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Regional environmental-economic performance in Italy: RAMEA panel and applications

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Abstract

This paper presents and applies a new Italian Regional Accounting Matrix of Environmental Accounts (RAMEA) panel (1995–2019) to demonstrate how hybrid environmental–economic accounting can inform regional assessments of eco-efficiency and structural change. Using Emilia-Romagna and Lazio as two contrasting regional economies, we implement a sequence of applications: (i) long-run sectoral economic–environmental profiles, (ii) emission-intensity measures for greenhouse gases (GHG) and PM10, and (iii) an employment-based decomposition of emission dynamics. The results point to broad improvements in eco-efficiency: PM10 abatement is predominantly explained by within-sector technique gains, whereas GHG reductions reflect a combination of compositional shifts and technique effects, with the latter becoming stronger after 2005. We further exploit RAMEA granularity by zooming into manufacturing sub-sectors and by estimating a targeted econometric specification linking emissions per worker to productivity, investment, and EU ETS exposure, illustrating how decomposition diagnostics can be complemented with econometric evidence on potential drivers.

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1. Introduction

Reducing greenhouse-gas (GHG) emissions while improving local air quality is a central policy challenge in Italy, but progress is far from uniform across space. Italian regions differ markedly in productive specialisation, technology, and the territorial concentration of emission-intensive activities. As a result, the same national and EU regulatory framework can translate into heterogeneous environmental–economic trajectories. This heterogeneity limits the interpretability of aggregate indicators: national averages can hide structural drivers, misrepresent regional responsibilities, and offer an incomplete basis for territorial benchmarking and policy design. Hybrid environmental–economic accounting frameworks—rooted in input–output analysis and later consolidated within the SEEA and NAMEA traditions—provide a coherent way to jointly track economic activity and environmental pressures under the same sectoral classifications and accounting conventions. A key advantage is consistency: emissions and other pressures can be attributed to the same economic entities recorded in national accounts (industries and households), enabling analyses that connect production structures, labour dynamics, and environmental outcomes within a single framework.

Against this background, this working paper demonstrates the analytical potential of a Regional Accounting Matrix of Environmental Accounts (RAMEA) by constructing and exploiting a new Italian RAMEA panel spanning 1995–2019 and by presenting a structured sequence of empirical applications. Within the GRINS project (PNRR) and its investments in data infrastructures for territorial policy analysis, we build two RAMEA datasets sharing a common economic backbone from ISTAT regional accounts—value added (2020 chain-linked volumes) and employment for 29 NACE Rev.2 industries, plus household final consumption expenditure (COICOP) aggregated into heating, transport, and other uses. The environmental module is organised as an emission satellite account consistent with national accounting principles: it records air emissions in physical units and allocates them to the same producing industries and household activities that generate value added and employment, following the residence principle and the standard sectoral classifications used in the System of National Accounts.

The paper focuses on the top-down RAMEA panel based on ISPRA's provincial disaggregation of the national emission inventory, reconstructed for six harmonised benchmark years (1995, 2000, 2005, 2010, 2015, 2019) and covering all 20 regions with full comparability across space and time. Using Emilia-Romagna and Lazio as illustrative cases with contrasting production structures (manufacturing-intensive versus service-centred), we first document long-run economic–environmental trajectories in levels for both a global pollutant (GHG) and a local air-quality pressure (PM10). We then move to eco-efficiency indicators (emission intensities), and to an employment-based scale–composition–technique decomposition to identify the drivers behind observed changes. Finally, we complement these accounting-based diagnostics with a targeted econometric exercise for manufacturing sub-sectors, exploring whether post-2005 technique improvements are systematically associated with investment dynamics and regulatory exposure.

The remainder of the paper is organised as follows. Section 2 presents the empirical applications based on the top-down RAMEA panel (regional sector profiles, eco-efficiency indicators, decomposition results, and the econometric specification focusing on post-2005 technique dynamics). Section 3 discusses implications for interpreting heterogeneous regional transition pathways and outlines extensions enabled by the same RAMEA infrastructure, including more granular sectoral focus and integration with regional modelling frameworks.

2. RAMEA panel

Environmental-economic accounts methodology goes back to the analysis of physical economy by Leontief (1970), who combined input-output modelling with environmental accounts. It constitutes a statistical framework that integrates environmental and economic data, providing a cohesive system to assess the environment's role in the economy and the economy's effects on the environment. The subsequent development of the System of Environmental-Economic Accounting (UN-SEEA, 2003) and the diffusion of NAMEA-style hybrid flow accounts established a coherent statistical architecture in which economic transactions and physical environmental flows are organised under the same accounting conventions and classification systems. A key implication of this approach is that environmental pressures can be consistently attributed to the same economic entities recorded in national and regional accounts—industries and households—typically following NACE/COICOP classifications, thereby enabling joint analyses of production structures, final demand, and emissions within a single framework. In Italy, this perspective has progressively expanded from the national to the sub-national level: while ISTAT has released national air emission accounts since the mid-2000s and early regional NAMEA exercises were produced for limited years, the added value of RAMEA lies in introducing an explicit territorial dimension alongside the sectoral one, which is essential in a country characterised by strong regional heterogeneity in productive specialisation, technology, and environmental pressures. At the same time, sub-national accounting raises a well-known empirical challenge: regional environmental accounts are only as informative as the quality and granularity of the underlying local emission inventories, and purely top-down allocation methods may miss place-specific drivers and technological differences if not complemented by local monitoring systems (La Notte and Dalmazzone, 2013).

Within the GRINS project (PNRR) and its investments in data infrastructures for territorial policy analysis, this paper develops and exploits a new RAMEA regional panel designed specifically to support empirical applications on long-run environmental–economic dynamics. Concretely, we constructed two complementary datasets of regional environmental–economic accounts that share a common economic backbone and differ in the environmental module. In both panels, the economic component is derived from ISTAT regional accounts and provides harmonised information on value added (2020 chain-linked volumes) and employment for 29 NACE Rev.2 industries, together with household final consumption expenditure by COICOP categories aggregated into heating, transport, and other uses.

The first dataset is a top-down RAMEA panel that prioritises coverage and long-run comparability. Its environmental data come from ISPRA's provincial-level disaggregation of the national emission inventory and are reconstructed for six harmonised benchmark years—1995, 2000, 2005, 2010, 2015, and 2019—aligned with EU reporting cycles. Although not annual, the series provides a consistent long-term window over roughly twenty-five years, capturing structural and regulatory shifts in Italian air pollution and climate-relevant emissions. Because ISPRA applies the same reconstruction method across provinces and pollutants, the resulting panel is strictly comparable across regions and over time, yielding a complete matrix of 20 regions × 6 benchmark years × pollutants × (industries + household uses). This makes the top-down dataset particularly suitable for inter-regional benchmarking, analyses of territorial disparities, and cross-region assessments of decoupling and eco-efficiency patterns. The second dataset is a bottom-up RAMEA panel that prioritises local detail and temporal richness, but necessarily has partial and asymmetric territorial coverage. At present, only eight regions—Emilia-Romagna, Lombardia, Veneto, Friuli-Venezia Giulia, Toscana, Campania, Sicilia, and Trentino-Alto Adige—provide sufficiently complete and regularly updated ARPA inventories to support a consistent reconstruction. Where available, these inventories typically offer annual or biennial estimates from around 2010 to 2021 and, in several cases, extend to 2022 or 2023 depending on local updates (e.g. INEMAR-based systems). Because bottom-up inventories rely more directly on plant-level and municipal-level activity data and locally calibrated emission factors, they are well suited to applications focused on intra-regional dynamics, sector-specific eco-efficiency, and fine-grained decomposition exercises where local technological characteristics matter.

In the remainder of this paper, and in order to present a coherent set of applications over the longest available horizon, we rely on the top-down RAMEA panel constructed from ISPRA's provincial-based emissions, using Emilia-Romagna and Lazio as two illustrative cases with markedly different production structures. This choice provides a transparent and replicable baseline for demonstrating how a regional RAMEA panel can be used to reconstruct economic–environmental trajectories in levels, assess eco-efficiency through emission intensities, and then move to decomposition and econometric analysis to investigate the drivers of observed changes.

2.1 Regional evolution of economic-environmental sector profiles

This section uses the Top-down RAMEA panel to provide a descriptive picture of long-run economic and environmental dynamics in Emilia-Romagna and Lazio over 1995–2019. The two regions are selected because they represent contrasting production structures under the same national institutional and policy framework. Emilia-Romagna is one of Italy's most manufacturing-oriented regions, with a strong base of medium–high-tech activities and export-oriented SMEs. Lazio, instead, is structurally dominated by services and public administration, with a comparatively smaller industrial base. This contrast offers a useful setting to assess how sectoral structure and labour composition map into different emissions trajectories.

We track four core variables by macro-sector—value added (VA), employment (L), greenhouse gases (GHG), and PM10—to jointly characterise economic performance and environmental pressure. GHG emissions capture the main global externality targeted by climate policy and provide a consistent benchmark for decarbonisation patterns. PM10 emissions represent a salient local air-quality pressure. Considering both pollutants therefore supports a balanced reading of regional environmental performance. This descriptive profiling serves as the empirical foundation for the subsequent applications.

Figure 1 shows the evolution of economic activity (value added and employment) and emissions (GHG and PM10) in Emilia-Romagna across five macro-sectors—Agriculture (A), Manufacturing (B+C), Energy & Utilities (D+E), Construction (F), and Services (G–T)—over the period 1995–2019. As expected for a highly developed region, services dominate Emilia-Romagna's economic structure; however, manufacturing remains a central pillar of the regional economy, contributing substantially to both value added and employment throughout the entire period. Importantly, this persistent industrial weight coexists with a clear reduction in emissions, especially from manufacturing, pointing to substantial improvements in environmental performance. Energy & Utilities remain a relatively small contributor to VA and employment but initially account for a disproportionate share of GHG emissions, consistent with their energy-intensive profile. Agriculture, though modest in economic terms, contributes noticeably to PM10 emissions in the earlier years, with a steady reduction after 2005 that signals modernisation and stricter environmental compliance.

From an Environmental Kuznets Curve (EKC) perspective, the monotonic decline in GHG emissions over the entire period suggests that Emilia-Romagna is positioned on the right-hand side of the EKC, where environmental pressures fall as technological improvements, regulatory tightening and structural upgrading take effect. Although this pattern alone cannot establish a causal EKC mechanism, it is consistent with an economy that has already passed the turning point and is experiencing sustained reductions in emission intensity.

Figure 1. Economic–environmental profiles of regional sectors in Emilia-Romagna (1995–2019): value added (€ million, chain-linked volumes), employment (thousand workers), GHG emissions (tons CO_2-eq), and PM10 emissions (tons). *Source: own elaboration RAMEA top-down panel*

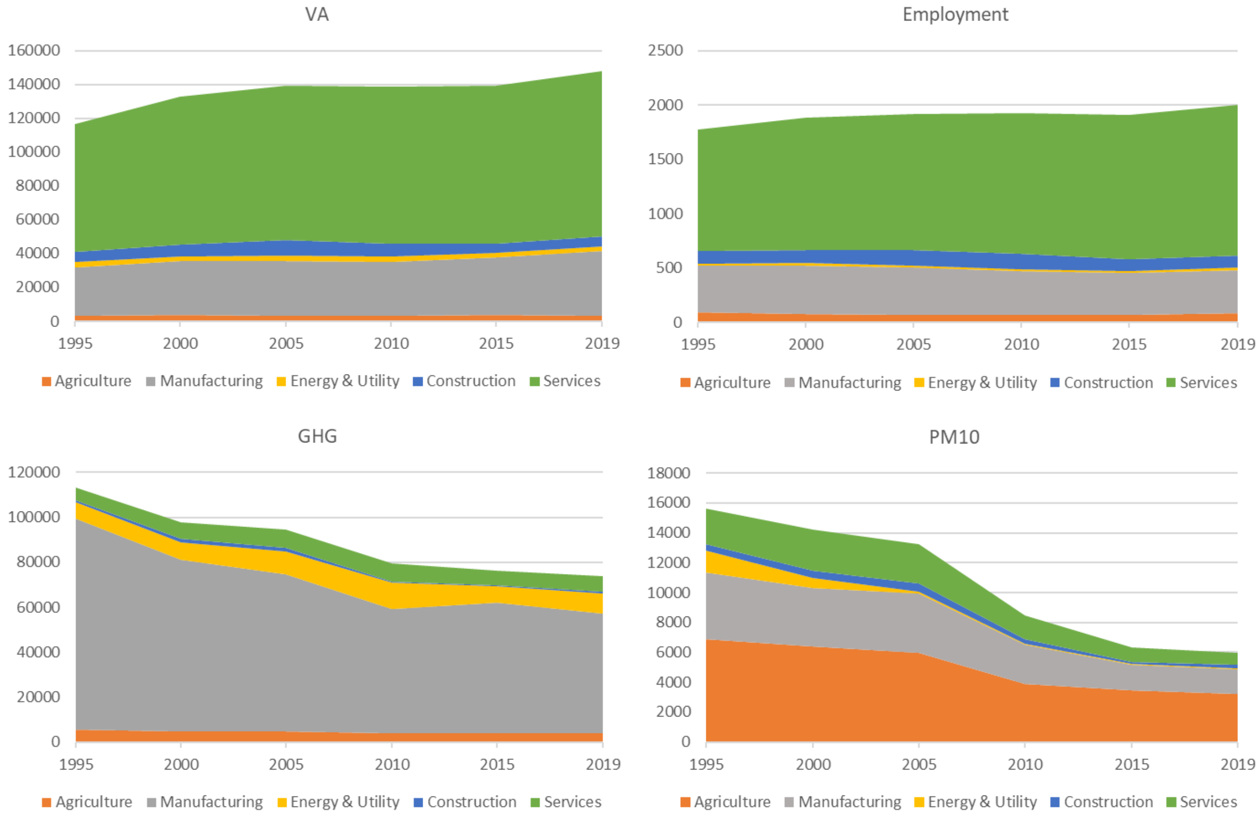
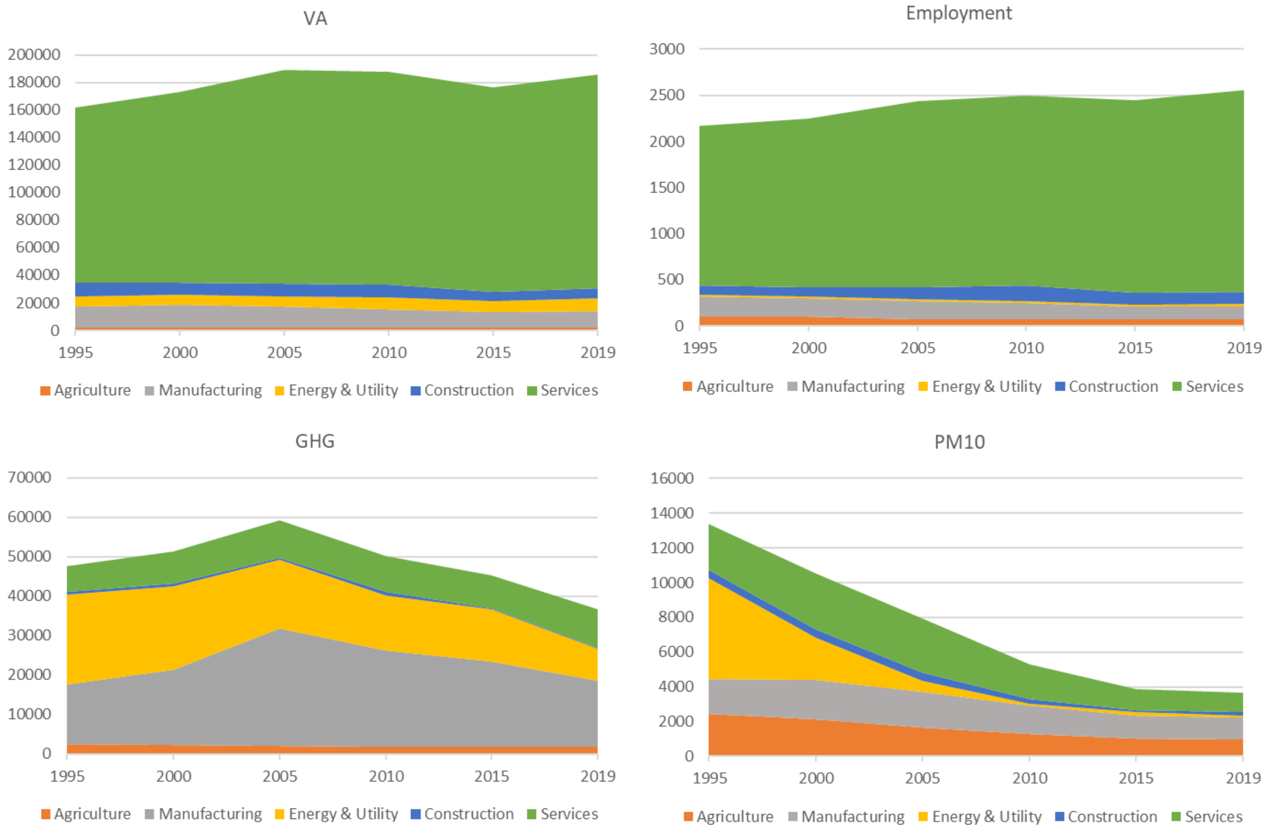


Figure 2 shows the analogous profiles for Lazio. As expected for a region centred around the capital city, services overwhelmingly dominate both value added and employment, even more than in Emilia-Romagna. Public administration, information and communication, financial services, and other knowledge-intensive activities structurally shape the regional profile. Unlike Emilia-Romagna—where manufacturing remains a core economic pillar—in Lazio manufacturing contributes a modest share of both VA and employment and declines gradually over time. As a result, regional GHG and PM10 emissions are less driven by industrial sources and more by services, transport, and energy-related activities. The Energy & Utilities sector, in particular, exhibits a substantial contribution to GHG emissions in the early 2000s, reflecting the presence of large energy production facilities around Rome. Emissions from this sector decline after 2005, mirroring national trends in fuel switching, technological upgrading, and tighter regulation. Agriculture represents a very small share of Lazio's economy but displays visible PM10 emissions in the earlier years, though far lower than in Emilia-Romagna. The reduction over time points to similar modernisation trends and stricter air-quality standards. From an EKC perspective, Lazio's GHG trajectory—characterised by a clear peak around 2005 followed by a sustained decline—resembles the canonical inverted-U shape more closely than Emilia-Romagna's pattern. This dynamic suggests that Lazio may have passed its emissions turning point in the mid-

2000s, with subsequent reductions likely driven by cleaner energy production, regulatory tightening, and improvements in efficiency within both manufacturing and energy-intensive activities.

Compared with Emilia-Romagna, Lazio's overall emission profile is shaped less by industrial dynamics and more by energy production, transport emissions, and the scale of service-related activities.

Figure 2. Economic–environmental profiles of regional sectors in Lazio (1995–2019): value added (€ million, chain-linked volumes), employment (thousand workers), GHG emissions (tons CO_2-eq), and PM10 emissions (tons). *Source: own elaboration RAMEA top-down panel*

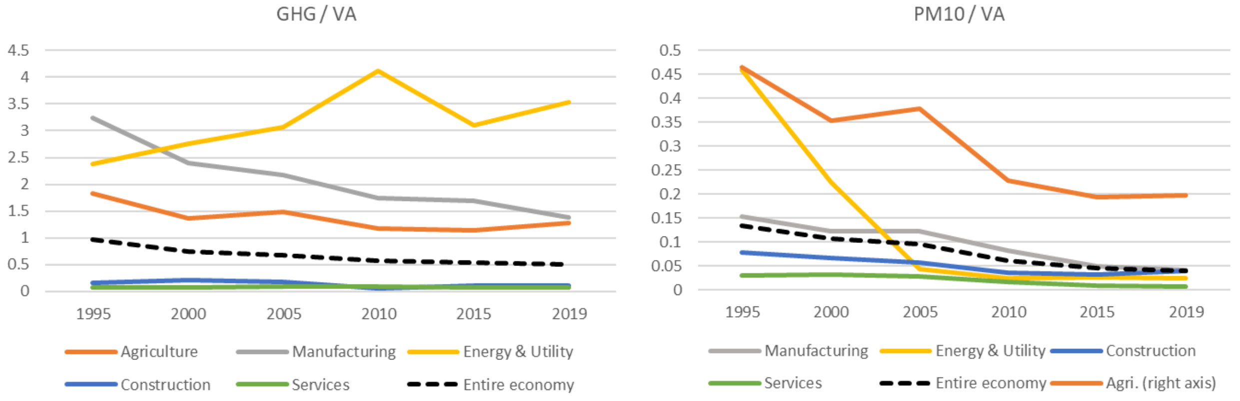


2.2 Regional evolution of eco-efficiency

The absolute evolution of economic activity and emissions alone do not capture how efficiently regional sectors generate output relative to their environmental pressure. To evaluate the environmental performance of Emilia-Romagna and Lazio in a more comparable way, this section moves from absolute profiles to relative indicators, focusing on emission intensity. Emission intensity—expressed here as GHG/VA and PM10/VA—serves as a relative measure of eco-efficiency, indicating how many emissions are produced per unit of value added. It essentially enables to show the extent to which economic growth has been accompanied by cleaner production patterns.

Figure 3 reports emission intensities for Emilia-Romagna across the five macro-sectors (Agriculture, Manufacturing, Energy & Utilities, Construction, and Services), separately for GHG/VA (left panel) and PM10/VA (right panel), together with the intensity for the entire economy. To improve readability, the PM10 intensity of Agriculture—substantially higher than the other sectors—is plotted on a secondary right axis. For interpretation, the GHG/VA indicator measures the kilograms of CO_2-equivalent emitted per euro of value added in each sector, while PM10/VA reflects the grams of PM10 emitted per euro of value added.

Figure 3. Sectoral emission intensities in Emilia-Romagna (1995–2019): GHG per value added (kg tonn CO_2-eq/millions €) and PM10 per value added (tonn PM10/millions €), by macro-sector. *Source: own elaboration RAMEA top-down panel*



Emission intensities in Emilia-Romagna have declined substantially over the 1995–2019 period. For the entire economy, GHG intensity falls from roughly 1.0 kg CO_2-eq/€ in 1995 to around 0.5 kg/€ in 2019, while PM10 intensity decreases from about 0.13 g/€ to 0.04 g/€, indicating a marked improvement in regional eco-efficiency. Across all sectors, both GHG/VA and PM10/VA exhibit a general downward trend, except for Energy & Utilities for GHG, where intensity increases in most of the period covered. This likely reflects a more carbon-intensive regional energy mix during the years—despite Emilia-Romagna's comparatively small role in national power generation.

Figure 4. Sectoral emission intensities in Lazio (1995–2019): GHG per value added (kg tonn CO_2-eq/millions €) and PM10 per value added (tonn/millions €), by macro-sector. *Source: own elaboration RAMEA top-down panel*

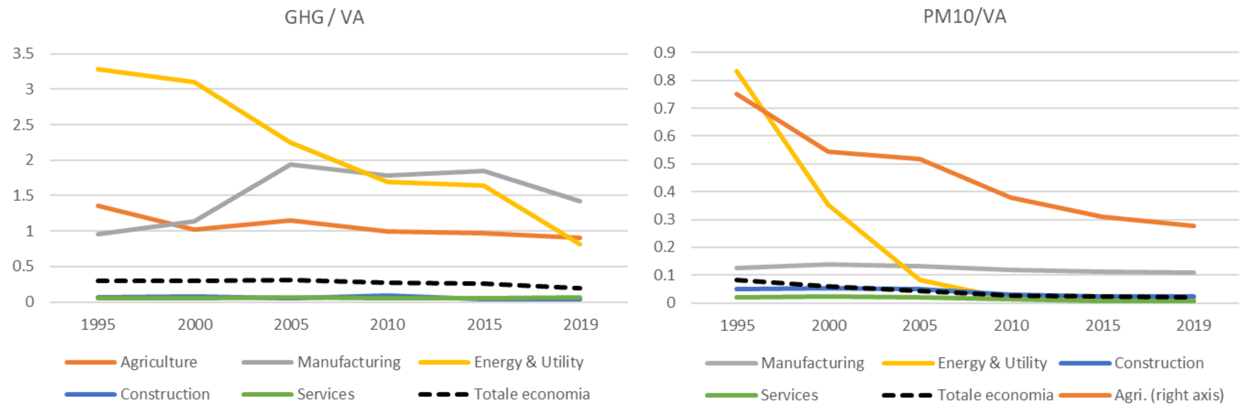


Figure 4 reports emission intensities for Lazio following the same logic adopted for Emilia-Romagna. For the entire economy, GHG/VA declines from roughly 0.3 kg CO_2-eq/€ in 1995 to around 0.2 kg/€ in 2019, while

PM10/VA falls from about 0.08 g/€ to 0.01 g/€, signalling substantial gains in eco-efficiency for both global and local pollutants. These values are significantly lower than those observed in Emilia-Romagna, reflecting the markedly different sectoral structure of the region: Lazio's economy is heavily service-based, with a far smaller manufacturing base and therefore lower emission intensity when measured per unit of value added.

Improvements in both GHG and PM10 intensity are largely driven by the progressive decarbonisation of the regional energy mix, with Energy & Utilities showing a dramatic decline—from about 3.2 to 0.8 kg CO_2-eq/€ for GHG and from 0.8 g/€ to 0.01 g/€ for PM10 between 1995 and 2019. This sector alone accounts for much of the aggregate reduction.

In contrast, manufacturing does not exhibit a decline in emission intensity; if anything, its GHG/VA profile shows mild deterioration over time. This pattern is consistent with the GHG peak around 2005 observed in the absolute data (Figure 2), where a relatively small but environmentally intensive manufacturing sector—combined with fluctuations in energy production—produces a trajectory that resembles the standard inverted-U EKC pattern for Lazio.

2.3 Decomposition analysis

Understanding how regional emissions evolve requires going beyond aggregate trends and emission-intensity indicators. Even when total emissions decline, the mechanisms behind that reduction can differ substantially across regions and across pollutants—implying very different policy interpretations. To disentangle these mechanisms, this section applies a standard decomposition framework that attributes changes in regional emissions to three core components: scale, industry composition, and technique (Dunn, 1960; Mazzanti and Montini, 2010). Scale captures how the overall size of the economy changes over time: all else equal, larger economies tend to emit more. Industry composition reflects changes in the sectoral structure—shifts toward cleaner activities (e.g. services) can reduce emissions even in the absence of technological progress. Technique, finally, measures genuine within-sector changes in environmental performance, such as energy-efficiency gains, abatement technologies, cleaner processes, and compliance with regulatory constraints.

While decomposition exercises are often conducted using value added as the scaling variable, at the regional level in Italy this perspective would miss a key dimension of the transition: how emissions evolve relative to employment. This labour-related dimension is central to regional labour–climate strategies and to the broader debate on just transitions, where the concern is not only whether emissions fall, but how decarbonisation interacts with jobs and sectoral reallocation. For this reason, we adopt a decomposition identity expressed in terms of emissions per worker, which enables us to separate the contribution of labour scale, employment structure, and sector-specific efficiency within a coherent accounting framework. This accounting perspective is particularly relevant at the sub-national level, where climate ambition must be aligned with regional development and employment objectives. Emilia-Romagna's *Patto per il Lavoro e per il Clima* is an explicit example of this approach: regional decarbonisation is framed not only as an environmental target, but as a strategy that must remain consistent with job quality, industrial competitiveness, and the ability of workers and firms to adjust. This link between emissions and employment also mirrors what emerges from international evidence on climate-policy support. Dechezleprêtre et al. (2025) show that public acceptance of climate policy rests on three connected questions: (i) whether policies are perceived as effective at reducing emissions; (ii) what the individual costs are (prices, taxes, constraints); and (iii) who is expected to gain and lose from the transition. Translating these concerns to the regional scale implies that credible climate strategies must make the "who wins/who loses" dimension visible—especially in terms of jobs and sectoral reallocation.

Formally, total emissions in region *r* at time *t* can be decomposed into:

$$E_{rt} = \underbrace{\frac{L_{rt}}{L_{r0}}}_{Scale} \times \underbrace{\sum_i s_{irt}\ k_{ir0}}_{Industry\ Composition} \times \underbrace{\frac{k_{irt}}{k_{ir0}}}_{Technique}$$

Where:

- E_{rt} = total emissions in region *r* at time *t*
- L_{rt} = total employment in region *r* at time *t*
- $s_{irt} = \frac{L_{irt}}{L_{rt}}$ is employment share in industry *i*, region *r* at time *t*
- $k_{irt} = \frac{E_{irt}}{L_{irt}}$ is emission intensity (emissions per worker) in industry *i*, region *r* at time *t*
- Subscript **0** = base year (1995)

By using employment rather than value added as the reference variable, the interpretation of the decomposition components shifts toward a labour-centred perspective. In this framework, scale reflects changes in total regional employment relative to the base year, industry composition captures shifts in the employment structure toward cleaner or more emission-intensive sectors, and technique measures changes in emissions per worker within sectors, thus isolating genuine improvements in environmental efficiency.

Figure 5 presents the results of this employment-based decomposition for PM10 emissions in Emilia-Romagna and Lazio, with all components indexed to 1995 = 100. As already shown in Figures 1 and 2, both regions experienced a substantial decline in particulate emissions between 1995 and 2019. Emilia-Romagna reduced PM10 emissions by approximately 62%, from about 15,600 tonnes to 6,000 tonnes, largely driven by improvements in manufacturing-related emissions. Lazio achieved an even larger reduction of roughly 73%, with emissions falling from around 13,400 tonnes to 3,600 tonnes, primarily due to changes in the energy production sector. The decomposition adds an important layer of interpretation to these descriptive patterns. In both regions, changes in employment scale and composition alone would not have generated comparable reductions. Instead, the results clearly point to the dominant role of technique effects in driving PM10 abatement[6]. As expected for a local pollutant with direct and locally perceived health impacts—hence more likely to trigger political salience, social consensus, and enforceable standards—the observed decline in PM10 emissions is not primarily driven by deindustrialisation or employment contraction, but by within-sector technological upgrading, abatement investment, and process improvements.

Figure 5. Decomposition of PM10 emissions by scale, composition, and technique in Emilia-Romagna and Lazio (1995 = 100). *Source: own elaboration RAMEA top-down panel*

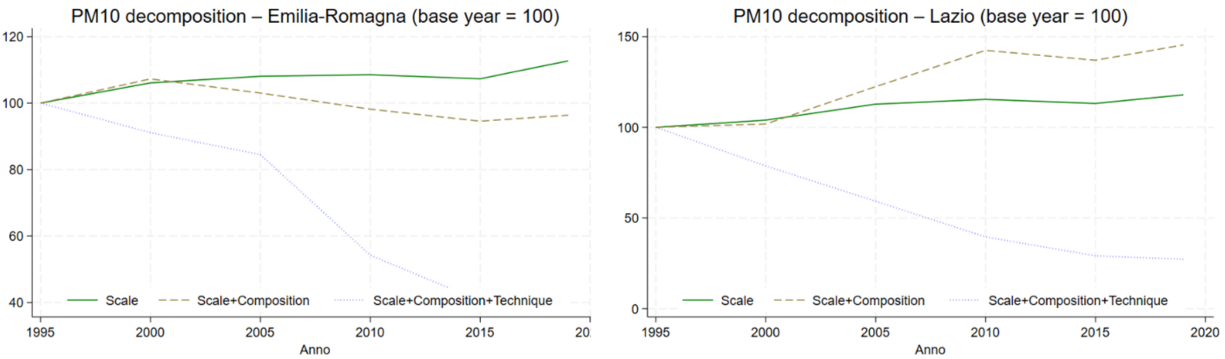


Figure 6 reports the corresponding employment-based decomposition for GHG emissions. As documented in Figures 1 and 2, GHG reductions are more moderate than those observed for PM10. Emilia-Romagna reduced CO_2-equivalent emissions by approximately 36%, from about 113,000 thousand tonnes in 1995 to 73,000 thousand tonnes in 2019, while Lazio recorded a reduction of around 24%, with emissions falling from roughly 47,500 to 36,500 thousand tonnes. In Emilia-Romagna, the decline is closely associated with manufacturing-related improvements, whereas in Lazio it is primarily linked to changes in the energy sector.

The decomposition highlights the central role of technique effects, which become particularly strong from around 2005 onwards. In Emilia-Romagna, technique improvements progressively outweigh the persistence of an emission-intensive industrial base, while in Lazio they account for the turning point observed around 2005 in the descriptive emission profiles. This timing is not coincidental. 2005 marks the start of Phase I of the EU Emissions Trading System (EU ETS), which for the first time introduced a binding carbon constraint for large emitters in energy production and energy-intensive manufacturing. Even though the pilot phase (2005–2007) was characterised by relatively low carbon prices and generous allowance allocation, it established monitoring, reporting, and verification requirements and created early incentives for firms to begin investing in abatement technologies and energy-efficiency measures.

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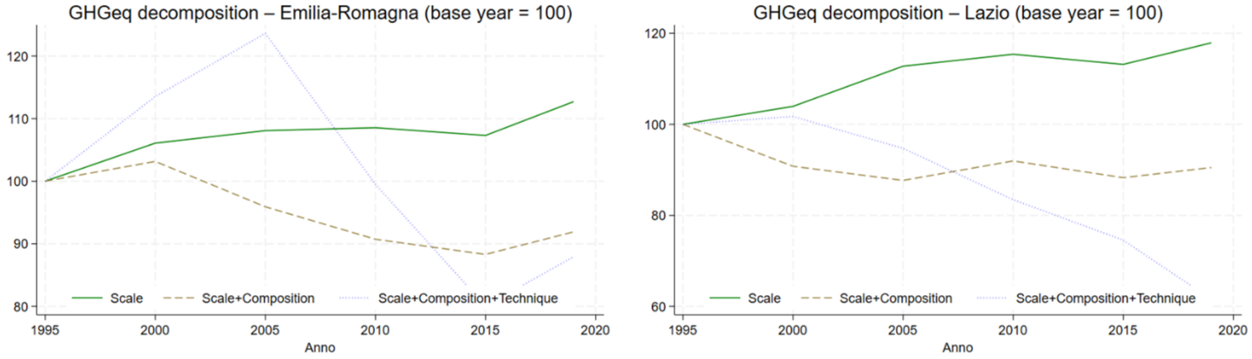
[6] The green line (Scale) shows how total emissions would change if only overall regional employment varied over time, keeping both sectoral structure and emissions per worker fixed at 1995 levels. The brown dashed line (Scale + Composition) also allows the employment structure across sectors to change, but still assumes no within-sector efficiency gains; the gap from green captures structural change. The blue dotted line (Scale + Composition + Technique) adds changes in emissions per worker, matching the observed path; the gap from brown identifies the technique effect (within-sector efficiency/technology improvements).

Figure 6. Decomposition of GHG emissions by scale, composition, and technique in Emilia-Romagna and Lazio (1995 = 100). *Source: own elaboration RAMEA top-down panel*



One of the key advantages of the RAMEA framework is its sectoral granularity, which allows decomposition analysis to be conducted not only at the level of the whole economy but also within specific macro-sectors. This feature is particularly valuable for manufacturing[7] (NACE section C), which plays a central role in regional emission dynamics and climate policy, especially in industrialised regions. When the analysis is confined to manufacturing, scale captures changes in manufacturing employment, composition reflects shifts across manufacturing sub-sectors with different emission intensities, and technique isolates changes in emissions per worker within manufacturing activities. As a result, structural effects now reflect intra-industrial reallocation rather than deindustrialisation.

Figure 7 reports the decomposition of GHG emissions in manufacturing sub-sectors for Emilia-Romagna and Lazio, indexed to 1995 = 100. Over the period 1995–2019, Emilia-Romagna experienced a substantial reduction in manufacturing-related GHG emissions of approximately 46%, confirming the central role of industrial decarbonisation in the region's overall emission trajectory. Lazio, by contrast, recorded a more modest decline of about 12%, consistent with its smaller and less emission-intensive industrial base.

The manufacturing-focused decomposition is particularly informative for Emilia-Romagna. The scale effect indicates a moderate contraction of manufacturing employment—around 8% relative to 1995 —which contributes only marginally to emission reductions. Changes in the manufacturing employment structure also play a role, as labour reallocates toward relatively cleaner manufacturing sub-sectors, but this composition effect remains secondary. The dominant driver of emission reductions is the technique effect, which becomes particularly strong from 2005 onwards and explains the bulk of the observed decline in manufacturing-related GHG emissions.

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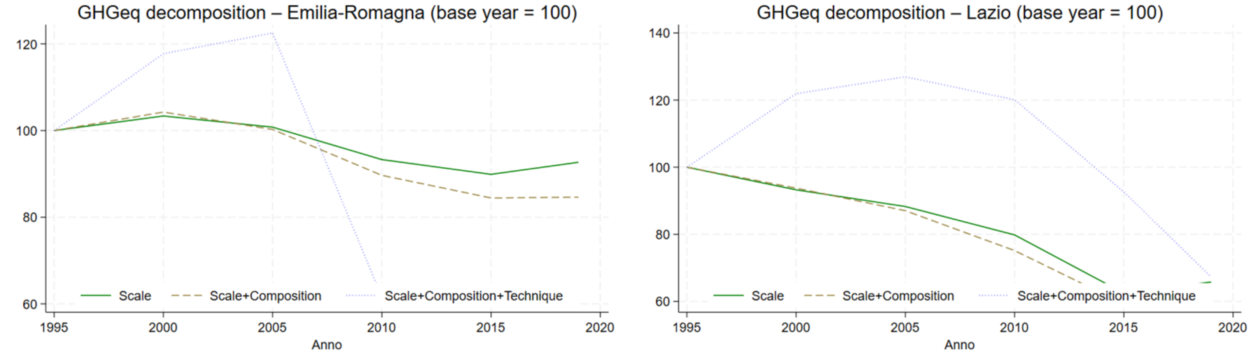
[7] Manufacturing activities in RAMEA (NACE Rev.2, Section C) are grouped into nine sectoral aggregates: C10–C12 (food, beverages, tobacco); C13–C15 (textiles, apparel, leather); C16–C18 (wood, paper, printing); C19–C21 (coke and refined petroleum, chemicals, pharmaceuticals); C22–C23 (rubber, plastics, non-metallic minerals); C24–C25 (basic metals and fabricated metal products); C26–C28 (electronics, electrical equipment, machinery); C29–C30 (motor vehicles and transport equipment); and C31–C33 (other manufacturing and repair).

Figure 7. Decomposition of GHG emissions in manufacturing sub-sectors (C) by scale, composition, and technique in Emilia-Romagna and Lazio (1995 = 100). *Source: own elaboration RAMEA top-down panel*



Importantly, the role of technique effects in manufacturing from 2005 onwards is not unique to Emilia-Romagna. Similar patterns emerge in other emission-intensive regions where manufacturing activity is concentrated. The next section builds on this evidence by moving from descriptive decomposition to econometric analysis, with the aim of assessing whether the observed post-2005 improvements in technique can be statistically linked to capital investment and EU ETS regulation in covered industries. Exploiting the sector–region panel structure of RAMEA.

2.4 Econometric application

The decomposition analysis carried out in the previous sections provides clear and consistent evidence that technique effects play a dominant role in driving the post-2005 reduction of GHG emissions, particularly within manufacturing activities in carbon emission-intensive regions. While the decomposition framework is powerful in isolating the relative contribution of scale, composition, and technique, it remains inherently descriptive. As such, it cannot establish whether the observed improvements in sector-level emission efficiency are causally linked to specific policy instruments or investment dynamics. This section complements the decomposition exercise with an econometric analysis aimed at testing whether the post-2005 improvement in environmental technique can be causally linked with capital investment dynamics in EU-ETS-regulated industries.

Building on the sectoral granularity of RAMEA, the econometric framework reformulates the Environmental Kuznets Curve (EKC) relationship at the sector–region level, following Mazzanti et al. (2008) and Marin and Mazzanti (2013). This approach departs from standard EKC specifications based on aggregate income or population and instead focuses on production-side. In this setting, environmental technical efficiency—measured as emissions per full-time equivalent worker—is modelled as a function of labour productivity, capital investment, and EU-ETS regulation, while controlling for unobserved region-sector heterogeneity and common macroeconomic shocks through fixed effects:

$$\ln\left(\frac{E_{rs,t}}{L_{rs,t}}\right) = \beta_1 \ln\left(\frac{VA_{rs,t}}{L_{rs,t}}\right) + \beta_2 \ln(\mathrm{K}_{rs,t}) + \beta_3 ETS_{rs,t} + \beta_4 \left[\ln(\mathrm{K}_{rs,t}) \times ETS_{rs,t}\right] + \alpha_{rs} + \gamma_t + \varepsilon_{rs,t} \qquad (1)$$

The econometric exercise is estimated on a balanced panel of region × manufacturing sub-sector (NACE section C) observations for Italy over the six RAMEA benchmark years (1995, 2000, 2005, 2010, 2015, 2019), for a total of 1,080 observations (20 regions × 9 manufacturing aggregates × 6 years). The dependent variable is $(E_{rs,t}/L_{rs,t})$, i.e. CO2eq emission per-worker in manufacturing sub-sector s and region r at time t. On the right-hand side, $(VA_{rs,t}/L_{rs,t})$ measures labour productivity, while $(K_{rs,t})$is gross fixed capital investment (source ISTAT), capturing capital deepening and the potential adoption of cleaner technologies. $ETS_{rs,t}$ is a policy dummy equal to one from 2005 onwards for sector–region observations covered by the EU Emissions Trading System, reflecting the introduction of binding carbon regulation for large emitters in energy and energy-intensive manufacturing. The interaction term between capital investment and the ETS dummy tests whether capital accumulation has a differential effect on emission intensity in regulated sectors relative to non-regulated ones. The model is estimated in log–log form, allowing the coefficients to be interpreted as elasticities. Region–industry fixed effects (α_{rs}) control for time-invariant structural differences in production technologies, industrial composition, and regulatory environments, while year fixed effects (γ_t) absorb common macroeconomic shocks, business cycles, and nationwide policy changes. As a result, identification relies on within-industry, within-region variation over time.

Table *1* shows regression results. Although the relationship between $\ln(VA/L)$and $\ln(CO_2/L)$can be framed within an EKC-type specification (Marin & Mazzanti, 2013), here it mainly serves as a productivity control to account for time-varying differences in sectoral performance and scale within each region–subsector. In the baseline model, $\ln(K)$ is weakly negative, suggesting that capital deepening can be associated with lower CO2-intensity, but the key insight emerges once regulation is allowed to condition this link. In column (2), the interaction term $\ln(K) \times ETS$ is negative and significant, while the ETS dummy alone is not statistically different from zero. This pattern is consistent with a "policy–investment complementarity" mechanism: ETS coverage does not mechanically reduce emissions per worker on its own, but it is associated with stronger emission reductions when accompanied by investment (i.e., when investment is plausibly directed toward energy efficiency, process upgrading, or abatement required/induced by compliance).

Table 1. Regression results of Model (1) for manufacturing sub-sectors (C). *Source: own elaboration RAMEA top-down panel*

	(1) ln(CO2/L)	(2) ln(CO2/L)
ln(VA/L)	0.483***	0.516***
	(0.119)	(0.108)
ln(K)	-0.0841	-0.0586
	(0.0517)	(0.0455)
ETS_dummy	-0.0720	0.373
	(0.0849)	(0.250)
ETS_ dummy#ln(K)		-0.0918**
		(0.0432)
Constant	1.038*	0.782
	(0.556)	(0.504)
Industry-Region FE	YES	YES
Year FE	YES	YES
Observations	1,080	1,080
R-squared	0.891	0.892

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3. Discussion and conclusions

This working paper illustrates the analytical potential of a RAMEA regional panel (1995–2019) by combining descriptive profiling, eco-efficiency indicators, decomposition analysis, and a targeted econometric exercise. The empirical applications highlight how RAMEA-based accounting can move beyond static reporting to support interpretation of long-run environmental–economic dynamics and, crucially, to distinguish between alternative transition pathways that may look similar in aggregate but imply very different sectoral and labour-market adjustments.

A first message is that regional structure matters not only for the level of emissions but also for the way decarbonisation unfolds. The comparison between Emilia-Romagna and Lazio captures two distinct production models within the same national policy context. Emilia-Romagna combines a service-dominated economy with a persistently strong manufacturing base—both in value added and employment—yet exhibits a sustained decline in GHG and PM10, suggesting environmental upgrading within an industrialised economy rather than simple industrial retreat. Lazio, by contrast, is structurally more service-centred and hosts a smaller industrial base, so its emissions profile is shaped less by manufacturing and more by energy-related and service-linked activities; consistent with this structure, its GHG path displays a clearer turning point around the mid-2000s. These differences already indicate why regional decarbonisation cannot be interpreted through aggregate national indicators alone: the same national policy environment translates into heterogeneous trajectories because regions differ in sectoral composition and in the relative weight of emission-intensive activities.

A second message concerns the shift from levels to intensities as a measure of eco-efficiency. Emission intensity indicators (GHG/VA and PM10/VA) show strong improvements in both regions, but also reveal that "cleaner" intensity levels can reflect structural composition as much as technological performance. Lazio's lower economy-wide intensities are largely consistent with the mechanical effect of a service-heavy economy, while Emilia-Romagna's higher intensities reflect its manufacturing specialisation. This is precisely why eco-efficiency indicators are most informative when interpreted together with the underlying structural profiles: intensities allow comparison across time and space, but their levels are inseparable from the production structure that generates value added and employment.

The decomposition analysis provides the key interpretative step, because it clarifies where improvements come from. By decomposing emission changes into scale, composition, and technique—and doing so in terms of emissions per worker—the paper aligns the environmental accounting exercise with the sub-national policy challenge of reconciling climate ambition with employment and structural adjustment. This is particularly relevant in contexts such as Emilia-Romagna, where the Patto per il Lavoro e per il Clima explicitly frames decarbonisation together with jobs, competitiveness, and social cohesion. More broadly, it speaks to the political economy of climate policy: international evidence shows that support for climate action depends not only on perceived effectiveness but also on perceived individual costs and distributional consequences—who gains and who loses. A labour-centred decomposition makes this distributional dimension legible at the regional scale by distinguishing emission reductions driven by employment contraction from those driven by within-sector efficiency gains. The econometric exercise is designed to complement decomposition by moving from "what happened" to "why it happened". Decomposition identifies timing and sectoral concentration—especially the post-2005 strengthening of technique effects—while econometrics tests whether these patterns are systematically associated with plausible drivers, in particular capital investment under regulatory exposure.

A final implication concerns what this evidence enables beyond retrospective analysis. The same sectoral and geographical granularity that supports decomposition and econometrics also makes RAMEA a natural bridge to scenario building when integrated with regional input–output (IO) models. Linking RAMEA emissions accounts to IO structures allows policymakers to simulate how alternative development pathways—industrial upgrading, electrification, shifts in final demand, or targeted investment programmes—propagate through inter-industry linkages, generating not only direct emission changes but also indirect upstream and downstream effects. This integration is particularly valuable at the regional level, where policy mixes often aim to jointly steer production structure, employment, and environmental outcomes. In practice, a RAMEA–IO framework can support ex ante assessments of "just transition" packages by quantifying trade-offs and co-benefits across sectors (emissions, value added, and jobs) under different assumptions about technology, energy mixes, and demand reallocation.

Overall, the paper shows that sectoral and geographical granularity is not a technical detail but a substantive advantage. It enables in-depth analysis of structural change, technology and efficiency dynamics, and region–sector heterogeneity that aggregate indicators hide. For firms, RAMEA-type hybrid accounting can strengthen self-assessment by providing meaningful benchmarks for economic and environmental performance and by supporting continuous monitoring approaches that underpin certification and management systems (e.g., ISO and EMAS). For policymakers, NAMEA/RAMEA provides evidence on the effects and channels of climate-, energy-, and circularity-related policies at macroeconomic and meso (sectoral/regional) levels, supporting tailored policy design that accounts for technological differences and heterogeneous abatement costs. In this sense, RAMEA supports a practical “toolbox” of regional transition policies—standards, targeted subsidies, taxes, and voluntary agreements—aimed at aligning emissions reduction with employment and competitiveness.

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