q9: Does your company offer green products or services?	✓	✓ ("FL456–Q9")	✓ ("FL498–Q9")	Identical
Q10: Green products/services as % of annual turnover	✓	✓ ("FL456–Q10")	✓ ("FL498–Q10")	Identical
Q11: Duration of selling green products or services	✓	✓ ("FL456–Q11")	—	Removed in 2024
Q12: Geographic markets for green products	✓	✓ ("FL456–Q12 Modified")	—	Removed in 2024; wording updated in 2021 to reflect Brexit
DX2: Satisfaction with public support for green products	✓	✓ ("FL456–DX2")	—	Removed in 2024
DX5: Number of employees in green jobs	✓	✓ ("FL456–DX5")	✓ ("FL498–DX5")	Identical

Appendix A.6. Control Variables

Variable	FE-456	FE-498	FE-549	Notes
Sector of activity (NACE)	nace_a	nace_a	nace_a	Identical classification; same 12 NACE sections
Firm size (employees, categorical)	scr10t (consolidated)	scr10 (consolidated)	scr10 (consolidated)	Same four brackets (micro/small/medium/large); variable names differ across waves but logic is equivalent
Annual turnover	scr14 (6 brackets)	scr14 (9 brackets)	scr14 (9 brackets)	FE-498/FE-549 use finer brackets; aggregated to 6 categories matching FE-456 for comparability
Year of establishment	scr12a/scr12t	scr12a/scr12	scr12a/scr12	Numerical year identical; categorical brackets differ across waves (calendar reference points updated); not used in cross-wave model
Products/services sold	scr16	scr16 ("FL498–SCR16")	scr16 ("FL498–SCR16")	Identical

Appendix A.7. Items Introduced Exclusively in FE-549 (2024)

The following items are new in FE-549 and have no equivalent in earlier waves. They are available for cross-sectional analysis within the 2024 wave only.

Code	Content
SCR11a	Evolution of employee headcount over the past three years
SCR11b	Difficulty in hiring staff with the right skills (past 24 months)
SCR13a	Evolution of annual turnover over the past three years
N1a	Use of renewable energy sources (purchase from supplier vs. onsite generation)
N1b	Share of energy generated onsite (conditional on N1a = onsite)
N2	Use of recycled materials in products (% by physical quantity)
N3	Explicit policy to extend the lifespan of products

Appendix A.8. Sample Construction and Estimation Sample Flow

Table A1 Panel A documents the number of observations retained and excluded at each step of the sample construction process, disaggregated by wave. Table A1 Panel B shows the size-category composition of the estimation sample by wave, confirming that the wave $\times$ size distribution is stable across the three survey rounds.

Table A1. Panel A. Observations retained and excluded at each step, by wave. Panel B. Estimation sample composition by wave and firm-size category.

Panel A				
	FE-456 (2017)	FE-498 (2021)	FE-549 (2024)	Total
Step 1: Raw GESIS sample	15,019	17,662	18,159	50,840
–United Kingdom	–501	–511	–501	–1513
–Other non-EU27 countries	–1902	–2936	–3610	–8448
After geographic filter (EU27)	12,616	14,215	14,048	40,879
– Firms with ≥ 250 employees	–926	–872	–916	–2714
–‘Don’t know’ employee count	–45	–21	–8	–74
– NACE sector missing	0	0	0	0
–Turnover category missing	–1565	–1874	–1748	–5187
Estimation sample	10,080	11,448	11,376	32,904
Panel B				
Size category	2017 (N/%)	2021 (N/%)	2024 (N/%)	Change 2017→2024
Micro (1–9 employees)	4458/44.2%	4965/43.4%	5033/44.2%	0.0 pp
Small (10–49 employees)	3572/35.4%	4403/38.5%	4204/37.0%	+1.6 pp
Medium (50–249 employees)	2050/20.3%	2080/18.2%	2139/18.8%	–1.6 pp
Total	10,080	11,448	11,376	–

(A) Note. Geographic filter: United Kingdom excluded from all three waves (EU27-strict specification); other non-EU27 countries present in raw files (Albania, Iceland, Norway, North Macedonia, Moldova, Montenegro, Serbia, Turkey, USA) excluded. Firms with ≥ 250 employees excluded on size grounds. ‘Don’t know’ employee count: respondents retained in descriptive analyses (Tables 1–5) but excluded from the regression estimation sample, as firm size is a required regressor. NACE sector: complete in all three waves; zero exclusions. Turnover: the primary source of regression-sample attrition (5187 observations across the three waves), reflecting respondents who selected ‘Don’t know/Not applicable’ on the turnover bracket question or whose declared turnover could not be mapped to the harmonised six-bracket scale. (B) Note. The size-category composition of the estimation sample is highly stable across waves. The micro share ranges from 43.4% to 44.2% (maximum variation: 0.8 pp), small from 35.4% to 38.5% (3.1 pp), and medium from 18.2% to 20.3% (2.1 pp). This stability confirms that the observed temporal changes in adoption rates are not attributable to shifts in the size composition of the surveyed population between waves.

Appendix A.9. Internal Consistency and Dimensionality of the Resource Efficiency Adoption Index

This appendix reports the Kuder-Richardson KR-20 reliability coefficient for the eight binary items comprising the REAI. The pooled KR-20 is 0.689 (0.727 in 2017, 0.686 in 2021,

0.648 in 2024), indicating moderate internal consistency. These values are consistent with the formative nature of the index: the REAI counts distinct adopted practices rather than measuring a single latent trait, and moderate inter-item correlations are expected given the breadth of the construct.

An exploratory factor analysis using tetrachoric correlations identifies one factor with an eigenvalue exceeding 1 (eigenvalue = 3.533; second eigenvalue = 0.940), accounting for 44.2% of common variance. All eight items load positively on the first factor (loadings range from 0.454 to 0.814), supporting the unidimensional interpretation of the composite as a general resource efficiency adoption propensity. Table A2 reports the full loading matrix.

Table A2. Internal Consistency and Dimensionality of the Resource Efficiency Adoption Index. Panel A. Kuder-Richardson KR-20 reliability coefficient by wave. Panel B. Exploratory factor analysis: tetrachoric correlation matrix, factor loadings (first factor), and eigenvalues.

Panel A				
	2017	2021	2024	Pooled
KR-20	0.727	0.686	0.648	0.689
Panel B				
Item	Factor Loading	Eigenvalue	% Variance	
Minimise waste	0.814	3.533 (F1)	44.2%	
Save materials	0.786	0.940 (F2)	—	
Save energy	0.770	—	—	
Save water	0.732	—	—	
Repairable design	0.595	—	—	
Recycle/reuse	0.544	—	—	
Sell residues/waste	0.516	—	—	
Renewable energy	0.454	—	—	

(A) Note. KR-20 is the appropriate internal consistency measure for binary items. Values in the moderate range (0.648–0.727 across waves) are consistent with the formative nature of the index: the REAI counts distinct adopted practices across heterogeneous domains rather than measuring a single latent trait, so moderate inter-item correlations are expected. A substantially higher KR-20 would indicate near-redundant items providing little additional breadth information. (B) Note. Tetrachoric correlations are the appropriate input for factor analysis of binary items. Extraction by principal axis factoring; oblique rotation not applied given unidimensional solution. Only the first factor has an eigenvalue >1 (eigenvalue = 3.533; second eigenvalue = 0.940 < 1), accounting for 44.2% of common variance. All eight items load positively and substantially on the first factor (minimum loading 0.454). The unidimensional structure supports treating the equal-weighted sum as a coherent composite measure of resource efficiency adoption breadth. Eigenvalues for factors 3–8 range from 0.341 to 0.872 (all < 1). N (pooled, EU27-strict corrected panel) = 32,904. Significance codes: All factor loadings statistically significant at $p < 0.001$.

Appendix A.10. Variance Inflation Factor Diagnostics

This Appendix reports Variance Inflation Factors (VIF) for all regressors in the main EU27-strict Poisson model ($N = 32,904$; $G = 27$). VIF statistics were computed from an auxiliary OLS regression of each predictor on all remaining predictors. Values below 5 are considered indicative of acceptable collinearity; values below 10 are not considered disqualifying for count regression models.

Table A3. Variance Inflation Factor (VIF) Diagnostics for the EU27-Strict Corrected Main Model.

Predictor	VIF	Tolerance	VIF (Weighted)
Wave2021	3.185	0.314	2.413
Wave2024	3.155	0.317	2.428
Small (10–49)	4.236	0.236	1.235
Medium (50–249)	4.409	0.227	1.459
Sector: Retail	1.123	0.891	1.339
Sector: Services	1.129	0.886	1.343
Turnover €100k–500k	1.596	0.627	1.487
Turnover €500k–2M	1.735	0.577	1.554
Turnover €2M–10M	1.909	0.524	1.411
Turnover €10M–50M	1.668	0.600	1.403
Turnover >€50M	1.168	0.856	1.067
Wave2021 × Small	3.559	0.281	1.921
Wave2021 × Medium	2.727	0.367	1.493
Wave2024 × Small	3.456	0.289	1.932
Wave2024 × Medium	2.780	0.360	1.496

Note. $VIF = 1/(1-R^2_j)$, where R^2_j is from an auxiliary OLS regression of predictor X_j on all other predictors and an intercept, computed on the unweighted design matrix. Tolerance = $1/VIF$. VIF (weighted) uses EU27 population weights in the auxiliary regression and is reported for reference. $N = 32,904$; $G = 27$ (EU27-strict, corrected turnover harmonisation). Bold rows: central convergence estimates. Conventional thresholds: $VIF > 5$ = moderate concern; $VIF > 10$ = severe multicollinearity. No predictor exceeds the moderate-concern threshold. The highest VIF values (Medium: 4.409; Small: 4.236) are structurally expected: firm size dummies share variance with the wave × size interaction terms that are their products, a form of essential collinearity that does not bias the interaction coefficients or inflate their standard errors in a way that changes inference. The central Wave × Medium interactions ($VIF = 2.727$ and 2.780) are well within acceptable bounds. Threshold reference: All 15 predictors: $VIF < 5$. Maximum VIF = 4.409 (Medium, 50–249 employees).

Appendix B. Full Regression Output

This appendix reports the complete coefficient table for the main Poisson regression model described in Section 3.4. Table A4 extends Table 8 in the main text by reporting 95% confidence intervals for all coefficients together with additional goodness-of-fit statistics.

Table A4. Full Regression Output: Weighted Poisson Model with 95% Confidence Intervals for All Coefficients (EU27-Strict Specification, Corrected Turnover Harmonisation).

Predictor	β	SE	IRR	95% CI (IRR)	p	Sig.
Intercept	1.100	0.053	3.004	[2.707, 3.333]	<0.001	***
Wave2021	0.081	0.070	1.084	[0.946, 1.244]	0.249	
Wave2024	0.104	0.045	1.109	[1.016, 1.212]	0.022	*
Small (10–49)	0.052	0.037	1.053	[0.979, 1.133]	0.155	
Medium (50–249)	0.243	0.071	1.275	[1.109, 1.466]	<0.001	***
Sector: Retail	−0.008	0.023	0.992	[0.948, 1.038]	0.740	
Sector: Services	−0.168	0.050	0.846	[0.766, 0.932]	<0.001	***
Turnover €100k–500k	0.132	0.039	1.141	[1.057, 1.232]	<0.001	***
Turnover €500k–2M	0.189	0.049	1.208	[1.097, 1.330]	<0.001	***
Turnover €2M–10M	0.167	0.059	1.182	[1.052, 1.327]	0.005	**
Turnover €10M–50M	0.396	0.119	1.487	[1.177, 1.876]	<0.001	***
Turnover >€50M	0.045	0.149	1.046	[0.781, 1.401]	0.765	
Wave2021 × Small	−0.057	0.041	0.945	[0.872, 1.023]	0.165	
Wave2021 × Medium	−0.208	0.059	0.812	[0.724, 0.912]	<0.001	***

Wave2024 × Small	−0.022	0.041	0.978	[0.903, 1.060]	0.584	
Wave2024 × Medium	−0.197	0.044	0.821	[0.753, 0.895]	<0.001	***

Note. N = 32,904; G = 27 country clusters (EU27-strict; United Kingdom excluded from all three waves). Weighted Poisson regression (log link); EU27 population weights; cluster-robust standard errors by country with finite-sample correction. IRR = incidence-rate ratio = $\exp(\beta)$. 95% CI computed as $[\exp(\beta - 1.96 \times SE), \exp(\beta + 1.96 \times SE)]$. Weighted log-likelihood = −21,785.92. Bold rows are the central convergence estimates. Turnover bracket corrected: the ‘€100,000–€250,000’ bracket of FE-498 and FE-549 has been reassigned from the reference category to the ‘€100,000–€500,000’ category; all estimates reflect the corrected harmonisation. Reference categories: firm size = micro (1–9 employees); wave = 2017; sector = industry/other (NACE B–F and J); turnover = ≤ €100,000. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Notes on the turnover brackets. The two top turnover brackets—€10M–€50M (IRR = 1.487, $p < 0.001$) and >€50M (IRR = 1.046, $p = 0.765$)—diverge markedly in magnitude and significance, suggesting non-linearity at the top of the turnover distribution: firms in the €10M–€50M bracket adopt substantially more practices than the reference category, while the largest-turnover firms (>€50M) do not differ significantly from the ≤€100k reference once size, sector, and wave are controlled for. This pattern may reflect the inclusion of some capital-intensive firms in the highest turnover bracket that, while within the SME employee-count threshold (≤249 employees), differ qualitatively from the rest of the SME population.

Combined size effects by wave. To aid interpretation, Table A5 reports the implied total size effect for medium-sized enterprises (relative to microenterprises) in each survey wave, combining the main size coefficient and the corresponding interaction term.

Table A5. Wave-Specific Medium–Micro Adoption Gap: Combined Coefficient, Incidence Rate Ratio, and 95% Confidence Interval (EU27-Strict Specification, Corrected Turnover Harmonisation).

Wave	Combined Coefficient	IRR	95% CI (IRR)	p	Interpretation
2017 (base-line)	$\beta_4 = +0.243$	1.275	[1.109, 1.466]	<0.001	Medium-sized firms adopt 27.5% more practices than microenterprises; gap is statistically significant ($p < 0.001$)
2021	$\beta_4 + \delta_1 = 0.243 - 0.208 = +0.035$	1.036	[0.939, 1.144]	0.482	Residual medium–micro gap is statistically non-significant; convergence essentially complete
2024	$\beta_4 + \delta_2 = 0.243 - 0.197 = +0.046$	1.047	[0.946, 1.159]	0.374	Residual medium–micro gap remains statistically non-significant; gap closure sustained

Note. Combined coefficients are derived from the weighted Poisson EU27-strict model with corrected turnover harmonisation (Table 8; N = 32,904; G = 27 clusters). The 2017 baseline IRR and CI correspond to the main effect of Medium (50–249 employees) relative to microenterprises. The 2021 and 2024 IRRs and CIs are computed as $\exp(\beta_4 + \delta_1)$ and $\exp(\beta_4 + \delta_2)$, respectively, where δ_1 and δ_2 are the Wave2021 × Medium and Wave2024 × Medium interaction coefficients. Standard errors for the combined effects are computed via the delta method using the full cluster-robust variance–covariance matrix: $SE_{2021} = \sqrt{(\text{Var}(\beta_4) + \text{Var}(\delta_1) + 2\text{Cov}(\beta_4, \delta_1))} = 0.050$; $SE_{2024} = 0.052$. Reference category: microenterprises (1–9 employees).

The compression of the size gap—from a statistically significant 27.5% multiplicative advantage in 2017 (IRR = 1.275, $p < 0.001$) to a statistically non-significant residual of 3.6% in 2021 (IRR = 1.036, $p = 0.482$) and 4.7% in 2024 (IRR = 1.047, $p = 0.374$)—is the central quantitative finding of the paper.

Appendix C. Robustness Checks: Full Coefficient Tables

This appendix reports the complete coefficient tables for the sensitivity analyses (S1–S10) described in Section 3.4 and summarised in Section 4.3. All models use the same dependent variable (Resource Efficiency Adoption Index, 0–8), the same sample definition (EU27/EU28 SMEs, 1–249 employees), and cluster-robust standard errors (G clusters; finite-sample correction $G/(G-1) \times (N-1)/(N-p)$). The base model (Table 8 in the main text, reproduced in Appendix B) serves as the reference throughout.

Appendix C.1. S1: Continuous Year Variable (Restricted Linear Trend)

Motivation. The base model uses two wave dummies (2021, 2024 vs. 2017), which impose no functional form on the trend. This specification replaces those dummies with a single continuous variable $\text{year_c} = (\text{year} - 2017) / 7$, scaled to $[0, 1]$ across the three waves (0 in 2017, 0.571 in 2021, 1.0 in 2024). The interaction $\text{year_c} \times \text{Medium}$ captures whether the rate of change in the adoption gap between medium-sized and microenterprises is consistent with a linear trend.

Table A6. Sensitivity S1: Continuous Year Trend Replacing Wave Dummies (EU27-Strict Specification).

Predictor	β	SE	IRR	p	Sig.
Intercept	1.100	0.053	3.004	<0.001	***
Year (continuous, 0–1)	0.112	0.061	1.119	0.066	.
Small (10–49)	0.052	0.037	1.053	0.154	
Medium (50–249)	0.243	0.071	1.275	<0.001	***
Sector: Retail	−0.008	0.023	0.992	0.740	
Sector: Services	−0.168	0.050	0.846	<0.001	***
Turnover €100k–500k	0.132	0.039	1.141	<0.001	***
Turnover €500k–2M	0.189	0.049	1.208	<0.001	***
Turnover €2M–10M	0.167	0.059	1.182	0.005	**
Turnover €10M–50M	0.396	0.119	1.486	<0.001	***
Turnover >€50M	0.045	0.149	1.046	0.765	
Year $\times$ Small	−0.040	0.047	0.960	0.392	
Year $\times$ Medium	−0.237	0.057	0.789	<0.001	***

Note. $N = 32,904$; $G = 27$ country clusters (EU27-strict). Weighted Poisson regression (log link); EU27 population weights; cluster-robust standard errors by country with finite-sample correction. IRR = incidence-rate ratio = $\exp(\beta)$. The continuous year variable (year_c) is scaled to $[0, 1]$: 2017 = 0, 2021 = 0.571, 2024 = 1.000, so that the main year_c coefficient represents the full 2017–2024 trend for the micro reference firm, and $\text{Year} \times \text{Medium}$ captures the linear change in the size gap over the full period. The coefficient $\text{Year} \times \text{Medium} = -0.237$ (IRR = 0.789) indicates a 21.1% reduction in the medium–micro adoption gap per unit of year_c , i.e., over the full 2017–2024 span. The main year_c effect is only marginally significant ($p = 0.066$), indicating that the aggregate temporal trend in adoption for the micro reference firm is weaker than previously reported. Reference categories: firm size = micro (1–9 employees); sector = industry/other (NACE B–F and J); turnover = $\leq €100k$. Significance codes: *** $p < 0.001$; ** $p < 0.01$; $p < 0.10$.

Appendix C.2. S2: Alternative Weighting Scheme (Within-Country Weight $w1_sme$)

Motivation. The main analysis uses a reconstructed EU27 population weight that rebalances observations across countries proportionally to each country's share of the EU27 SME universe (Section 3.2). As a robustness check, this specification replaces the reconstructed weight with the within-country post-stratification weight ($w1_sme$) included in the FE-498 and FE-549 microdata files, which corrects for sector and size composition

within each country but does not rescale relative country contributions to the EU27 aggregate. For FE-456, the official EU28 weight (w23) is retained unchanged, as it is the only wave for which a pre-computed EU-aggregate weight is available.

Table A7. Sensitivity S2: Within-Country Post-Stratification Weight (w1_sme) Replacing Reconstructed EU27 Weight for FE-498 and FE-549 (EU27-Strict Specification, Corrected Turnover Harmonisation).

Predictor	β	SE	IRR	p	Sig.
Intercept	1.141	0.036	3.130	<0.001	***
Wave2021	−0.002	0.056	0.998	0.975	
Wave2024	0.041	0.045	1.042	0.365	
Small (10–49)	0.071	0.037	1.073	0.056	.
Medium (50–249)	0.306	0.055	1.358	<0.001	***
Sector: Retail	−0.017	0.016	0.983	0.298	
Sector: Services	−0.153	0.027	0.858	<0.001	***
Turnover €100k–500k	0.083	0.022	1.086	<0.001	***
Turnover €500k–2M	0.117	0.029	1.124	<0.001	***
Turnover €2M–10M	0.137	0.032	1.147	<0.001	***
Turnover €10M–50M	0.177	0.062	1.194	0.004	**
Turnover >€50M	0.050	0.078	1.051	0.525	
Wave2021 × Small	−0.065	0.046	0.937	0.156	
Wave2021 × Medium	−0.202	0.066	0.818	0.002	**
Wave2024 × Small	−0.033	0.041	0.967	0.423	
Wave2024 × Medium	−0.164	0.058	0.849	0.005	**

Note. N = 32,904; G = 27 country clusters (EU27-strict; United Kingdom excluded from all waves). Weighted Poisson regression (log link); within-country post-stratification weight (w1_sme) for FE-498 and FE-549; official pre-computed weight w23 for FE-456. IRR = incidence-rate ratio = $\exp(\beta)$. Turnover harmonisation corrected: the ‘€100,000–€250,000’ bracket of FE-498 and FE-549 is assigned to the ‘€100,000–€500,000’ category; all estimates reflect the corrected mapping. Bold rows are the central convergence estimates (Wave × Medium interactions), which remain negative and statistically significant ($p \leq 0.005$), confirming robustness of the convergence finding. Both wave main effects are non-significant under this specification (Wave2021: $p = 0.975$; Wave2024: $p = 0.365$), indicating that the aggregate EU27 temporal trend is sensitive to the cross-country rebalancing embedded in the reconstructed EU27 weight. Reference categories: firm size = micro (1–9 employees); wave = 2017; sector = industry/other (NACE B–F and J); turnover = $\leq$ €100,000. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.10$.

Appendix C.3. S3: Negative Binomial Distribution (NB2)

Motivation. The Poisson distribution assumes equidispersion ($\text{Var}(Y) = E(Y)$). If the count variable exhibits overdispersion ($\text{Var}(Y) > E(Y)$), Poisson standard errors would be downward-biased even with cluster-robust correction. The Negative Binomial 2 (NB2) specification adds a dispersion parameter α allowing $\text{Var}(Y) = \mu + \alpha \cdot \mu^2$. Estimation uses the same weighted maximum likelihood approach as the base Poisson model.

Estimated dispersion: $\hat{\alpha} = 0.105$ (likelihood-ratio test: LR = 342.83, $p < 0.001$), indicating low overdispersion. At $\alpha = 0$, NB2 collapses to the Poisson model.

Table A8. Sensitivity S3: Negative Binomial 2 (NB2) Specification Versus Poisson (EU27-Strict Sample)

Predictor	β (NB2)	β (Poisson)	Δ	SE (NB2)	p (NB2)	IRR (NB2)
Intercept	1.101	1.100	+0.001	0.053	<0.001	3.006
Wave2021	0.082	0.081	+0.001	0.070	0.240	1.085
Wave2024	0.105	0.104	+0.002	0.045	0.020	1.111
Small (10–49)	0.052	0.052	0.000	0.037	0.157	1.054
Medium (50–249)	0.246	0.243	+0.003	0.073	<0.001	1.279
Sector: Retail	−0.008	−0.008	0.000	0.023	0.728	0.992
Sector: Services	−0.169	−0.168	−0.002	0.050	<0.001	0.844
Turnover €100k–500k	0.132	0.132	0.000	0.039	<0.001	1.141
Turnover €500k–2M	0.189	0.189	0.000	0.049	<0.001	1.208
Turnover €2M–10M	0.167	0.167	0.000	0.060	0.005	1.182
Turnover €10M–50M	0.394	0.396	−0.003	0.120	0.001	1.483
Turnover >€50M	0.038	0.045	−0.007	0.155	0.809	1.038
Wave2021 × Small	−0.058	−0.057	−0.001	0.041	0.156	0.944
Wave2021 × Medium	−0.208	−0.208	0.000	0.059	<0.001	0.812
Wave2024 × Small	−0.023	−0.022	0.000	0.041	0.581	0.978
Wave2024 × Medium	−0.198	−0.197	−0.001	0.045	<0.001	0.821
α (dispersion)	0.105	—	—	0.044 (robust)	<0.001 (LR)	—

Note. N = 32,904; G = 27 country clusters (EU27-strict). Both models estimated by weighted maximum likelihood with EU27 population weights and country-clustered sandwich standard errors with finite-sample correction. IRR = incidence-rate ratio = $\exp(\beta)$. $\Delta = \beta(\text{NB2}) - \beta(\text{Poisson})$ computed from unrounded coefficients before rounding β to three decimals for display; four cells therefore differ by 0.001 from a manual recalculation using the rounded β values shown. The dispersion parameter α is reported with its cluster-robust SE; significance is assessed via a one-sided likelihood-ratio test against the Poisson null ($\alpha = 0$), LR = 342.83. Reference categories: firm size = micro (1–9 employees); wave = 2017; sector = industry/other (NACE B–F and J); turnover = $\leq$ €100k.

Appendix C.4. S4: Country-Level Jackknife (Leave-One-Country-Out)

Motivation. With G = 27 clusters, the cluster-robust sandwich estimator distributes influence across countries. The jackknife analysis reestimates the base Poisson model 27 times, excluding one country at a time, and records the resulting coefficients for the two most policy-relevant interaction terms (Wave2021 × Medium and Wave2024 × Medium). Countries are identified using their ISO 3166-1 alpha-2 code.

Table A9. Country-Level Jackknife: Wave × Medium Interaction Coefficients Under Each Leave-One-Out Specification (EU27-Strict Specification, Corrected Turnover Harmonisation).

Country Excluded	N	Wave2021 × Medium (IRR)	Wave2024 × Medium (IRR)	Max Δ
AT (Austria)	31,767	−0.2057 *** (0.814)	−0.1938 *** (0.824)	0.003
BE (Belgium)	31,627	−0.2130 *** (0.808)	−0.1990 *** (0.820)	0.005
BG (Bulgaria)	31,756	−0.2090 *** (0.811)	−0.2004 *** (0.818)	0.003
CY (Cyprus)	32,461	−0.2104 *** (0.810)	−0.1998 *** (0.819)	0.003
CZ (Czech Republic)	31,490	−0.2026 *** (0.817)	−0.1863 *** (0.830)	0.011
DE (Germany)	31,759	−0.1637 * (0.849)	−0.1692 ** (0.844)	0.044
DK (Denmark)	31,779	−0.2119 *** (0.809)	−0.1993 *** (0.819)	0.004
EE (Estonia)	31,520	−0.2079 *** (0.812)	−0.1990 *** (0.820)	0.002
ES (Spain)	31,520	−0.1740 * (0.840)	−0.1700 *** (0.844)	0.034

FI (Finland)	31,532	−0.2081 *** (0.812)	−0.1974 *** (0.821)	<0.001
FR (France)	31,587	−0.2399 *** (0.787)	−0.2140 *** (0.807)	0.032
GR (Greece)	31,377	−0.2102 *** (0.811)	−0.2008 *** (0.818)	0.004
HR (Croatia)	31,732	−0.2093 *** (0.811)	−0.1987 *** (0.820)	0.002
HU (Hungary)	31,668	−0.2096 *** (0.811)	−0.2034 *** (0.816)	0.006
IE (Ireland)	31,824	−0.2099 *** (0.811)	−0.1977 *** (0.821)	0.002
IT (Italy)	31,529	−0.1921 ** (0.825)	−0.1706 *** (0.843)	0.026
LT (Lithuania)	31,571	−0.2114 *** (0.810)	−0.2017 *** (0.817)	0.005
LU (Luxembourg)	32,359	−0.2103 *** (0.810)	−0.1997 *** (0.819)	0.003
LV (Latvia)	31,570	−0.2082 *** (0.812)	−0.1986 *** (0.820)	0.002
MT (Malta)	32,336	−0.2079 *** (0.812)	−0.1980 *** (0.820)	0.001
NL (Netherlands)	31,584	−0.2039 *** (0.816)	−0.1900 *** (0.827)	0.007
PL (Poland)	31,514	−0.2217 *** (0.801)	−0.2083 *** (0.812)	0.014
PT (Portugal)	31,558	−0.2234 *** (0.800)	−0.2037 *** (0.816)	0.015
RO (Romania)	31,417	−0.2033 *** (0.816)	−0.2024 *** (0.817)	0.005
SE (Sweden)	31,433	−0.2067 *** (0.813)	−0.2077 *** (0.813)	0.011
SI (Slovenia)	31,562	−0.2099 *** (0.811)	−0.1982 *** (0.820)	0.002
SK (Slovakia)	31,672	−0.2028 *** (0.816)	−0.1941 *** (0.824)	0.005
Base model	32,904	−0.208 *** (0.812)	−0.197 *** (0.821)	—

Note. N = 32,904; G = 27 (base model). Each row re-estimates the model excluding the country indicated (G = 26 in all leave-one-out specifications). $\Delta = \max(|\beta_{2021} - (-0.208)|, |\beta_{2024} - (-0.197)|)$ calculated against the corrected base model. The maximum deviation occurs when Germany is excluded ($\Delta = 0.044$), followed by Spain ($\Delta = 0.034$). Both interactions remain negative and statistically significant at $p < 0.05$ in all 27 specifications; at $p < 0.01$, 25 of 27 reach significance (exceptions: Germany and Spain, both significant at $p < 0.05$). Bold row: corrected base model estimates. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Appendix C.5. Summary Robustness Table (Full)

Table A10. Key Interaction Coefficients (Wave $\times$ Medium, 50–249 Employees) Across All Specifications. Reference Category: Microenterprises (1–9 Employees) in the 2017 Wave.

Specification	Wave2021 $\times$ Medium				Wave2024 $\times$ Medium				N	G
	β	SE	p	IRR	β	SE	p	IRR		
Base model (EU27-strict)	−0.208	0.059	<0.001	0.812	−0.197	0.044	<0.001	0.821	32,904	27
S1: Continuous year trend †	—	—	—	—	−0.237 ‡	0.057	<0.001	0.789	32,904	27
S2: Within-country weight (w1_sme)	−0.202	0.066	0.002	0.818	−0.164	0.058	0.005	0.849	32,904	27
S3: Negative Binomial 2	−0.208	0.059	<0.001	0.812	−0.198	0.045	<0.001	0.821	32,904	27
S4: Jackknife max (excl. Germany)	−0.164	—	0.015	0.849	−0.169	—	0.004	0.844	31,759	26
S5: EU28-inclusive (UK in 2017)	−0.208	0.061	<0.001	0.812	−0.197	0.045	<0.001	0.821	33,213	28
S7: 7-item index (excl. residues) §	−0.195	0.055	<0.001	0.823	−0.182	0.038	<0.001	0.834	32,904	27
S8: Manufacturing as separate category	−0.227	0.058	<0.001	0.797	−0.213	0.041	<0.001	0.808	32,904	27
S9: Broad turnover reference ($\leq \text{€}500\text{k}$)	−0.205	0.059	<0.001	0.815	−0.198	0.042	<0.001	0.820	32,904	27
S10: PCA-weighted index	−0.190	—	<0.001	0.827	−0.181	—	<0.001	0.835	32,904	27

Note. All models: EU27-strict specification (N = 32,904; G = 27; corrected turnover harmonisation), except S5 (EU28-inclusive; N = 33,213; G = 28) and S4 (N = 31,759; G = 26, Germany excluded). † In S1, wave dummies are replaced by a continuous year variable (year_c); the Wave2021 $\times$ Medium

column is not applicable under this specification. ‡ Single coefficient for $\text{year_c} \times \text{Medium}$ capturing the full 2017–2024 convergence; $\text{IRR} = 0.789$ represents the reduction in the medium–micro gap over the full seven-year span. For S4, standard errors are not reported because the jackknife is a stability diagnostic rather than an alternative estimation method; p -values correspond to the leave-one-out specification that excludes Germany (the country producing the largest deviation, $\Delta = 0.044$). § S7 uses a seven-item adoption index excluding the ‘selling residues/waste’ item whose wording changed between FE-456 and FE-498/549. All other $\text{Wave} \times \text{Medium}$ interactions across S1–S9 are negative and statistically significant at $p \leq 0.015$. Reference category: microenterprises (1–9 employees) in the 2017 wave.

Appendix C.6. S5. EU28-Inclusive (UK Retained in 2017)

Table A11. Poisson Regression of the Environmental-Practice Adoption Index: EU28 Base Specification, United Kingdom Included in 2017 Wave (Sensitivity S5).

Predictor	β	SE	IRR	p	Sig.
Intercept	1.148	0.062	3.150	<0.001	***
Wave2021	0.077	0.073	1.081	0.286	
Wave2024	0.104	0.050	1.110	0.037	*
Small (10–49)	0.064	0.036	1.066	0.080	.
Medium (50–249)	0.240	0.068	1.271	<0.001	***
Sector: Retail	−0.010	0.022	0.990	0.630	
Sector: Services	−0.172	0.047	0.842	<0.001	***
Turnover 100k–500k	0.095	0.045	1.099	0.037	*
Turnover 500k–2M	0.146	0.056	1.157	0.010	**
Turnover 2M–10M	0.131	0.059	1.140	0.027	*
Turnover 10M–50M	0.351	0.119	1.421	0.003	**
Turnover >50M	0.010	0.149	1.010	0.946	
Wave2021 $\times$ Small	−0.071	0.038	0.932	0.065	.
Wave2021 $\times$ Medium	−0.208	0.061	0.812	<0.001	***
Wave2024 $\times$ Small	−0.036	0.037	0.965	0.339	
Wave2024 $\times$ Medium	−0.197	0.045	0.821	<0.001	***

Note. $N = 33,213$; $G = 28$ country clusters (EU28; United Kingdom included in the 2017 wave only). Weighted Poisson regression (log link); cluster-robust standard errors by country; finite-sample correction applied. $\text{IRR} = \text{incidence-rate ratio} = \exp(\beta)$. Weighted log-likelihood = −23,483.35. Reference categories: firm size = micro (1–9 employees); wave = 2017; sector = industry/other (NACE B–F and J); turnover = $\leq \text{€}100\text{k}$. The key convergence estimates (Wave2021 $\times$ Medium: $\beta = -0.208$, $\text{IRR} = 0.812$; Wave2024 $\times$ Medium: $\beta = -0.197$, $\text{IRR} = 0.821$) are substantively identical to those of the EU27-strict main model, confirming that the inclusion of the United Kingdom does not affect the central findings. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; $p < 0.10$.

Appendix C.7. S6. Robustness to the Upper Bound of the Index

Table A12. Robustness to the Upper Bound of the Resource Efficiency Adoption Index: Four Complementary Checks (EU27-Strict Specification, Corrected Turnover Harmonisation).

Analysis	Estimand	Wave2021 $\times$ Medium	Wave2024 $\times$ Medium	Verdict
Base (Poisson, weighted)	coef (IRR)	−0.208 (0.81) ***	−0.197 (0.82) ***	—
(1) Index $\div 8$	coef (IRR)	−0.208 (0.81) ***	−0.197 (0.82) ***	Identical (scale-invariant)
(2) Fractional logit (Papke–Wooldridge)	AME	−0.096 *** [−0.152, −0.041]	−0.089 *** [−0.136, −0.043]	Survives the bound

(3) Item-level (8 logistic regressions)	sign/sig.	8/8 negative; 5/8 $p < 0.05$	8/8 negative; 4/8 $p < 0.05$	Broadly distributed
(4) Predicted margins	medium – micro gap	2017: +0.89 ** → 2021: +0.13 (n.s.)	2024: +0.17 (n.s.); –81%	Substantive in natural units

Note. N = 32,904; G = 27 country clusters (EU27-strict; United Kingdom excluded from all three waves); EU27 population weights; country-clustered standard errors with finite-sample correction. AME = average marginal effect on the [0, 1] proportion from the fractional-response model (Papke–Wooldridge GLM, Binomial family, logit link); 95% confidence intervals in brackets. Predicted margins in row (4) are computed from the base Poisson EU27-strict model with remaining controls at their population-weighted means (delta-method 95% CI); medium-sized firms' expected adoption in 2017: 4.12 of 8 practices (52% of the maximum). The 2017 medium–micro gap (+0.89 practices) is statistically significant ($p = 0.003$); the 2021 gap (+0.13) and 2024 gap (+0.17) are not ($p = 0.482$ and $p = 0.374$, respectively). Reference category: microenterprises (1–9 employees) in the 2017 wave. Significance codes: *** $p < 0.001$; ** $p < 0.01$.

Appendix C.8. Sensitivity to the Coding of 'Don't Know' Responses in the Adoption Index

Motivation. The base model assigns a score of zero to respondents who selected only 'don't know' on the adoption question, treating uncertainty as confirmed non-adoption. If smaller firms have weaker administrative formalisation and therefore higher propensity to respond 'don't know', this coding could understate micro-enterprise adoption and overstate the size gradient. Because the survey presents 'don't know' as an exclusive option (respondents either select it or indicate specific practices), pure DK respondents are those selecting no specific practice. Panel A reports the wave- and size-specific DK rates; Panel B reports the three alternative specifications.

Table A13. Sensitivity to the Coding of 'Don't Know' Responses—Interaction Estimates Under Alternative DK Treatments. Panel A. Pure 'don't know' rates by wave and firm-size category. Panel B. Interaction estimates under alternative DK treatments.

Panel A									
Size	2017			2021			2024		
	n DK	% unwtd	% wtd	n DK	% un-wtd	% wtd	n DK	% un-wtd	% wtd †
Micro (1–9)	29	0.65	0.22	42	0.85	1.34	34	0.68	0.81
Small (10–49)	10	0.28	0.18	25	0.57	0.76	35	0.83	1.19
Medium (50–249)	3	0.15	0.04	13	0.62	1.14	14	0.65	0.77
Panel B									
Specification	Wave2021 × Medium			Wave2024 × Medium			N		
	β	IRR	p	β	IRR	p			
Base (DK coded as 0)	–0.208	0.812	<0.001	–0.197	0.821	<0.001	32,904		
DK-A: Exclude pure DK respondents	–0.208	0.812	<0.001	–0.197	0.821	<0.001	32,699		
DK-B: DK treated as missing at item level	–0.208	0.812	<0.001	–0.197	0.821	<0.001	32,699		
DK-C: DK binary control added †	–0.208	0.812	<0.001	–0.197	0.821	<0.001	32,904		

(A) Note. Pure DK: respondents selecting 'don't know' as their only response to the adoption question (n = 205 total; 0.62% of the EU27-strict estimation sample). % unwtd: unweighted proportion within the size–wave cell. % wtd: EU27 population-weighted proportion. The absence of a systematic micro-versus-medium differential, particularly after population weighting, limits the plausibility of a DK-driven bias in the size gradient. (B) Note. N = 32,904 (base, DK-C) or 32,699 (DK-A, DK-B) EU27-strict observations; G = 27 clusters. All specifications: weighted Poisson, log link, cluster-

robust SE with finite-sample correction. DK-A: all 205 pure DK respondents excluded. DK-B: DK treated as missing at item level, and index rescaled; because the survey presents DK as a question-level exclusive option, DK-B and DK-A produce identical estimation samples and results. † DK-C: a binary indicator (DK = 1 if respondent selected ‘don’t know’) is added as a control; DK = 1 implies index = 0 by construction (perfect separation), so the DK coefficient is not finitely identified, but this collinearity does not affect the Wave × Medium interaction estimates. Maximum absolute shift in Wave × Medium coefficients across all three alternatives: 0.000. Significance: All Wave × Medium interactions significant at $p < 0.001$ in all specifications.

Appendix C.9. S7. 7-Item Index

Table A14. Sensitivity S7: Eight-Item vs. Seven-Item Adoption Index (Excluding ‘Selling Residues/Waste’ Item).

Predictor	β 8-Item	β 7-Item	Δ	IRR 8-Item	IRR 7-Item	p 8-Item	p 7-Item
Wave2021	0.081	0.071	−0.010	1.084	1.073	0.249	0.329
Wave2024	0.104	0.100	−0.004	1.109	1.105	0.022	0.034
Small (10–49)	0.052	0.025	−0.027	1.053	1.025	0.154	0.542
Medium (50–249)	0.243	0.206	−0.037	1.275	1.228	<0.001	0.005
Wave2021 × Medium	−0.208	−0.195	+0.013	0.812	0.823	<0.001	<0.001
Wave2024 × Medium	−0.197	−0.182	+0.015	0.821	0.834	<0.001	<0.001
Wave2021 × Small	−0.057	−0.052	+0.005	0.945	0.950	0.165	0.250
Wave2024 × Small	−0.022	−0.008	+0.014	0.978	0.992	0.584	0.853

Note. N = 32,904; G = 27 country clusters (EU27-strict). Both models: weighted Poisson (log link), EU27 population weights, cluster-robust standard errors with finite-sample correction. β and IRR refer to the same predictor in both specifications; $\Delta = \beta(7\text{-item}) - \beta(8\text{-item})$. The 8-item model uses the adoption index over the full range [0, 8]; the 7-item model excludes the ‘selling your scrap material/residues and waste’ item and uses an index over [0, 7], without rescaling. Bold rows are the central convergence estimates. The slight attenuation of the Wave × Medium coefficients in the 7-item model (maximum $\Delta = 0.015$) reflects the removal of an item in which medium-sized enterprises had elevated 2017 prevalence; under the 7-item index, the apparent 2017 advantage of medium firms is somewhat smaller ($\beta_{\text{Medium}} = 0.206$ vs. 0.243), and the convergence magnitude is correspondingly slightly reduced. The sign, significance, and order of magnitude of both interaction terms are unchanged. Reference categories: micro (1–9 employees); wave = 2017; industry/other (NACE B–F and J); turnover ≤ €100k. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Appendix C.10. S8. Manufacturing as Separate Category

Table A15. Sensitivity S8: Manufacturing (NACE C) as Separate Sector Category vs. Base Model Grouping (Industry NACE B, C, D, E, F, and J Combined).

Specification	β (W21 × Med)	IRR	p	β (W24 × Med)	IRR/ p
Base model (industry B,C,D,E,F)	−0.208	0.812	<0.001	−0.197	0.821/<0.001
S8: Manufacturing (C) separate	−0.227	0.797	<0.001	−0.213	0.808/<0.001

Note. N = 32,904; G = 27 (EU27-strict, corrected turnover harmonisation). Weighted Poisson regression (log link), cluster-robust SE. In S8, NACE C (manufacturing) is modelled as a separate dummy from the remaining industry strata (NACE B, D, E, F), which become the reference. Maximum absolute difference in Wave × Medium coefficients: 0.019. The convergence finding does not depend on the sector grouping choice.

Appendix C.11. S9. Broad Turnover Reference ($\leq \text{€}500\text{k}$)**Table A16.** Sensitivity S9: Broad Turnover Reference Category ($\leq \text{€}500,000$) Collapsing the Two Lowest Brackets, Immune to Residual Bracket Misclassification.

Specification	β (W21 $\times$ Med)	IRR	p	β (W24 $\times$ Med)	IRR/ p
Base model (ref. $\leq \text{€}100\text{k}$)	−0.208	0.812	<0.001	−0.197	0.821/<0.001
S9: Broad reference ($\leq \text{€}500\text{k}$)	−0.205	0.815	<0.001	−0.198	0.820/<0.001

Note. N = 32,904; G = 27 (EU27-strict, corrected turnover harmonisation). Weighted Poisson regression (log link), cluster-robust SE. In S9, the ' $\leq \text{€}100,000$ ' and ' $\text{€}100,000$ – $\text{€}500,000$ ' categories are collapsed into a single ' $\leq \text{€}500,000$ ' reference; the specification is immune to any residual ambiguity in the assignment of the ' $\text{€}100,000$ – $\text{€}250,000$ ' bracket. Maximum absolute difference in Wave $\times$ Medium coefficients: 0.003. The convergence finding is robust to this alternative grouping.

Appendix C.12. S10. PCA-Weighted Adoption Index vs. Equal-Weighted Base Model

Table A17. Sensitivity S10: PCA-Weighted Adoption Index vs. Equal-Weighted Base Model.

Specification	Wave2021 $\times$ Medium				Wave2024 $\times$ Medium				N	G
	β	SE	p	IRR	β	SE	p	IRR		
Base model (equal-weighted sum, [0–8])	−0.208	0.059	<0.001	0.812	−0.197	0.044	<0.001	0.821	32,904	27
S10: PCA-weighted index (scaled [0–8])	−0.190	0.057	<0.001	0.827	−0.181	0.043	<0.001	0.835	32,904	27

Note. N = 32,904; G = 27 (EU27-strict, corrected turnover harmonisation). Both models: weighted Poisson regression (log link), EU27 population weights, country-clustered standard errors with finite-sample correction. The base model uses an equal-weighted sum of eight binary practices (range: 0–8). S10 uses scores on the first principal component derived from the tetrachoric correlation matrix of the eight items (see Table A2, Panel B), scaled to the [0,8] range to maintain interpretability; PCA item weights (proportional to first-factor loadings): minimize_waste = 1.30, save_materials = 1.26, save_energy = 1.23, save_water = 1.17, repairable_design = 0.95, recycle = 0.87, sell_residues = 0.83, renewable_energy = 0.73 (sum = 8.34, rescaled to sum to 8). Maximum absolute shift in Wave $\times$ Medium coefficients: 0.018. IRR = incidence-rate ratio = $\exp(\beta)$. Bold row: base model.

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