Results in Engineering 30 (2026) 110314

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Research paper

Spain's decarbonisation to 2030: An integrated LMDI–LEAP assessment

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ARTICLE INFO

Keywords:
LMDI
LEAP
Spain
Energy policy
Decarbonisation

ABSTRACT

Spain's National Energy and Climate Plan (PNIEC) requires deep decarbonisation, yet it remains unclear whether current trends are sufficient to meet the 2030 targets. This study integrates an LMDI decomposition of energy-related CO_2 emissions (1990–2024), aligned with PNIEC sector categories, with a trend-based LEAP projection to 2030, and benchmarks results against the official PNIEC targets. The LMDI analysis shows that economic activity is the main upward driver of emissions, while energy-efficiency improvements and cleaner fuel substitution exert mitigating effects; however, transport and industry exhibit persistent inertia. Under the Baseline scenario, the TES-based CO_2 proxy reaches −15.8% relative to 1990 by 2030, far from the PNIEC target of −32.0% (a 16.2 percentage-point gap). Supply-side progress outpaces demand-side transformation: renewable electricity reaches 89.0% of generation versus the 81.0% PNIEC benchmark, whereas electrification in final energy reaches only 25.8% versus the 35.0% target, leaving most of the gap concentrated in diffuse end-use sectors. These findings provide a transparent diagnostic framework for identifying where additional measures are required to align Spain's current trajectory with its 2030 decarbonisation commitments.

1. Introduction

In recent decades, the global energy and climate landscape has been reshaped by geopolitical tensions, volatile energy markets, and increasingly ambitious climate commitments. The COVID-19 pandemic, the war in Ukraine, and the intensification of conflict in the Middle East have exposed the vulnerability of energy systems that remain heavily reliant on fossil fuels. Moreover, the 2018 IPCC report underscored the urgent need to limit global warming to 1.5°C by reducing CO_2 emissions by 45% by 2030 [1]—a target enshrined in the Paris Agreement at COP21 [2] and reaffirmed at recent climate summits. Nevertheless, the conclusions of COP30, held in Belém (Brazil), again highlighted the difficulty of advancing the phase-out of fossil fuels despite the efforts of the European Union and other nations [3]. At the same time, reports such as the Global Carbon Budget indicate that global CO_2 emissions reached a record high in 2024, driven by growth in India, China, and other emerging economies, although emissions declined in the United States and the European Union [4]. Together, these developments confirm the persistent gap between international climate commitments and actual outcomes.

In the European Union (EU), the war in Ukraine triggered an energy crisis that accelerated the evolution of the political and regulatory framework:

- The *Fit for 55* legislative package was adopted to reduce greenhouse gas emissions by 55% by 2030, laying the foundations for climate neutrality by 2050, as set out in the European Green Deal [5].
- Subsequently, *REPowerEU* was launched to complement these efforts by reducing dependence on Russian fossil fuels and accelerating renewable energy deployment [6].

Beyond regulatory packages, achieving high shares of variable renewable energy also depends on sustained technological progress to ensure reliable grid integration and compliance with power-quality requirements. Recent work on wind energy systems, for instance, highlights ongoing improvements in turbine control and operational performance under variable wind and grid conditions, supporting supply-side decarbonisation efforts [7,8]. In parallel, contemporary green-engineering research also points to innovation in renewable generation technologies,

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https://doi.org/10.1016/j.rineng.2026.110314
Received 22 January 2026; Received in revised form 10 March 2026; Accepted 27 March 2026
Available online 28 March 2026

Abbreviations

CO_2	Carbon dioxide.
CO_2eq	Carbon dioxide equivalent.
FEC	Final energy consumption.
GHG	Greenhouse gases.
LEAP	Low Emissions Analysis Platform.
LMDI	Logarithmic Mean Divisia Index.
PNIEC	Spain's Integrated National Energy and Climate Plan.
pp	Percentage points.
RES	Renewable energy sources.
TES	Total energy supply.
EU	European Union.

including nanostructured photovoltaic concepts—such as heterojunction quantum-dot solar-cell architectures—proposed to enhance conversion performance and improve material efficiency [9,10]. The diffusion of advanced materials and power-electronics-intensive assets also raises additional sustainability considerations, including economic viability, safe handling and occupational practices, and end-of-life management for specific material classes. While these aspects are not assessed in this paper, they form part of the broader sustainability context in which low-carbon technologies are deployed. These enabling factors reinforce rapid progress on the supply side, but they do not remove the need for economy-wide structural change—particularly in end-use sectors—which motivates the integrated LMDI–LEAP assessment and PNIEC benchmarking developed in this study.

Despite this progress, the EU continues to display considerable heterogeneity among Member States, both in the evolution of emissions and in the composition of energy mixes. This divergence underscores the need for a detailed examination of the structural determinants of emissions in order to assess convergence across countries and evaluate the effectiveness of existing climate policies.

Spain constitutes a relevant case study within the broader European context, having experienced rapid renewable deployment over recent decades and now exhibiting high renewable penetration in the power system [11–14]. This progress, however, coexists with persistent structural imbalances on the demand side, including strong dependence on oil in transport and insufficient electrification in industry. Earlier evidence documented this supply–demand asymmetry in Spain: while policy instruments succeeded in deploying renewables, comparatively limited emphasis on demand-side efficiency contributed to high energy intensity and sustained growth in final energy demand, particularly in transport and buildings [11]. In response to these challenges, the Integrated National Energy and Climate Plan (PNIEC) 2023–2030 was updated in 2023, introducing more ambitious targets and sector-specific measures [15]. These persistent demand-side bottlenecks—namely, slow electrification and limited fuel substitution in key end-use sectors—raise a critical question: are current trends unfolding rapidly enough to meet the PNIEC targets for 2030?. Despite the strategic significance of the PNIEC, an important gap remains in the academic literature: the absence of a long-term assessment that disaggregates emissions at both national and sectoral levels while incorporating recent developments shaped by the COVID-19 pandemic, the subsequent energy crisis, and marked changes in the national energy mix.

Although there is extensive literature on the factors driving emissions, most studies on Spain or the EU examine comparatively short periods, rely on aggregate energy data, or remain limited to the national level without incorporating the sectoral structure defined in the Spanish PNIEC. Furthermore, available analyses seldom integrate recent changes in the energy mix following the pandemic and the 2021–2023 energy crisis, nor do they combine historical decomposition with prospective energy-system modelling. This limits the rigorous evaluation of Spain's decarbonisation pathway and its alignment with national climate targets. This paper examines whether the continuation of recent trends is sufficient to meet Spain's PNIEC 2030 targets. By combining a long-horizon, PNIEC-aligned LMDI diagnosis with a trend-based LEAP projection, we quantify the policy gap and identify the main sectoral bottlenecks (see Section 2.3).

In light of these limitations, the objective of this study is twofold. First, it analyses the evolution of CO_2 emissions in Spain at national and sectoral level using an expanded version of the Kaya identity, disaggregating energy by fuel type (solid, liquid, gas, and renewable) and applying the LMDI technique, following approaches adopted in previous research [16–19]. Second, this historical decomposition is integrated with a forward-looking model of the Spanish energy system using LEAP (Low Emissions Analysis Platform) software [20]. In particular, LEAP explicitly represents sectoral energy demand through an activity–intensity structure and links end-use electrification to the evolution of the electricity generation mix, thereby translating the historically identified bottlenecks into a transparent trend-based assessment to 2030. LEAP is used to construct a trend-based baseline scenario to 2030, which is then compared with the PNIEC 2030 targets in order to quantify the policy gap and assess whether the current trajectory is sufficient to meet the planned decarbonisation objectives.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on LMDI/Kaya decomposition and LEAP-based energy modelling. Section 3 describes the datasets and methodological framework, including the national and sectoral LMDI formulations and the LEAP model calibration and baseline design. Section 4 reports the results from the historical decomposition and the trend-based LEAP outlook to 2030, including benchmarking against PNIEC targets. Section 5 discusses the policy implications and methodological insights. Section 6 concludes with the main messages and recommendations.

2. Literature review

The decomposition of emissions based on Kaya's identity [21], particularly when combined with the LMDI approach, is one of the most widely used frameworks for analysing the structural drivers of CO_2 emissions due to its additive and multiplicative consistency. In the literature, index decomposition analysis (IDA) [22,23] is often used to examine structural changes, particularly variations in the industrial product mix and energy sector dynamics. In contrast, structural decomposition analysis (SDA) [24,25] is applied to analyse changes in energy and emissions indicators. The main distinction lies in the level of disaggregation: SDA uses input–output information for certain variables, whereas IDA relies on aggregated sector-level data [26]. Both approaches provide valuable sectoral insights but differ in data requirements and analytical scope. This review therefore focuses on the evidence most relevant to PNIEC-aligned sectoral assessment and long-term emission drivers [27].

In parallel, the energy planning literature has widely employed modelling tools such as LEAP to analyse future scenarios and mitigation strategies. However, historical decomposition and prospective modelling have generally evolved as separate strands, limiting their ability to jointly explain past dynamics and future trajectories of energy systems. Recent studies have begun to bridge this gap by integrating LMDI-based driver analysis within long-term energy planning frameworks, linking historical drivers with scenario design [28]. Similar hybrid approaches combine decomposition (LMDI) with LEAP-based scenario analysis to connect macro drivers with energy-system pathways, although these applications are typically developed for local or sector-specific contexts [29].

This section reviews the main contributions in this field for Spain and the European Union and highlights the gaps that motivate the present study.

To synthesise the existing evidence, Tables 1 and 2 summarise the main studies on emission decomposition (LMDI/Kaya) and energy system modelling (LEAP/PNIEC), respectively, focusing on temporal scope, geographical coverage, sectoral structure, and methodological limitations.

Table 1
Comparative summary of previous studies on emission decomposition with LMDI relevant to Spain and the EU.

Study	Period	Level	Scope	Comments
Fernández González et al. [30]	2001–2008	EU-27	Aggregated	Macro comparison between energy mix and CO_2 levels.
Marcucci and Fragkos [31]	2100 prospective	EU-28, USA, China, India	Aggregated	Carbon intensity reduction emerges as key strategy.
Cansino et al. [32]	1995–2009	Spain	35 WIOD sectors (multi-sectoral)	Short horizon; not aligned with PNIEC.
Colinet and Collado [33]	2003–2012	Andalusia	Services, primary, transport, residential, industry	Reductions linked to structural and intensity effects.
Moutinho et al. [34]	1995–2010	EU-15	Aggregated	Reductions in CO_2 driven by intensity and renewables.
Madaleno et al. [35]	1995–2014	EU-28	Aggregated	Dependence on petroleum and energy intensity as main drivers.
Lima et al. (2017) [36]	1990–2012	Multi-country	Aggregated	Structural view on energy consumption; no emissions breakdown.
Román-Collado et al. [37]	2000–2013	Spain	Multi-sectoral	LMDI; Breakdown of factors driving energy consumption (without emissions). Emphasis on domestic consumption.
Cansino et al. (2019) [38]	2000–2015	Spain	Multi-sectoral	Study based on three national action plans (not including the PNIEC). Study of the rebound effect for energy efficiency measures.
Román Collado et al. [39]	2000–2015	Andalusia	Industry, residential, transport	Regional insights; not generalisable to PNIEC.
Serrano-Puente [40]	1995–2017	EU-28	Multi-sectoral	Analysis of primary energy and carbon dioxide emissions in economic and non-productive sectors. Not PNIEC.
Papiez et al. [41]	1996–2017	EU-28	Aggregated	No sector resolution; Not PNIEC.
Ortega-Ruiz et al. [42]	1990–2018	EU, USA, China, Russia, India and Japan	Aggregated	Decomposition of CO_2 emissions. Economy growth has been the main driving force that increases CO_2 emissions.
Koval et al. [43]	1995–2021	EU-25	Aggregated (Electric power sector)	Individual contribution of Member States to changes in energy transformation.
Bianco et al. [44]	1995–2019	EU-27	Aggregated	EU-wide trends; lacks sectoral and fuel differentiation but introduces the climate factor in its breakdown of emissions.
Cámara-Aceituno et al. [19]	1990–2021	EU-27	Aggregated	LMDI and convergence analysis; EU-wide trends; It uses five simple factors for the breakdown but does not take into account the PNIEC or sectoral structure.
Rivera-Niquepa et al. (2025) [45]	1995–2020	Spain	Multi-sectoral	LMDI; Sectoral breakdown into seven sectors not related to the PNIEC. No mention of the PNIEC.

Table 2
Review of energy system modelling studies evaluating the PNIEC.

Study	Level	Methodology	PNIEC	Comments
García-Gusano et al. [46]	Spain	Energy modelling (LEAP).	No	LEAP electrical modelling; not PNIEC.
Parrado-Hernando et al. [47]	Spain	Energy modelling.	Yes	Modelling of the energy matrix of the electricity sector.
Auguádra et al. [48]	Spain	Renewable Energy Integration modelling	Yes	No breakdown; no sectorisation; highlights the need to increase energy storage capacity.
Sáez et al. (2023) [49]	Spain	Photovoltaic potential modelling	Yes	Insufficient PV self-consumption potential in terms of PNIEC. Policy makers are urged to promote it.
Parrado-Hernando et al. [50]	Spain	Electricity sector modelling	Yes	Study the sensitivity of energy supply (2017–2020), showing results below the 2030 horizon.
Galán-Cano et al. [51,52]	Andalusia (Spain)	Energy modelling (LEAP)	Yes	Scenarios aligned exclusively with the regional PNIEC, not the national one.

2.1. Review of studies based on factorial decomposition of energy and emissions

As shown in Table 1, most LMDI applications to Spain or the EU rely on aggregated sectoral structures or relatively short time horizons, usually ending around 2021. Although multisectoral analyses exist, their sector definitions are heterogeneous and rarely aligned with the PNIEC framework. Moreover, none of the studies include the post-pandemic period or the 2021–2023 energy crisis, nor do they provide a consistent breakdown of solid, liquid, gas, and renewable energy sources. As a result, the literature provides only a partial view of the long-term structural dynamics relevant to Spain's decarbonisation strategy. A more complete assessment would require extending the analysis closer to the 2030 horizon established by the PNIEC.

2.2. Review of studies that develop models related to LEAP and PNIEC

Table 2 shows that LEAP has been widely used in Spain to analyse electricity demand, renewable integration, storage needs, and PNIEC-related challenges. However, these studies usually focus on the electricity system, use simplified sectoral structures, and do not include historical decomposition analysis. Some recent studies have integrated LEAP with LMDI to support scenario analysis and mitigation pathways, but these applications are generally limited to local or sector-specific contexts (e.g., industrial clusters) rather than PNIEC-aligned national benchmarking [29]. Consequently, although these works provide valuable insights into system operation and technological requirements, they do not connect prospective scenarios with the structural drivers observed in previous decades. While some studies address regional cases, a gap remains at the national scale.

2.3. Novelty of the proposed research

Across both strands of the literature, three main gaps can be identified:

1. No LMDI study for Spain covers the full 1990–2024 period, including the pandemic and the 2021–2023 energy crisis.

Table 3
Positioning of the proposed framework relative to common standalone approaches in the literature. Own elaboration.

Focus	Previous studies	Current study
Coverage	Often shorter horizons; limited post-2021 evidence	1990–2024 LMDI + Baseline projection to 2030
Structure	Mixed sector definitions; coarse fuel detail	PNIEC sectors + solid/liquid/gas/RES split
Linkage	Drivers or scenarios analysed separately	Drivers interpreted via Baseline vs PNIEC targets
Output	Explanatory drivers or scenario narratives	KPI-based PNIEC gap and sectoral bottlenecks

Table 4
Reclassification of INE economic activities into the sectoral structure adopted in this study.

Sector	Included activities
Primary	Agriculture, livestock, forestry and fishing.
Industrial	Mining and quarrying; electricity, gas, steam and air-conditioning supply; water supply, sewerage and waste management; manufacturing; construction.
Services	Wholesale and retail trade; repair of motor vehicles; transport and storage; accommodation and food services; information and communication; real estate activities; professional, scientific and technical activities; administrative and support services; public administration and defence; compulsory social security; education; human health and social work; arts, entertainment and recreation; other service activities; activities of households as employers of domestic staff and as producers of goods and services for own final use.

2. No sectoral decomposition fully aligns with the PNIEC structure (residential, services, industry, primary, transport) while simultaneously disaggregating solid, liquid, gas, and renewable energy.
3. Although a limited number of studies combine LMDI and LEAP for scenario analysis in specific contexts, no previous work applies a PNIEC-aligned national framework for Spain with explicit benchmarking of a trend-based baseline against PNIEC 2030 targets within a unified historical–prospective assessment.

This study addresses these gaps and proposes an analytical framework that allows a systematic comparison between future policy pathways and the historical behaviour of emission drivers. The analysis identifies sectors structurally aligned with the decarbonisation trajectory and those still characterised by activity-driven emission growth, linking structural change, energy efficiency, and fuel substitution effects to the PNIEC sectoral structure. In this way, the framework provides an ex-ante diagnostic tool for evaluating the internal coherence and feasibility of national climate policy objectives, while also offering a structured interpretation of historical dynamics.

Table 3 summarises the positioning of the proposed framework relative to common standalone approaches in the literature.

3. Data and methods

3.1. Data sources

The analysis uses publicly available data from official international and national sources. The study period covers 1990–2024 for the national decomposition and 1995–2024 for the sectoral analysis, with 2024 used as the base year for LEAP model calibration.

– **GDP and population**: Gross domestic product (GDP) and population data were obtained from the World Bank, which provides long historical series for 1990–2024 [53]. These data were cross-checked with Eurostat [54], which provides harmonised European series from 1995 onwards. GDP values are expressed in constant 2020 euros to remove inflation effects and ensure consistency in real economic growth comparisons.

– **Sectoral economic data**: Sectoral gross value added (GVA), expressed in constant euros, was obtained from the Spanish National Statistics Institute (INE) [55]. Based on the original INE classification, activities were regrouped according to the sectoral structure adopted in this study (the residential and transport sectors do not require further disaggregation), as shown in Table 4.

– **National and sectoral energy data**: Energy consumption by sector and fuel type was obtained from Eurostat energy balances, expressed in kilotonnes of oil equivalent (ktoe) [56]. Total energy supply at national level was also obtained from Eurostat [57]. Fuels were classified into four categories: solid fossil fuels, liquid fossil fuels, fossil gas, and renewable energy sources.

– **CO_2 emission factors**: CO_2 emissions were estimated from energy consumption using IPCC emission factors [58] for each fossil fuel type: solid: 4082.13 $kgCO_2$/toe; liquid: 3068.92 $kgCO_2$/toe; gas: 2348.79 $kgCO_2$/toe.

All energy values are expressed in kilotonnes of oil equivalent (ktoe), following Eurostat methodology to ensure comparability across time and sectors. Where minor discontinuities arose from methodological revisions in the energy balances, official Eurostat adjustments were applied and no additional estimates were introduced. GVA and GDP were converted into constant, harmonised units (base year 2020) to avoid inflation-driven distortions. No interpolation or synthetic data generation was performed, preserving the integrity of the original datasets.

According to the official Spanish energy balances published by IDAE [59], electricity generation accounts for approximately 65% of total domestic energy production in Spain in the base year. More specifically, gross electricity generation amounts to 24,756.2 ktoe, compared with total primary energy production of 38,628.5 ktoe. This structural feature highlights the central role of the electricity sector in Spain's energy system and provides the empirical basis for placing particular emphasis on electricity generation and electrification pathways in the prospective analysis.

Energy demand and generation data were validated and harmonised using official statistics from IDAE and the Spanish Transmission System Operator [60]. This ensures consistency between national energy balances and electricity system data and supports the calibration of the LEAP model for the 2024 base year.

Model verification and base-year calibration. LMDI numerical correctness is verified by reporting the additive residual $R = \Delta C_{\text{tot}} - \sum_i \Delta C_i$, which is negligible (national max $|R| = 7.6 \times 10^{-6}$; sectoral max $|R| = 2.6 \times 10^{-8}$; Appendix A, Section A.1, Tables A.1–A.2). LEAP base-year (2024) calibration is verified by benchmarking exported sector totals against the official energy-balance inputs used to build the model; the maximum absolute relative deviation is 0.016% for sectoral final energy demand and 0.0487% for final-energy-based CO_2 at the reported aggregation level (Appendix A, Section A.2, Tables A.3 and A.4). Full yearly additive series are reported in Appendix B.

3.2. Methodology

3.2.1. The Kaya identity

The first step of the analysis is to define the factors driving CO_2 emissions. This study uses the Kaya identity [21], which decomposes emissions into multiplicative components reflecting demographic, economic, and energy-system characteristics.

For the national analysis, two complementary decomposition exercises are carried out: (i) an aggregated decomposition for the whole economy; and (ii) a sectorally disaggregated decomposition aligned with the PNIEC structure.

At the aggregated level, total CO_2 emissions can be expressed as:

$$C = \sum_j C_j = \sum_j P\left(\frac{Q}{P}\right)\left(\frac{E}{Q}\right)\left(\frac{E_j}{E}\right)\left(\frac{C_j}{E_j}\right) = P \cdot q \cdot EI \cdot \sum_j M_j \cdot U_j, \tag{1}$$

where:

- P denotes population,
- $q = Q/P$ is GDP per capita,
- $EI = E/Q$ is the energy intensity of the economy,
- $M_j = E_j/E$ is the share of fuel j in total energy use,
- $U_j = C_j/E_j$ is the CO_2 emission factor of fuel j.

This formulation provides the basis for extending the Kaya identity to sectoral factors. Accordingly, the national decomposition structure in Cámara-Aceituno et al. [19] is adapted and complemented with elements from related studies [38,45] to establish a PNIEC-aligned sector–fuel decomposition framework. Total emissions are defined as the sum of emissions from each sector j and each fuel type r:

$$C = \sum_{j=1}^{k} \sum_{r=1}^{m} C_{jr}. \tag{2}$$

For each sector–fuel combination, emissions can be expressed as:

$$C_{jr} = P \cdot \left(\frac{Q}{P}\right) \cdot \left(\frac{Q_j}{Q}\right) \cdot \left(\frac{E_j}{Q_j}\right) \cdot \left(\frac{E_{jr}}{E_j}\right) \cdot \left(\frac{C_r}{E_{jr}}\right), \tag{3}$$

which can be written more compactly as:

$$C = P \cdot q \cdot \sum_{j=1}^{k} \left[S_j \cdot EI_j \cdot \sum_{r=1}^{m} M_{jr} \cdot U_r \right], \tag{4}$$

where:

- $S_j = Q_j/Q$ (sectoral share),
- $EI_j = E_j/Q_j$ (sectoral energy intensity),
- $M_{jr} = E_{jr}/E_j$ (sectoral fuel mix),
- $U_r = C_r/E_{jr}$ (emission factor).

3.2.2. The Logarithmic Mean Divisia Index (LMDI)

To quantify the contribution of each driving factor in Kaya's identity, the additive Logarithmic Mean Divisia Index (LMDI) method is applied. This method was originally proposed by Ang et al. [61,62] and has been widely used in later studies. Following the standard formulation, the total change in CO_2 emissions between a base year 0 and a target year T is expressed as:

$$\Delta C = C^T - C^0 = \Delta C_{\text{pop}} + \Delta C_{\text{act}} + \Delta C_{\text{int}} + \Delta C_{\text{mix}}, \tag{5}$$

where the emission–factor term is omitted because fuel–specific emission factors remain constant over time.

To simplify notation, the logarithmic–mean weight associated with sector j and fuel r is defined as:

$$w_{jr} = \frac{C_{jr}^T - C_{jr}^0}{\ln C_{jr}^T - \ln C_{jr}^0}. \tag{6}$$

This weighting factor, widely used in the LMDI literature, guarantees an exact decomposition with no residual term. In practice, only negligible floating-point residuals may appear; these are reported for transparency in Appendix A, Section A.1.

Table 5
Comparison between national and sectoral LMDI formulations. Own elaboration.

Effect	National LMDI	Sectoral LMDI
Population	$\Delta C_{\text{pop}} = \left(\sum w_{jr}\right) \ln\left(\frac{P^T}{P^0}\right)$	$\Delta C_{\text{pop}} = \sum w_{jr} \ln\left(\frac{P^T}{P^0}\right)$
Economic activity	$\Delta C_{\text{act}} = \left(\sum w_{jr}\right) \ln\left(\frac{q^T}{q^0}\right)$	$\Delta C_{\text{act}} = \sum w_{jr} \ln\left(\frac{q^T}{q^0}\right)$
Sectoral structure	—	$\Delta C_{\text{sec}} = \sum w_{jr} \ln\left(\frac{S_j^T}{S_j^0}\right)$
Energy intensity	$\Delta C_{\text{int}} = \left(\sum w_{jr}\right) \ln\left(\frac{EI^T}{EI^0}\right)$	$\Delta C_{\text{int}} = \sum w_{jr} \ln\left(\frac{EI_j^T}{EI_j^0}\right)$
Energy mix	$\Delta C_{\text{mix}} = \left(\sum w_{jr}\right) \ln\left(\frac{M_r^T}{M_r^0}\right)$	$\Delta C_{\text{mix}} = \sum w_{jr} \ln\left(\frac{M_{jr}^T}{M_{jr}^0}\right)$

When the Kaya identity is extended to the sectoral level, the decomposition includes the sectoral share effect. Thus, the total change in emissions becomes:

$$\Delta C = \Delta C_{\text{pop}} + \Delta C_{\text{act}} + \Delta C_{\text{sec}} + \Delta C_{\text{int}} + \Delta C_{\text{mix}}. \tag{7}$$

The explicit expressions for each effect in both the national (aggregated) and sectoral decomposition are summarised in Table 5.

3.2.3. LEAP calibration and scenarios

LEAP calibration. The prospective analysis of the Spanish energy system is conducted using the Low Emissions Analysis Platform (LEAP), which extends the historical LMDI decomposition into a forward-looking framework. The modelling approach builds on a framework previously developed and applied by the research team [52], adapted here to the national scale, the 2024 base year, and the specific objectives of the present study. The LEAP model is implemented at national level, with 2024 as the base year and a projection horizon to 2030, in line with the targets set out in Spain's Integrated National Energy and Climate Plan (PNIEC).

The structure of the LEAP model is fully consistent with the sectoral and fuel disaggregation adopted in the LMDI analysis, ensuring methodological coherence between historical and prospective assessments. Final energy demand is modelled for the five PNIEC sectors (residential, services, industry, transport, and primary), while energy production and transformation processes are represented at national level.

Final energy demand is modelled using a bottom-up activity–intensity approach. For each sector, demand is disaggregated by energy carrier and fuel type according to the structure shown in Fig. 1. In the base year (2024), sectoral energy consumption by fuel is calibrated to reproduce the official national energy balances. In addition to the sectoral structure illustrated in Fig. 1, the demand module includes a set of relocated energy uses not explicitly shown in the figure for clarity. These include coke, refined oil products (petrol, kerosene, diesel, and aviation gasoline), natural gas, renewable energy carriers (solar thermal and biofuels), heat pumps, and electricity, all of which are explicitly included in the base-year calibration and the scenario simulations.

Final energy demand is formulated consistently with the LMDI framework, with energy consumption expressed as the product of sectoral activity levels and energy intensities:

$$E_{s,f,t} = A_{s,t} \cdot I_{s,f,t}, \tag{8}$$

where $E_{s,f,t}$ denotes final energy demand for fuel f in sector s at time t, $A_{s,t}$ represents the corresponding sectoral activity level, and $I_{s,f,t}$ is the associated energy intensity.

Energy production and transformation are represented through the modelling of electricity and heat generation technologies, as illustrated in Fig. 2. The base-year electricity mix is calibrated using official statistics to reproduce observed generation levels by technology in 2024. Renewable and non-renewable sources are explicitly distinguished, includ-

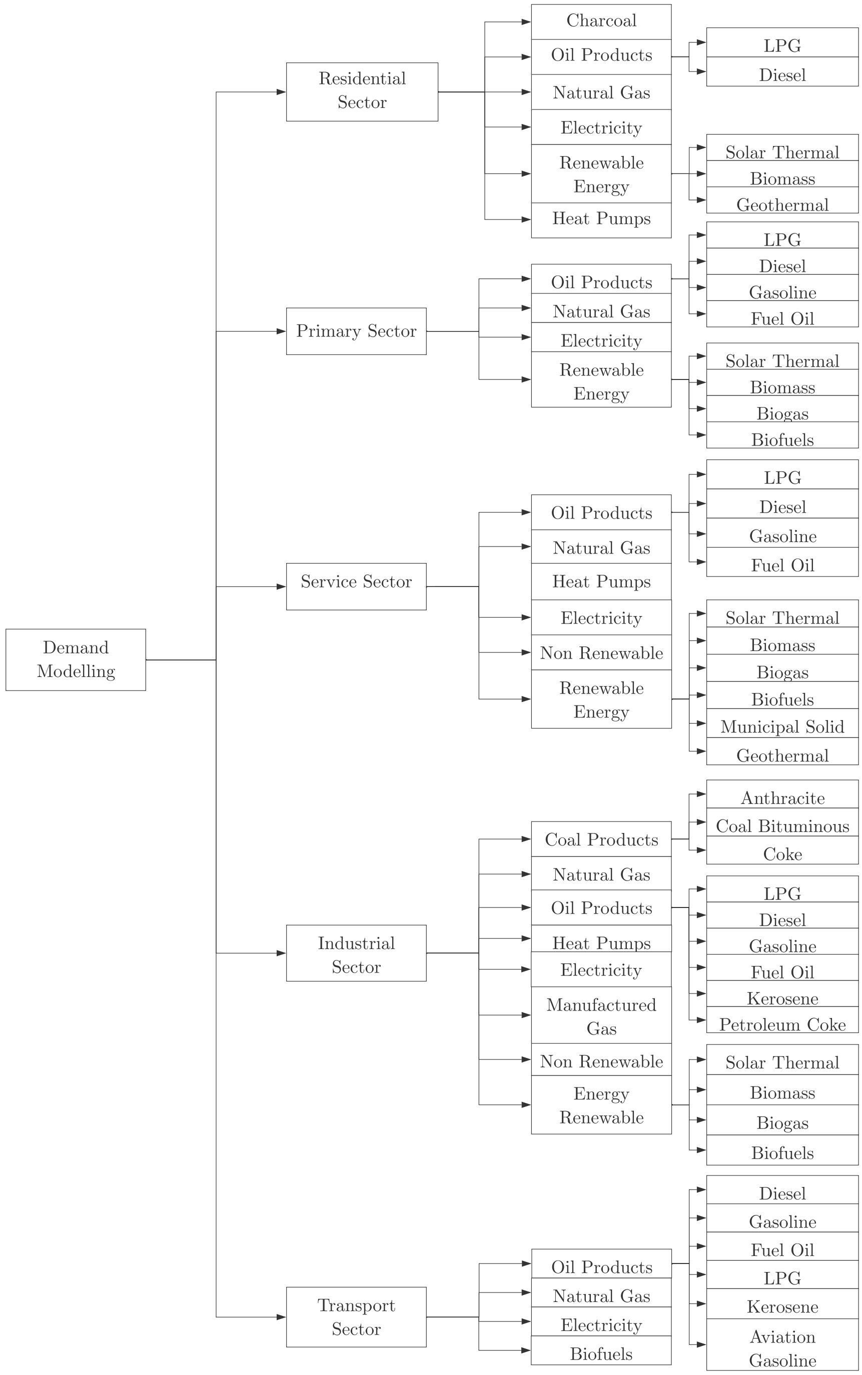

Fig. 1. Structure of final energy demand modelling in LEAP by sector and energy carrier. Own elaboration.

ing nuclear energy, fossil-based generation, and renewable technologies such as wind, solar, hydro, biomass, and waste.

Over the projection period, the evolution of the generation mix reflects the progressive deployment of renewable energy sources, shifts in fossil-based generation, and the role of nuclear power, in line with PNIEC trajectories. Transmission and distribution losses are introduced as aggregate parameters, and electricity is treated as an energy carrier whose associated emissions depend on the generation mix.

CO_2 emissions are calculated endogenously in LEAP by applying fuel-specific emission factors to energy consumption in both final demand and transformation processes. Emission factors are assumed to remain constant over time and are consistent with those used in the LMDI decomposition. To avoid any ambiguity regarding the emissions boundary and the treatment of electricity, we report two complementary energy-related CO_2 indicators, each serving a distinct purpose. First, *final-energy-based CO_2* emissions are quantified from the direct combustion of fossil fuels in final-demand sectors, applying fuel-specific emission factors as defined by the IPCC. Electricity is treated as a secondary energy carrier and, accordingly, does not generate direct CO_2 emissions at the point of use [63]. Secondly, for the PNIEC benchmarking exercise (whose mitigation targets are expressed in total GHG, CO_2eq), we also report a *TES-based CO_2 proxy* consistent with the national energy-

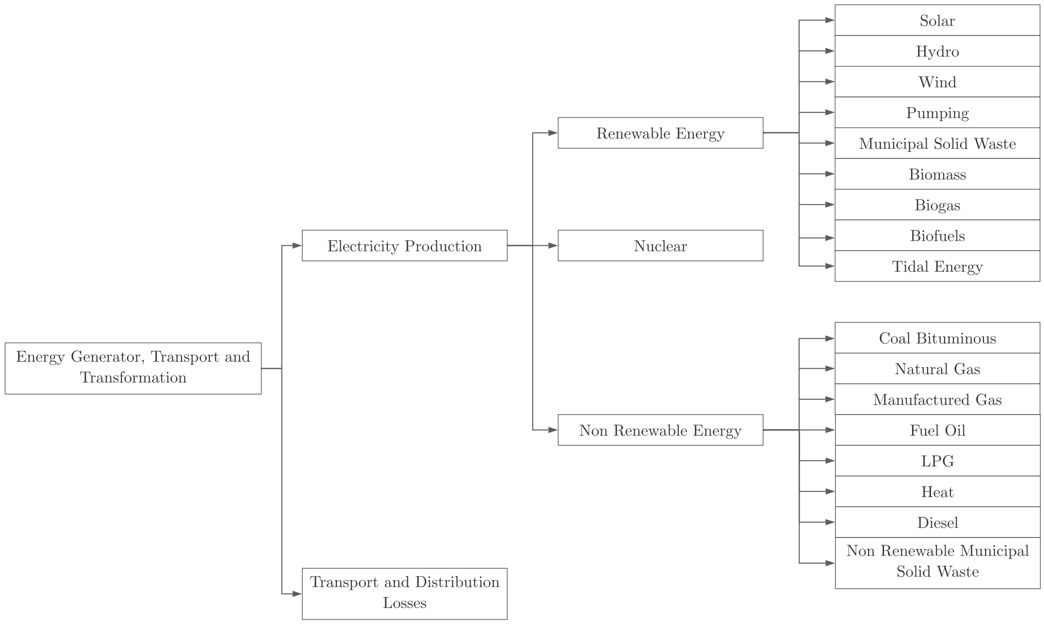

Fig. 2. Structure of energy production, transformation and electricity generation modelled in LEAP. Own elaboration.

Table 6
Baseline scenario design and PNIEC 2030 targets used for benchmarking.

Dimension	Baseline scenario (modelled)	PNIEC 2030 benchmark
Policy framework	Continuation of recent historical trends; no additional measures	Targets and sectoral objectives stated in the updated PNIEC
Energy demand	Trend-based evolution by sector (activity–intensity approach)	Final energy efficiency objective (EU/PNIEC)
Electrification	Endogenous evolution following recent patterns	Electrification target (share of electricity in final energy)
Renewables	Gradual increase consistent with recent deployment trends	Renewable share targets in final energy and in electricity generation
Electricity generation mix	Mix evolves from 2024 calibration under trend assumptions	Renewable electricity share target; supporting flexibility/storage objectives
CO_2 emissions	Emissions derived from baseline demand and supply trajectories	Economy-wide 2030 reduction target and sectoral focus areas

balance perspective, which captures fossil-fuel combustion in transformation processes, including power generation. Under both the LMDI framework and the LEAP implementation, electricity-related emissions are accounted for once—where the fuels are combusted (i.e., in the power sector)—and are not reallocated to electricity consumption in end-use sectors, thereby avoiding double counting. Differences between the Baseline trajectory and the PNIEC benchmarks arise from demand growth, energy efficiency improvements, electrification rates, and the evolution of the electricity generation mix, allowing a direct comparison between the historical emission drivers identified through LMDI and the prospective pathways required to meet PNIEC targets by 2030.

Scenario definition and PNIEC benchmarking. A single prospective scenario is implemented in LEAP to extend the most recently observed dynamics of Spain's energy system to the 2030 horizon. This *Baseline* scenario is explicitly trend-based: sectoral activity drivers, energy intensities, electrification rates, and fuel substitution patterns are extrapolated from recent historical evidence and anchored in the 2024 calibrated energy balance.

Rather than modelling a separate PNIEC policy scenario, the updated PNIEC 2030 objectives are used as an external benchmark against which the outputs of the trend-based Baseline are compared. The Baseline projections are assessed against the PNIEC headline targets (e.g., economy-wide emissions, renewable shares, and electrification indicators) to quantify the policy gap and identify the principal sectoral bottlenecks. This approach keeps the prospective assessment fully consistent with the historical LMDI narrative, while directing the contribution of this paper towards a transparent diagnosis of whether current trends are sufficient to achieve the national targets by 2030 (Tables 6, B.1, B.2).

4. Results

4.1. National LMDI results

Fig. 3 presents the cumulative additive LMDI decomposition of national CO_2 emissions in Spain over 1990–2024. The results show a clearly differentiated multi-phase trajectory, with the cumulative change peaking around 2007 relative to the 1990 base year.

Between 1990 and 2007, total CO_2 emissions increased steadily, reaching a cumulative rise of approximately 140 $MtCO_2$. This growth phase was mainly driven by the economic activity effect, which more than offset the mitigating effects of improvements in energy intensity and changes in the fuel mix. Population growth played a secondary role, contributing only marginally to the overall increase in emissions.

The onset of the financial crisis marked a clear turning point. Between 2007 and 2013, cumulative emissions declined sharply, with a net reduction of around 110 $MtCO_2$. This decrease was mainly associated with a strong contraction in economic activity, while the energy intensity and fuel mix effects continued to exert downward pressure on emissions, reinforcing the decline.

During the subsequent recovery phase (2013–2019), emission dynamics stabilised. Total emissions remained relatively flat, reflecting the combined effect of renewed economic activity and continued improvements in energy intensity. The energy intensity effect remained negative throughout this period, partially offsetting the positive effect of economic activity.

The COVID-19 period (2019–2021) brought a further, though shorter, decline in emissions, followed by a partial rebound during the 2021–2024 energy crisis. Despite the rapid recovery of economic

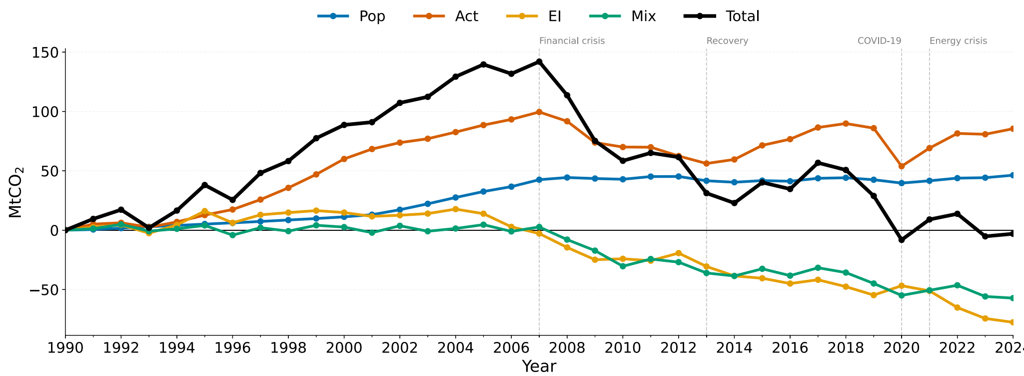

Fig. 3. Temporal evolution of CO_2 driving factors in Spain. Own elaboration.

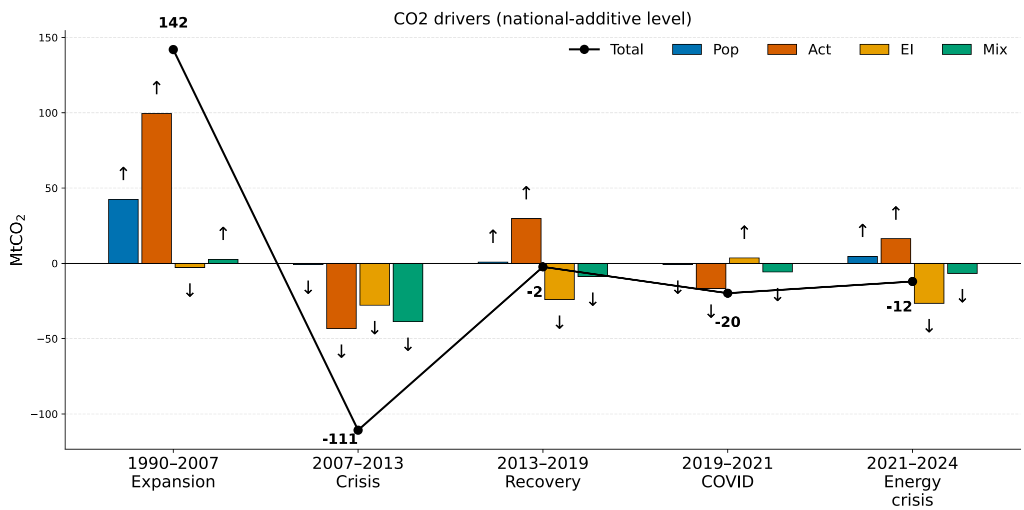

Fig. 4. Evolution of CO_2 driving factors by periods in Spain. Own elaboration.

activity, improvements in energy efficiency and changes in the energy mix continued to moderate total emissions.

To facilitate comparison across phases, Fig. 4 summarises the LMDI contributions by sub-period. The expansion phase (1990–2007) shows the largest positive change in emissions, whereas the financial crisis period (2007–2013) accounts for the largest reduction. Subsequent periods display more moderate net changes, indicating a weaker relationship between economic activity and CO_2 emissions at the national level.

Overall, the national LMDI results show that economic activity is the main positive contributor to changes in emissions, whereas improvements in energy intensity and shifts in the energy mix consistently contribute to emission reductions over the period analysed.

4.2. Sectoral decomposition of CO_2 emissions

Fig. 5 presents the cumulative additive LMDI decomposition of CO_2 emissions by sector in Spain over 1995–2024. The results reveal marked differences across sectors in both magnitude and temporal evolution, highlighting the heterogeneous nature of Spain's emission dynamics.

It is important to distinguish between the two economic-related effects in the sectoral decomposition. The *economic activity effect* reflects changes in emissions associated with the absolute growth of economy-wide activity, affecting sectoral output within the economy. By contrast, the *sectoral structure effect* (SEC) captures changes in emissions linked to variations in each sector's relative share of national economic activity, measured as the ratio of sectoral GDP to total GDP.

Transport and industry emerge as the dominant contributors (Figs. 5–7) to national emission changes over the period analysed. In transport, emission growth is largely driven by the economic activity effect, indicating that increases in transport-related output and demand translate directly into higher emissions. This effect consistently outweighs the mitigating contributions from improvements in energy intensity and changes in the energy mix. The sectoral structure effect remains comparatively limited, suggesting that transport emissions are driven mainly by scale effects rather than by changes in relative economic importance.

The industrial sector shows a more complex trajectory. Strong emission growth before the mid-2000s is followed by a marked decline during and after the financial crisis. While economic activity remains a key driver during expansionary phases, the sectoral structure effect becomes more relevant in later years, reflecting changes in the relative contribution of industry to national economic activity. These dynamics are accompanied by sustained negative contributions from improvements in energy intensity.

The services and residential sectors show more moderate but persistent increases in emissions over the period. In both cases, the economic activity effect is the main source of upward pressure, while the sectoral structure effect remains positive but relatively small. Improvements in energy intensity and changes in the fuel mix partially offset emission growth, though not enough to reverse the overall upward trend. Population-related effects are positive across sectors but remain secondary.

The primary sector shows relatively limited absolute changes in emissions over the period. Here, the sectoral structure and energy inten-

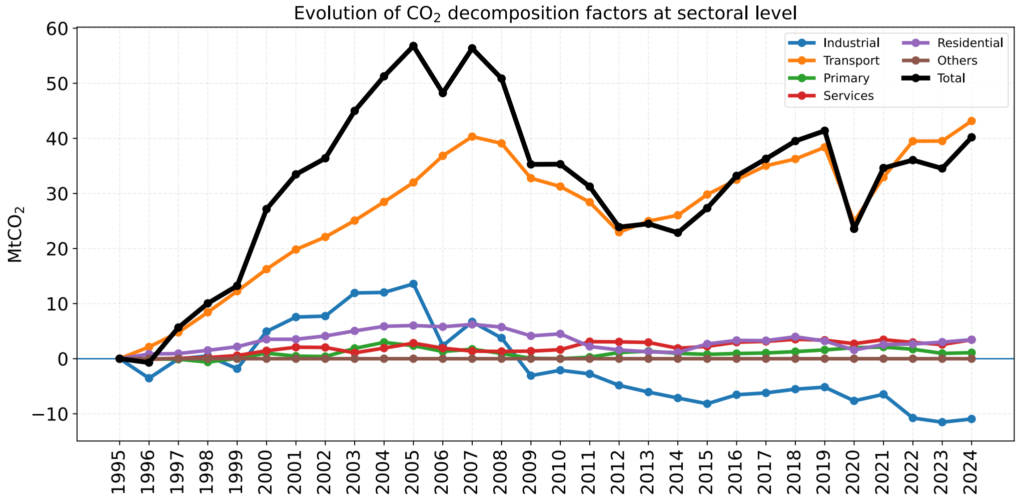

Fig. 5. Cumulative sectoral contributions to changes in CO_2 emissions in Spain (1995–2024), expressed in $MtCO_2$. Own elaboration.

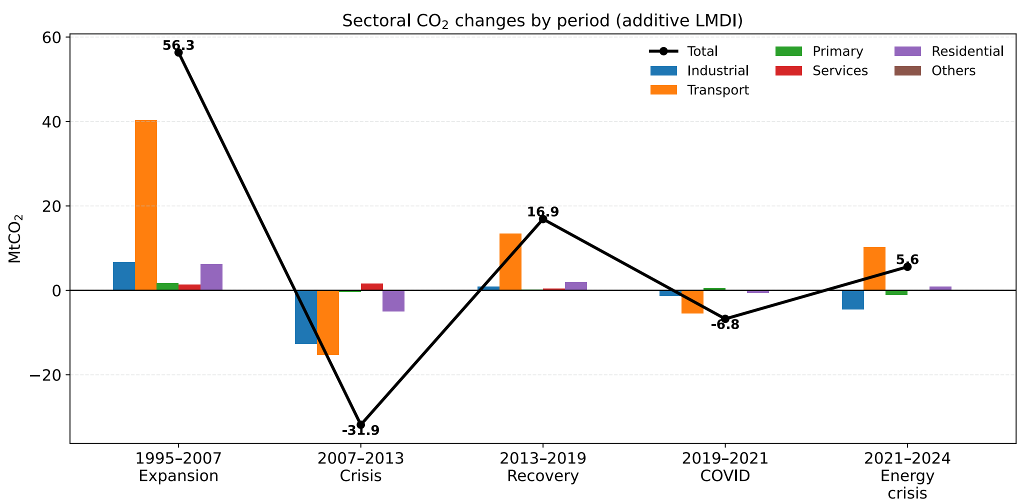

Fig. 6. Sectoral changes in CO_2 emissions by sub-period in Spain, with total emission change shown as a reference line ($MtCO_2$). Own elaboration.

sity effects play a more prominent relative role, while economic activity contributes modestly to emission changes. Emissions attributed to other sectors remain negligible throughout the sample.

To facilitate comparison across major macroeconomic phases, Fig. 6 summarises sectoral emission changes by sub-period. The expansion phase (1995–2007) is characterised by widespread emission increases, especially in transport and industry, driven mainly by economic activity. By contrast, the financial crisis period (2007–2013) accounts for the largest emission reductions, largely concentrated in the industrial sector. Subsequent periods show more moderate and sector-specific dynamics.

Further insight into the underlying drivers is provided by Fig. 7, which shows the temporal evolution of the main LMDI components at sectoral level. Across all sectors, the economic activity effect is the main source of upward pressure on emissions, while the sectoral structure effect shows more moderate and sector-specific contributions. Improvements in energy intensity are the most consistent mitigating factor over time, and changes in the energy mix play a secondary but increasingly visible role, particularly in the residential and services sectors in the later years of the sample.

Overall, the sectoral LMDI results highlight the uneven contribution of different sectors to national emission trends and the distinct roles played by scale-related effects and changes in sectoral economic structure, which are not captured by aggregate analyses alone.

4.3. Prospective results from the LEAP model

This section presents the prospective results obtained with the LEAP model for Spain, using 2024 as the base year and projecting to 2030. The prospective exercise complements the historical LMDI analysis: the base-year energy balance provides the calibrated starting point, and recent observed dynamics are translated into a trend-based (*Baseline*) outlook. At this stage, the *Baseline* scenario is presented as the modelled projection, while the updated PNIEC 2030 objectives are used as an external benchmark to quantify the remaining gap.

4.3.1. Base year calibration (2024)

The LEAP model is calibrated to reproduce the observed structure of Spain's energy system in 2024. Final energy demand by sector and energy carrier is aligned with the official national energy balances, while electricity generation and transformation processes are calibrated using harmonised statistics from IDAE and *Red Eléctrica de España*. This calibration is essential for interpreting the prospective results, as it ensures that subsequent changes reflect scenario assumptions rather than base-year inconsistencies. Calibration deviations between LEAP exports and the official inputs are reported in Appendix A, Section A.2.

Fig. 8 shows the distribution of final energy demand by sector in 2024 (79,793.44 ktoe in total). Transport and industry together account for more than 65% of total final energy consumption, while residential

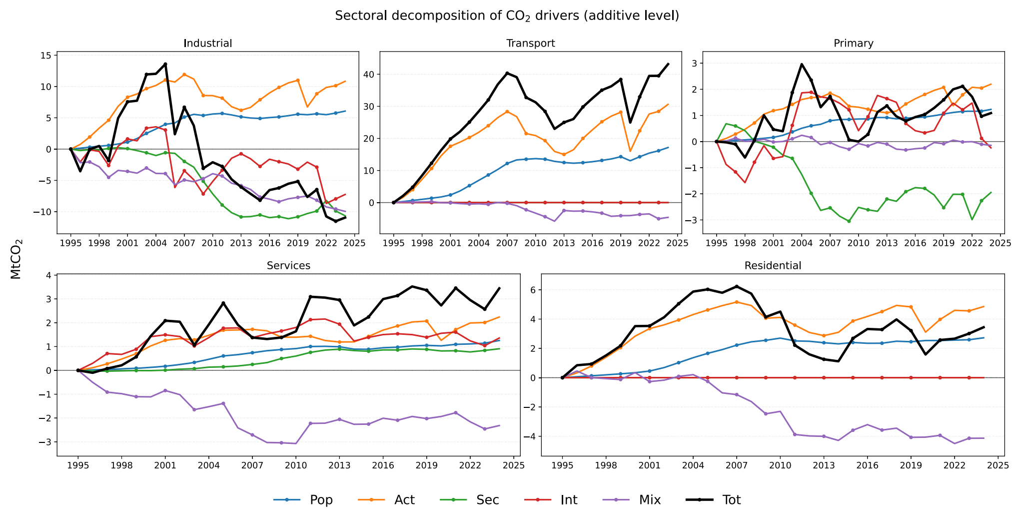

Fig. 7. Temporal evolution of LMDI components by sector in Spain (1995–2024), expressed in $MtCO_2$. Own elaboration.

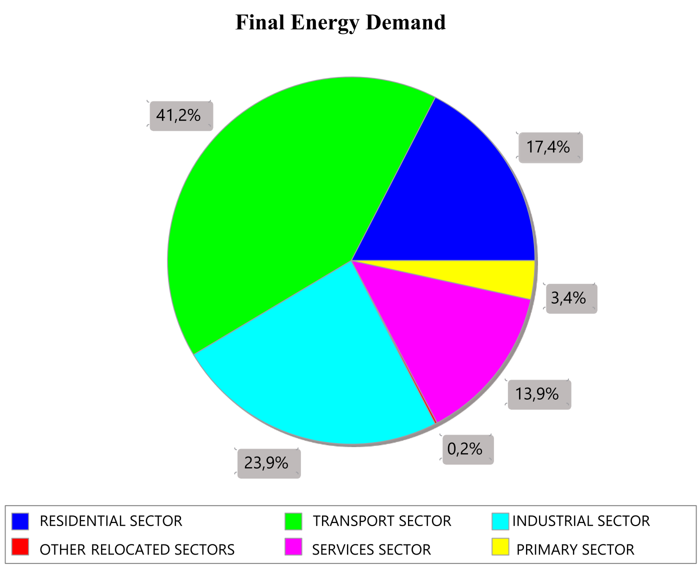

Fig. 8. Final energy demand by sector in Spain in the base year 2024. Own elaboration.

Table 7
Average annual variation in energy consumption and CO_2 emissions in Spain, calculated using CAGR (% per year). Own elaboration.

Indicator	1995–2024	2005–2024
Final energy consumption by sector		
Residential sector	1.11	−0.47
Industrial sector	−0.12	−2.34
Transport sector	1.04	−0.62
Services sector	3.31	1.53
Primary sector	0.72	-0.71
Final total consumption	0.92	−0.84
Primary energy consumption by fuel		
Fossil solid fuels	−4.79	−4.26
Natural gas	2.59	−1.41
Fossil liquid fuels	0.03	−1.50
Renewables	3.12	3.96
CO_2 emissions by sector		
Residential sector	−0.19	−2.30
Industrial sector	−1.20	−3.44
Transport sector	0.84	−0.88
Services sector	1.76	0.4
Primary sector	0.63	-0.92
Final total emissions	0.32	−1.51

and services represent a substantial but secondary share. The primary sector and other relocated uses remain marginal in relative terms.

The internal structure of energy flows in the base year is further illustrated by the Sankey diagram in Fig. 9. The diagram highlights the strong dependence on imported oil products and natural gas, the central role of electricity as a secondary energy carrier, and the still limited but increasing contribution of renewable sources to final energy consumption.

4.3.2. Baseline dynamics and trend characterisation

To parameterise the Baseline scenario, recent historical trends in energy consumption and CO_2 emissions were quantified using compound annual growth rates (CAGR). Two reference periods were considered: the full sample (1995–2024) and a more recent window (2005–2024), which isolates the post-crisis phase and the years in which decarbonisation dynamics become more pronounced in the energy balances.

Table 7 summarises the average annual variation in final energy consumption, primary energy consumption by fuel, and CO_2 emissions by sector. Over 1995–2024, final energy consumption increases on average, with services and transport as the main growing sectors. Over 2005–2024, most sectors show declining final energy consumption and lower emissions growth, or even outright decreases, while renewables continue to expand in primary energy terms. These observed rates provide the quantitative basis for the Baseline outlook, which extrapolates recent patterns in demand evolution, fuel substitution, and emissions intensity without introducing additional policy measures beyond those already embedded in the historical trajectory.

4.3.3. Evolution of final energy demand and emissions under the baseline scenario

Figs. 10 and 11 summarise the prospective evolution of final energy demand and CO_2 emissions under the Baseline scenario. Together, they provide a clear view of how demand-side dynamics translate into emission outcomes over the projection horizon.

Under the Baseline scenario, final energy demand remains broadly stable at aggregate level (Fig. 10). Moderate declines in transport and industry are partly offset by continued growth in the services sector, resulting in only limited net variation in total demand. Changes in the composition of energy carriers are gradual, with electricity and renewable sources gaining importance, but without a marked structural shift relative to recent historical trends.

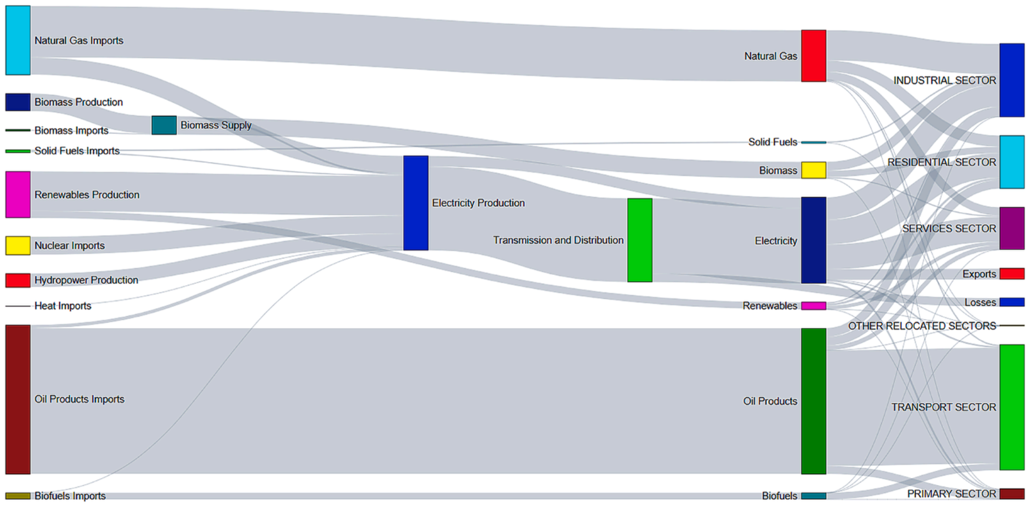

Fig. 9. Sankey diagram of the Spanish energy system in the base year 2024. Own elaboration.

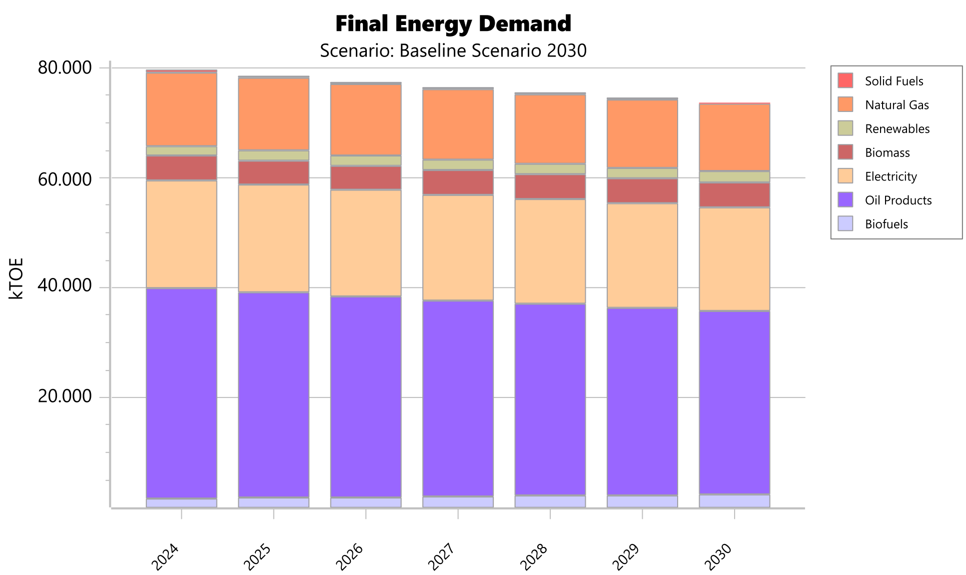

Fig. 10. Final energy demand by sector and energy carrier under the Baseline scenario (2024–2030). Own elaboration.

The corresponding emissions pathway reflects these dynamics (Fig. 11). CO_2 emissions decline only moderately between 2024 and 2030, indicating that efficiency improvements and incremental fuel substitution are largely offset by activity-related pressures. As a result, the Baseline scenario is associated with a moderate decline rather than a sustained reduction at the rate implied by the PNIEC benchmarks over the projection period.

4.3.4. Benchmarking the baseline outlook against PNIEC 2030 targets

To assess the consistency of the trend-based outlook with the updated PNIEC, the Baseline projections for 2030 are benchmarked against selected PNIEC targets (Table 9). Since the PNIEC mitigation objective is defined for total greenhouse gas emissions (GHG, CO_2eq), while this study estimates energy-related CO_2 from energy statistics, the comparison is performed using a transparent TES-based CO_2 proxy. This approach preserves coherence with the national energy-balance perspective underpinning the aggregated decomposition, while final-energy-based CO_2 is retained as a complementary diagnostic indicator.

For clarity, Table 8 reports the baseline levels and percentage changes in the core energy and CO_2 indicators, while Table 9 summarises the PNIEC 2030 benchmarks together with the resulting gaps (in percentage points). Specifically, the TES-based CO_2 proxy reaches −15.82% versus 1990 in the Baseline, compared with the PNIEC objective of −32.0%, i.e., a shortfall of 16.2 percentage points (and 6.7 pp versus the 2005 benchmark), which we refer to as the headline “policy gap” under current trend dynamics (Table 9). Demand-side bottlenecks are reflected in the electrification rate (25.8% vs 35.0%) and the renewable share in transport (13.89% vs 28.0%), among other indicators summarised in Table 9.

In the Baseline outlook, supply-side indicators show stronger progress than demand-side indicators. In particular, the electricity generation mix moves towards a very high renewable share by 2030, while end-use indicators related to electrification and renewable penetration in final demand show more limited changes. The emissions proxy derived from TES declines substantially relative to 2005, but remains short of the PNIEC economy-wide mitigation objective, indicating that the observed trend dynamics are not sufficient to close the remaining gap by 2030.

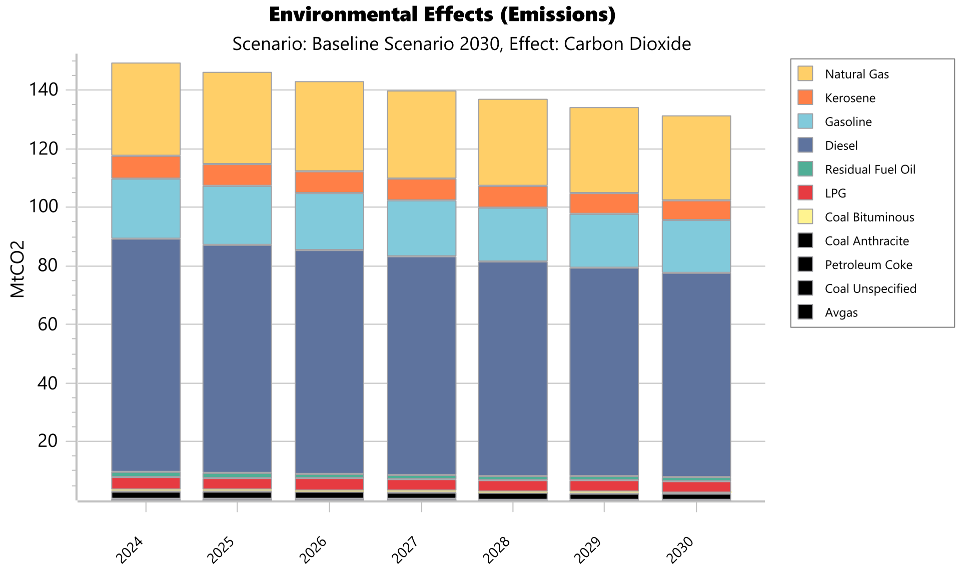

Fig. 11. CO_2 emissions trajectory under the Baseline scenario (2024–2030). Own elaboration.

Table 8
Key energy and CO_2 indicators in the Baseline outlook (levels and 2030 variations relative to benchmark years). Own elaboration.

Indicator	Unit	1990	2005	2019	2024	2030
CO_2 emissions (final energy-based)[a]	Mt	119.82	199.55	158.27	149.38	130.24
CO_2 emissions (TES-based proxy)[b]	Mt	221.77	361.37	250.62	218.74	186.67
Final energy consumption (FEC)	Mtoe	54.95	93.71	82.20	79.79	75.66
Total energy supply (TES)	Mtoe	87.31	141.29	121.94	113.97	106.49
2030 variation relative to benchmark years (%)						
Final-energy CO_2 variation in 2030 vs. year t	%	+8.70	−34.73	−17.71	−12.81	0.00
TES-based CO_2 variation in 2030 vs. year t	%	−15.82	−48.34	−25.52	−14.66	0.00
Final energy consumption (FEC) variation in 2030 vs. year t	%	+37.68	−19.27	−7.96	−5.18	0.00
Total energy supply (TES) variation in 2030 vs. year t	%	+21.97	−24.62	−12.67	−6.56	0.00

[a] Final-energy-based CO_2 is computed from final energy consumption by fuel using IPCC emission factors; it is reported as a diagnostic indicator.

[b] TES-based CO_2 is reported as a transparent proxy consistent with the national energy-balance perspective used in the aggregated LMDI analysis.

5. Discussion

Following the integrated assessment of Spain's decarbonisation trajectory—which combines long-term LMDI decomposition with a forward-looking, trend-based perspective using LEAP—it is possible to draw several conclusions regarding the structural factors driving emissions, the internal consistency of recent trends, and the extent to which these dynamics align with the targets set out in the updated PNIEC.

At the aggregate level, the national LMDI results confirm that economic activity has historically been the dominant driver of CO_2 emissions in Spain, particularly during the expansion phase before 2007 (Figs. 3 and 4). This finding is consistent with previous studies [19,45] for Spain and other EU countries, but the longer time horizon used here reveals an important structural shift. Since the mid-2000s, the contribution of economic activity has weakened, especially during the first crisis in 2008, while improvements in energy intensity and changes in the energy mix have had a sustained mitigating effect. This points to a partial decoupling between economic growth and emissions, although not yet strong enough to generate a persistent downward trend under normal economic conditions.

The sectoral breakdown adds a layer of interpretation that cannot be captured by national-level analysis alone. Transport and industry clearly emerge as the main sources of upward pressure on emissions in the long term, yet their internal dynamics differ substantially. In transport, emissions remain closely linked to activity growth, with limited compensation from efficiency gains or fuel substitution. By contrast, the industrial sector shows a stronger response to macroeconomic shocks and structural change, with improvements in energy intensity playing a key role in offsetting activity-related pressures. The services and residential sectors show more moderate but persistent emissions growth, reflecting the combined effect of expanding activity and comparatively slower structural transformation.

These sectoral patterns are especially relevant in the context of the PNIEC framework. The breakdown shows that the Plan's priority sectors—such as transport, buildings, and industry—are precisely those where historical trends reveal greater inertia. From this perspective, the LMDI results help explain why the incremental improvements observed in recent years may be insufficient to achieve the PNIEC targets without additional sector-specific measures. They also underline the importance of distinguishing between scale and structural effects: while economic growth remains a key factor, changes in sectoral composition and

Table 9
Benchmarking of the Baseline 2030 outlook against selected PNIEC 2030 targets. Own elaboration.

Indicator	Unit	Baseline 2030	PNIEC 2030	Gap	Compliance
GHG reduction vs 1990 (TES-based proxy)[a]	%	−15.82	−32.0	−16.2 pp	×
GHG reduction vs 2005 (TES-based proxy)[a]	%	−48.34	−55.0	−6.7 pp	×
Primary energy reduction vs 2019 (TES)[b]	%	−12.67	−39.5	−26.8 pp	×
Final energy reduction vs 2019 (FEC)[b]	%	−7.96	−43.0	−35.0 pp	×
Renewable share in final energy[c]	%	40.0	48.0	−8.0 pp	×
Renewable share in electricity generation	%	88.96	81.0	+7.96 pp	✓
Electrification rate (electricity share in final energy)	%	25.8	35.0	−9.2 pp	×
Transport GHG reduction vs 2019[d]	%	−12.72	−16.30	−3.58 pp	×
Renewable share in transport	%	13.89	28.0	−14.11 pp	×
Annual increase of renewables in industry (2026–2030)	%	0.17	2.97	−2.80 pp	×
Renewable final energy in buildings (residential + services)[c]	%	69.46	67.59	+1.87 pp	✓
Annual increase of renewables in buildings (heating/cooling, 2026–2030)	%	1.68	1.89	−0.21 pp	×

[a] PNIEC mitigation targets are defined for total greenhouse gas emissions (GHG, CO_2eq). This study reports energy-related CO_2; therefore, a TES-based CO_2 proxy is used for transparent benchmarking.
[b] Primary energy is proxied by TES; final energy corresponds to FEC as reported by the energy balances.
[c] In line with the PNIEC definition, this indicator includes direct renewable final energy uses and the renewable fraction embedded in electricity consumption; it is not equivalent to the official Eurostat RES-FEC indicator.
[d] Reported as an energy-related proxy consistent with the LEAP transport module and the accounting approach used in this study.

energy intensity determine whether that growth translates into higher emissions.

The prospective analysis conducted with LEAP reinforces these conclusions. In the trend-based reference scenario, the Spanish energy system continues to evolve in a way that is broadly consistent with recent developments. On the supply side, the electricity sector is undergoing rapid transformation, with a very high share of renewable generation projected for 2030. This suggests that the electricity sector is not the main bottleneck on the path to decarbonisation and, under current trends, could even exceed the PNIEC targets (Table 9).

It should be noted that the trend-based Baseline scenario does not represent a forecast, but a conditional projection based on recently observed dynamics, assuming no additional policy or behavioural changes. Its purpose is not to predict future outcomes, but to assess whether current structural trends are sufficient to meet the objectives set out in the PNIEC. From this perspective, the moderate decline in emissions observed in the Baseline scenario highlights the limits of incremental change and underscores the need for structural interventions to alter the underlying drivers of energy demand and emissions.

By contrast, demand dynamics are emerging as the critical constraint. Final energy consumption is projected to decline only moderately, and electrification is increasing much more slowly than required by the PNIEC (25.8% vs 35%). As a result, CO_2 emissions decrease only moderately, rather than at the rate implied by the PNIEC benchmark over the projection horizon. Comparison with the PNIEC benchmarks shows that the policy gap is not mainly related to the deployment of renewables in electricity generation, but to the slow transformation of energy end uses, particularly in transport and industry [11,64]. This asymmetry between supply-side progress and demand-side inertia is fully consistent with the historical patterns identified through the LMDI sectoral analysis [11,12].

From a policy perspective, the remaining gap identified in the Baseline is concentrated in *diffuse (non-ETS) end-use sectors*, as reflected by the key shortfalls reported in Table 9. Three intervention priorities stand out: **transport** (accelerating zero-emission vehicles, charging infrastructure, and modal shift), **buildings** (scaling deep renovations, heat-pump uptake, and low-carbon heat solutions), and **diffuse industrial heat** (electrification, waste-heat recovery, and targeted fuel switching, including low-carbon gases and biomass where appropriate). These priorities provide a clear mapping between the identified demand-side bottlenecks and the types of sector-specific instruments required to close the gap to the PNIEC trajectory.

Although this paper focuses on energy-related CO_2 dynamics and their alignment with PNIEC targets, accelerated decarbonisation also interacts with broader implementation dimensions (e.g., investment requirements, materials, occupational safety, and end-of-life practices). These aspects are beyond the scope of the present analysis, but remain relevant for responsible deployment.

Overall, the discussion suggests that Spain's decarbonisation challenge is no longer primarily one of renewable electricity deployment, but of accelerating structural change in final energy demand. Without stronger electrification, efficiency improvements, and fuel substitution in key sectors, the historical drivers identified in this study are likely to continue constraining progress towards the PNIEC objectives.

6. Conclusions and policy implications

This paper examines Spain's CO_2 emissions from both historical and prospective perspectives by combining an extended LMDI decomposition with a trend-based LEAP outlook to 2030. This integrated approach provides a coherent interpretation of past emission drivers and assesses whether recent dynamics are consistent with the objectives of the updated PNIEC. The historical analysis shows that economic activity has been the main force increasing emissions over the long term, while improvements in energy intensity and changes in the energy mix have acted as persistent mitigating factors. Although some decoupling between economic growth and emissions has emerged since the mid-2000s, it remains partial and highly sector-dependent. The sectoral LMDI results reveal marked heterogeneity across sectors, with transport and industry accounting for the largest contributions to emission changes, albeit through different mechanisms.

The prospective analysis indicates that, under current trends (Baseline), Spain is **not on a trajectory consistent with meeting the PNIEC 2030 mitigation benchmarks**. If recent dynamics persist, Spain is projected to achieve or even surpass the PNIEC targets related to renewable electricity generation. However, this progress is not matched on the demand side. Under the Baseline scenario, electrification and reductions in final energy consumption remain below the levels implied by the PNIEC benchmarks under the TES-based CO_2 proxy comparison used in this study. As a result, CO_2 emissions decline only moderately and remain above the level implied by the PNIEC benchmark by 2030 (Fig. 11 and Table 9), leaving a non-negligible policy gap (16.2 percentage points relative to the PNIEC 2030 benchmark under the TES-based proxy). From a policy perspective, closing this gap requires faster demand-side transformation in diffuse end-use sectors—particularly transport, buildings (residential and services), and diffuse industrial heat—through accelerated electrification, higher efficiency, and targeted fuel substitution. Accordingly, policy priorities should shift from further supply-side acceleration towards faster end-use transformation, especially in these sectors.

Finally, this study demonstrates the value of integrating decomposition analysis with energy system modelling. By linking historical drivers to prospective outcomes, the proposed framework offers a robust diagnostic tool for evaluating the internal coherence of national climate strategies. Unlike much of the existing literature, which typically applies decomposition or energy system modelling in isolation, this study combines a PNIEC-aligned, long-horizon LMDI diagnosis with a transparent LEAP-based trend assessment and an explicit benchmark against PNIEC targets. Future research could extend this approach by exploring alternative demand-side scenarios, incorporating explicit behavioural or technological assumptions, or testing the sensitivity of results to different electrification pathways. Such extensions would further improve the ability of policy-makers to design targeted and effective decarbonisation strategies aligned with Spain's long-term climate objectives. Overall, the results indicate that meeting Spain's 2030 climate objectives will depend less on further accelerating renewable electricity deployment and more on delivering a structural transformation of final energy demand across key sectors.

CRediT authorship contribution statement

Juan Cámara-Aceituno: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization; **Lucia Galán-Cano:** Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Conceptualization; **Juan de Dios Unión-Sánchez:** Writing – review & editing, Data curation; **Manuel Jesús Hermoso-Orzáez:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation; **Angel Mena-Nieto:** Writing – review & editing, Validation, Supervision; **Julio Terrados-Cepeda:** Writing – review & editing, Validation, Supervision, Resources.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work is funded by the University of Jaén as part of the package of 'Grants for the submission of projects under the National Plan (Programme R.1, Action R.1.d) of the 2025 Plan for Research and Knowledge Transfer'. Funding entity: University of Jaén. Managing centre: Vice-Rectorate for Research and Knowledge Transfer.

Appendix A. Verification and calibration checks

Notes. For LMDI, we report the additive residual $R = \Delta C_{\text{tot}} - \sum_i \Delta C_i$. For LEAP, we compare exported 2024 sector totals against the official inputs used for calibration; %Diff denotes absolute relative deviation.

A.1. Residual checks (LMDI)

A.2. LEAP base-year calibration checks (2024)

Table A.1
Residual check for the national additive LMDI decomposition.

Metric	Value
Max $\|R\|$ (1991–2024)	7.6×10^{-6}
Min R (1991–2024)	-7.2×10^{-6}

Table A.2
Residual check for the sectoral additive LMDI decomposition.

Metric	Value
Max $\|R\|$ across sectors/years (1995–2024)	2.6×10^{-8}
Typical residual magnitude	≈ 0 (floating-point)

Table A.3
LEAP base-year calibration (2024): final energy demand by sector (Mtoe).

Sector	DATA	LEAP	Abs. Diff.	% Diff.
Primary	2.7176	2.7176	2.9×10^{-5}	0.001
Services	11.0839	11.0839	2.6×10^{-5}	0.000
Other rel.	0.1338	0.1338	2.1×10^{-5}	0.016
Industry	19.0945	19.0945	1.1×10^{-5}	0.000
Transport	32.8701	32.8701	3.0×10^{-5}	0.000
Residential	13.8937	13.8936	1.0×10^{-4}	0.001
Total	**79.7935**	**79.7934**	**5.8e-5**	**0.000**

Table A.4
LEAP base-year calibration (2024): final-energy-based CO_2 by sector ($MtCO_2$).

Sector	DATA	LEAP	Abs. Diff.	% Diff.
Primary	6.5738	6.5739	1.2×10^{-4}	0.0018
Services	8.5690	8.5692	2.1×10^{-4}	0.0024
Other rel.	0.3233	0.3231	1.6×10^{-4}	0.0487
Industry	25.9862	25.9862	5.4×10^{-5}	0.0002
Transport	94.0557	94.0559	1.6×10^{-4}	0.0002
Residential	13.8770	13.8771	2.4×10^{-5}	0.0002
Total	**149.3852**	**149.3854**	**2.1e-4**	**0.0001**

Appendix B. Full additive LMDI outputs

Notes. Full yearly additive series are reported exactly as exported from the LMDI calculations. Residuals are documented in Appendix A, Section A.1.

Table B.1
National LMDI additive effects (ΔC) 1990–2024.

Year	ΔC_{pop}	ΔC_{act}	ΔC_{int}	ΔC_{mix}	ΔC_{tot}
1990	0.00	0.00	0.00	0.00	0.00
1991	5.76×10^{8}	5.12×10^{9}	2.50×10^{9}	1.31×10^{9}	9.50×10^{9}
1992	1.71×10^{9}	6.21×10^{9}	4.45×10^{9}	4.88×10^{9}	1.72×10^{10}
1993	2.81×10^{9}	2.54×10^{9}	-2.50×10^{9}	-8.30×10^{8}	2.01×10^{9}
1994	4.00×10^{9}	6.94×10^{9}	4.43×10^{9}	1.16×10^{9}	1.65×10^{10}
1995	5.23×10^{9}	1.27×10^{10}	1.61×10^{10}	4.02×10^{9}	3.81×10^{10}
1996	6.06×10^{9}	1.74×10^{10}	6.23×10^{9}	-4.20×10^{9}	2.55×10^{10}
1997	7.36×10^{9}	2.58×10^{10}	1.29×10^{10}	2.11×10^{9}	4.82×10^{10}
1998	8.52×10^{9}	3.57×10^{10}	1.48×10^{10}	-8.00×10^{8}	5.82×10^{10}
1999	9.87×10^{9}	4.70×10^{10}	1.65×10^{10}	4.14×10^{9}	7.75×10^{10}
2000	1.12×10^{10}	6.00×10^{10}	1.48×10^{10}	2.60×10^{9}	8.87×10^{10}
2001	1.31×10^{10}	6.84×10^{10}	1.16×10^{10}	-2.10×10^{9}	9.10×10^{10}
2002	1.72×10^{10}	7.37×10^{10}	1.26×10^{10}	3.70×10^{9}	1.07×10^{11}
2003	2.22×10^{10}	7.70×10^{10}	1.40×10^{10}	-8.90×10^{8}	1.12×10^{11}
2004	2.75×10^{10}	8.26×10^{10}	1.77×10^{10}	1.42×10^{9}	1.29×10^{11}
2005	3.26×10^{10}	8.85×10^{10}	1.39×10^{10}	4.64×10^{9}	1.40×10^{11}
2006	3.67×10^{10}	9.33×10^{10}	2.81×10^{9}	-1.00×10^{9}	1.32×10^{11}
2007	4.25×10^{10}	9.95×10^{10}	-2.80×10^{9}	2.72×10^{9}	1.42×10^{11}
2008	4.44×10^{10}	9.17×10^{10}	-1.50×10^{10}	-7.90×10^{9}	1.14×10^{11}
2009	4.35×10^{10}	7.38×10^{10}	-2.50×10^{10}	-1.70×10^{10}	7.52×10^{10}
2010	4.29×10^{10}	7.00×10^{10}	-2.40×10^{10}	-3.00×10^{10}	5.85×10^{10}
2011	4.52×10^{10}	6.99×10^{10}	-2.60×10^{10}	-2.40×10^{10}	6.51×10^{10}
2012	4.52×10^{10}	6.25×10^{10}	-1.90×10^{10}	-2.70×10^{10}	6.15×10^{10}
2013	4.16×10^{10}	5.62×10^{10}	-3.10×10^{10}	-3.60×10^{10}	3.12×10^{9}
2014	4.04×10^{10}	5.96×10^{10}	-3.90×10^{10}	-3.90×10^{10}	2.29×10^{10}
2015	4.18×10^{10}	7.14×10^{10}	-4.00×10^{10}	-3.30×10^{10}	4.02×10^{10}
2016	4.12×10^{10}	7.67×10^{10}	-4.50×10^{10}	-3.80×10^{10}	3.47×10^{10}
2017	4.37×10^{10}	8.65×10^{10}	-4.20×10^{10}	-3.20×10^{10}	5.68×10^{10}
2018	4.42×10^{10}	8.98×10^{10}	-4.80×10^{10}	-3.60×10^{10}	5.07×10^{10}
2019	4.25×10^{10}	8.59×10^{10}	-5.50×10^{10}	-4.50×10^{10}	2.89×10^{10}
2020	3.97×10^{10}	5.39×10^{10}	-4.70×10^{10}	-5.50×10^{10}	-8.20×10^{9}
2021	4.16×10^{10}	6.91×10^{10}	-5.10×10^{10}	-5.10×10^{10}	9.03×10^{9}
2022	4.38×10^{10}	8.15×10^{10}	-6.50×10^{10}	-4.60×10^{10}	1.38×10^{10}
2023	4.42×10^{10}	8.08×10^{10}	-7.40×10^{10}	-5.60×10^{10}	-5.20×10^{9}
2024	4.63×10^{10}	8.55×10^{10}	-7.80×10^{10}	-5.70×10^{10}	-3.00×10^{9}

Table B.2
Sectoral LMDI additive effects (ΔCDelta C) 1995–2024 ($MtCO_2$).

Sector	ΔC_{pop}	ΔC_{act}	ΔC_{sec}	ΔC_{int}	ΔC_{mix}	ΔC_{tot}
1995 (Base Year)						
Total	0.00	0.00	0.00	0.00	0.00	0.00
Industry	0.00	0.00	0.00	0.00	0.00	0.00
Transport	0.00	0.00	0.00	0.00	0.00	0.00
Primary	0.00	0.00	0.00	0.00	0.00	0.00
Services	0.00	0.00	0.00	0.00	0.00	0.00
Residential	0.00	0.00	0.00	0.00	0.00	0.00
1996						
Total	5.72×10^5	2.96×10^6	0	-5.28×10^4	-7.91×10^5	2.69×10^6
Industry	1.46×10^5	7.57×10^5	-2.30×10^5	-2.05×10^6	-2.17×10^6	-3.55×10^6
Transport	3.18×10^5	1.65×10^6	0	0	1.66×10^5	2.13×10^6
Primary	2.28×10^4	1.18×10^5	6.82×10^5	-8.73×10^5	1.93×10^4	-3.05×10^4
Services	2.13×10^4	1.10×10^5	-2.80×10^4	2.97×10^5	-5.03×10^5	-1.02×10^5
Residential	6.36×10^4	3.30×10^5	0	0	4.54×10^5	8.48×10^5
1997						
Total	1.16×10^6	7.31×10^6	0	3.68×10^5	-2.76×10^6	6.08×10^6
Industry	3.08×10^5	1.94×10^6	-9.50×10^4	-1.22×10^5	-2.05×10^6	-2.63×10^4
Transport	6.37×10^5	4.01×10^6	0	0	1.26×10^5	4.77×10^6
Primary	4.54×10^4	2.86×10^5	5.96×10^5	-1.16×10^6	1.34×10^5	-1.02×10^5
Services	4.34×10^4	2.74×10^5	-3.25×10^4	7.06×10^5	-9.14×10^5	7.70×10^4
Residential	1.27×10^5	7.99×10^5	0	0	7.03×10^3	9.33×10^5
1998						
Total	1.78×10^6	1.29×10^7	0	1.97×10^6	-2.59×10^6	1.41×10^7
Industry	4.62×10^5	3.35×10^6	-1.26×10^5	-3.63×10^5	-2.82×10^6	4.99×10^5
Transport	9.97×10^5	7.23×10^6	0	0	2.02×10^5	8.43×10^6
Primary	6.45×10^4	4.68×10^5	4.18×10^5	-1.57×10^6	6.83×10^3	-6.14×10^5
Services	6.56×10^4	4.76×10^5	-2.01×10^4	6.71×10^5	-9.79×10^5	2.13×10^5
Residential	1.92×10^5	1.39×10^6	0	0	-6.58×10^4	1.52×10^6
1999						
Total	2.39×10^6	1.87×10^7	0	7.85×10^5	-3.91×10^6	1.80×10^7
Industry	5.89×10^5	4.62×10^6	1.04×10^5	-2.61×10^6	-4.52×10^6	-1.82×10^6
Transport	1.35×10^6	1.06×10^7	0	0	2.92×10^5	1.23×10^7
Primary	9.07×10^4	7.11×10^5	1.41×10^4	-7.91×10^5	2.52×10^4	5.02×10^4
Services	8.97×10^4	7.03×10^5	-8.34×10^3	8.88×10^5	-1.10×10^6	5.67×10^5
Residential	2.61×10^5	2.05×10^6	0	0	-1.29×10^5	2.18×10^6
2000						
Total	3.14×10^6	2.63×10^7	0	3.53×10^6	-3.75×10^6	2.92×10^7
Industry	8.16×10^5	6.83×10^6	2.33×10^5	4.64×10^5	-3.41×10^6	4.94×10^6
Transport	1.74×10^6	1.45×10^7	0	0	-3.39×10^4	1.63×10^7
Primary	1.25×10^5	1.05×10^6	-9.52×10^4	-1.56×10^5	8.73×10^4	1.01×10^6
Services	1.23×10^5	1.03×10^6	-1.06×10^4	1.41×10^6	-1.11×10^6	1.44×10^6
Residential	3.38×10^5	2.83×10^6	0	0	3.47×10^5	3.52×10^6
2001						
Total	4.27×10^6	3.17×10^7	0	5.06×10^6	-4.71×10^6	3.63×10^7
Industry	1.12×10^6	8.29×10^6	7.79×10^4	1.63×10^6	-3.56×10^6	7.56×10^6
Transport	2.37×10^6	1.75×10^7	0	0	-9.48×10^4	1.98×10^7
Primary	1.60×10^5	1.18×10^6	-2.16×10^5	-6.45×10^5	-1.73×10^4	4.65×10^5
Services	1.70×10^5	1.26×10^6	8.90×10^3	1.49×10^6	-8.46×10^5	2.09×10^6
Residential	4.51×10^5	3.35×10^6	0	0	-2.68×10^5	3.53×10^6
2002						
Total	6.47×10^6	3.39×10^7	0	3.60×10^6	-5.33×10^6	3.86×10^7
Industry	1.68×10^6	8.81×10^6	-2.39×10^5	1.32×10^6	-3.84×10^6	7.73×10^6
Transport	3.59×10^6	1.88×10^7	0	0	-3.20×10^5	2.21×10^7
Primary	2.38×10^5	1.25×10^6	-5.18×10^5	-5.78×10^5	2.40×10^3	3.94×10^5
Services	2.55×10^5	1.33×10^6	5.07×10^4	1.42×10^6	-1.02×10^6	2.04×10^6
Residential	6.88×10^5	3.61×10^6	0	0	-1.69×10^5	4.13×10^6
2003						
Total	9.56×10^6	3.68×10^7	0	8.80×10^6	-4.83×10^6	5.03×10^7
Industry	2.51×10^6	9.67×10^6	-5.83×10^5	3.35×10^6	-3.01×10^6	1.19×10^7
Transport	5.27×10^6	2.03×10^7	0	0	-4.61×10^5	2.51×10^7
Primary	3.70×10^5	1.42×10^6	-6.42×10^5	6.18×10^5	1.06×10^5	1.87×10^6
Services	3.33×10^5	1.28×10^6	7.10×10^4	1.03×10^6	-1.65×10^6	1.06×10^6
Residential	1.02×10^6	3.94×10^6	0	0	8.68×10^4	5.05×10^6
2004						
Total	1.26×10^7	3.97×10^7	0	1.12×10^7	-5.48×10^6	5.79×10^7
Industry	3.22×10^6	1.02×10^7	-1.03×10^6	3.56×10^6	-3.88×10^6	1.20×10^7
Transport	6.93×10^6	2.19×10^7	0	0	-3.81×10^5	2.85×10^7
Primary	5.09×10^5	1.61×10^6	-1.26×10^6	1.86×10^6	2.41×10^5	2.96×10^6
Services	4.66×10^5	1.47×10^6	1.35×10^5	1.38×10^6	-1.53×10^6	1.93×10^6
Residential	1.36×10^6	4.31×10^6	0	0	2.05×10^5	5.88×10^6

Table B.2
Continued.

2005						
Total	1.55×10^{7}	4.32×10^{7}	0	1.13×10^{7}	-6.42×10^{6}	6.36×10^{7}
Industry	3.97×10^{6}	1.10×10^{7}	-5.73×10^{5}	3.05×10^{6}	-3.91×10^{6}	1.36×10^{7}
Transport	8.60×10^{6}	2.40×10^{7}	0	0	-5.71×10^{5}	3.20×10^{7}
Primary	6.04×10^{5}	1.68×10^{6}	-1.98×10^{6}	1.89×10^{6}	1.56×10^{5}	2.35×10^{6}
Services	6.06×10^{5}	1.69×10^{6}	1.49×10^{5}	1.77×10^{6}	-1.39×10^{6}	2.83×10^{6}
Residential	1.66×10^{6}	4.62×10^{6}	0	0	-2.55×10^{5}	6.03×10^{6}
2006						
Total	1.80×10^{7}	4.49×10^{7}	0	4.70×10^{6}	-1.02×10^{7}	5.75×10^{7}
Industry	4.49×10^{6}	1.11×10^{7}	-1.54×10^{6}	1.34×10^{6}	-4.89×10^{6}	1.05×10^{7}
Transport	1.01×10^{7}	2.52×10^{7}	0	0	-1.41×10^{6}	3.39×10^{7}
Primary	6.74×10^{5}	1.67×10^{6}	-2.31×10^{6}	1.25×10^{6}	2.66×10^{4}	1.31×10^{6}
Services	7.15×10^{5}	1.77×10^{6}	2.35×10^{5}	1.19×10^{6}	-1.98×10^{6}	1.94×10^{6}
Residential	1.99×10^{6}	4.95×10^{6}	0	0	-2.14×10^{6}	4.80×10^{6}
2007						
Total	2.06×10^{7}	4.80×10^{7}	0	2.50×10^{6}	-1.13×10^{7}	5.98×10^{7}
Industry	5.06×10^{6}	1.18×10^{7}	-2.69×10^{6}	3.55×10^{5}	-4.81×10^{6}	9.71×10^{6}
Transport	1.17×10^{7}	2.73×10^{7}	0	0	-1.63×10^{6}	3.73×10^{7}
Primary	7.55×10^{5}	1.76×10^{6}	-2.34×10^{6}	7.54×10^{5}	1.14×10^{5}	1.04×10^{6}
Services	8.13×10^{5}	1.89×10^{6}	2.59×10^{5}	1.16×10^{6}	-1.94×10^{6}	2.19×10^{6}
Residential	2.27×10^{6}	5.28×10^{6}	0	0	-3.07×10^{6}	4.48×10^{6}
2008						
Total	2.24×10^{7}	4.84×10^{7}	0	-3.11×10^{6}	-1.26×10^{7}	5.51×10^{7}
Industry	5.37×10^{6}	1.16×10^{7}	-4.68×10^{6}	-2.31×10^{6}	-5.09×10^{6}	4.92×10^{6}
Transport	1.27×10^{7}	2.75×10^{7}	0	0	-2.05×10^{6}	3.82×10^{7}
Primary	8.09×10^{5}	1.75×10^{6}	-2.48×10^{6}	6.64×10^{5}	4.41×10^{4}	7.82×10^{5}
Services	8.78×10^{5}	1.90×10^{6}	4.14×10^{5}	1.54×10^{6}	-2.34×10^{6}	2.40×10^{6}
Residential	2.51×10^{6}	5.43×10^{6}	0	0	-3.01×10^{6}	4.93×10^{6}
2009						
Total	2.37×10^{7}	4.13×10^{7}	0	-9.81×10^{6}	-1.53×10^{7}	3.99×10^{7}
Industry	5.61×10^{6}	9.78×10^{6}	-6.44×10^{6}	-5.19×10^{6}	-3.51×10^{6}	2.47×10^{5}
Transport	1.34×10^{7}	2.34×10^{7}	0	0	-2.97×10^{6}	3.39×10^{7}
Primary	8.52×10^{5}	1.49×10^{6}	-2.36×10^{6}	4.60×10^{5}	-1.33×10^{4}	4.23×10^{5}
Services	9.11×10^{5}	1.59×10^{6}	5.46×10^{5}	1.69×10^{6}	-2.86×10^{6}	1.88×10^{6}
Residential	2.67×10^{6}	4.65×10^{6}	0	0	-2.71×10^{6}	4.61×10^{6}
2010						
Total	2.41×10^{7}	3.67×10^{7}	0	-1.03×10^{7}	-1.60×10^{7}	3.46×10^{7}
Industry	5.61×10^{6}	8.54×10^{6}	-7.15×10^{6}	-5.17×10^{6}	-3.93×10^{6}	-2.10×10^{6}
Transport	1.37×10^{7}	2.09×10^{7}	0	0	-3.31×10^{6}	3.13×10^{7}
Primary	8.63×10^{5}	1.31×10^{6}	-2.52×10^{6}	4.16×10^{5}	-7.51×10^{4}	2.15×10^{2}
Services	9.15×10^{5}	1.39×10^{6}	6.01×10^{5}	1.80×10^{6}	-3.07×10^{6}	1.64×10^{6}
Residential	2.70×10^{6}	4.11×10^{6}	0	0	-2.30×10^{6}	4.51×10^{6}
2011						
Total	2.41×10^{7}	3.52×10^{7}	0	-1.26×10^{7}	-1.62×10^{7}	3.05×10^{7}
Industry	5.51×10^{6}	8.05×10^{6}	-7.50×10^{6}	-6.10×10^{6}	-4.83×10^{6}	-4.87×10^{6}
Transport	1.37×10^{7}	2.00×10^{7}	0	0	-3.12×10^{6}	3.06×10^{7}
Primary	8.69×10^{5}	1.27×10^{6}	-2.48×10^{6}	2.13×10^{5}	-4.84×10^{4}	-1.77×10^{5}
Services	9.22×10^{5}	1.35×10^{6}	6.13×10^{5}	1.76×10^{6}	-2.69×10^{6}	1.95×10^{6}
Residential	2.72×10^{6}	3.97×10^{6}	0	0	-2.75×10^{6}	3.94×10^{6}
2012						
Total	2.38×10^{7}	3.23×10^{7}	0	-1.71×10^{7}	-1.70×10^{7}	2.19×10^{7}
Industry	5.31×10^{6}	7.21×10^{6}	-8.04×10^{6}	-7.49×10^{6}	-5.91×10^{6}	-8.92×10^{6}
Transport	1.36×10^{7}	1.84×10^{7}	0	0	-2.93×10^{6}	2.91×10^{7}
Primary	8.80×10^{5}	1.20×10^{6}	-2.31×10^{6}	3.42×10^{5}	-1.13×10^{5}	-1.33×10^{3}
Services	9.21×10^{5}	1.25×10^{6}	6.46×10^{5}	1.70×10^{6}	-2.51×10^{6}	2.01×10^{6}
Residential	2.72×10^{6}	3.69×10^{6}	0	0	-2.75×10^{6}	3.66×10^{6}
2013						
Total	2.33×10^{7}	3.07×10^{7}	0	-2.13×10^{7}	-1.87×10^{7}	1.40×10^{7}
Industry	5.14×10^{6}	6.78×10^{6}	-8.84×10^{6}	-8.30×10^{6}	-6.70×10^{6}	-1.19×10^{7}
Transport	1.33×10^{7}	1.76×10^{7}	0	0	-3.01×10^{6}	2.79×10^{7}
Primary	8.79×10^{5}	1.16×10^{6}	-2.17×10^{6}	5.52×10^{5}	-2.03×10^{5}	2.15×10^{5}
Services	9.12×10^{5}	1.20×10^{6}	7.03×10^{5}	1.51×10^{6}	-2.39×10^{6}	1.94×10^{6}
Residential	2.68×10^{6}	3.54×10^{6}	0	0	-3.42×10^{6}	2.80×10^{6}

Table B.2
Continued.

2014						
Total	2.26×10^7	3.24×10^7	0	-2.32×10^7	-1.98×10^7	1.20×10^7
Industry	5.01×10^6	7.18×10^6	-9.47×10^6	-8.53×10^6	-7.21×10^6	-1.30×10^7
Transport	1.29×10^7	1.85×10^7	0	0	-2.85×10^6	2.85×10^7
Primary	8.84×10^5	1.27×10^6	-2.06×10^6	6.64×10^5	-2.59×10^5	4.96×10^5
Services	8.97×10^5	1.29×10^6	7.62×10^5	1.48×10^6	-2.30×10^6	2.12×10^6
Residential	2.53×10^6	3.63×10^6	0	0	-3.53×10^6	2.63×10^6
2015						
Total	2.18×10^7	3.51×10^7	0	-2.54×10^7	-2.09×10^7	1.05×10^7
Industry	4.89×10^6	7.88×10^6	-1.05×10^7	-2.77×10^6	-7.66×10^6	-8.18×10^6
Transport	1.24×10^7	2.00×10^7	0	0	-2.63×10^6	2.98×10^7
Primary	8.94×10^5	1.44×10^6	-1.92×10^6	6.93×10^5	-3.22×10^5	7.86×10^5
Services	8.85×10^5	1.42×10^6	8.04×10^5	1.38×10^6	-2.26×10^6	2.24×10^6
Residential	2.40×10^6	3.87×10^6	0	0	-3.59×10^6	2.68×10^6
2016						
Total	2.14×10^7	3.81×10^7	0	-2.93×10^7	-2.19×10^7	8.24×10^6
Industry	4.88×10^6	8.68×10^6	-1.06×10^7	-3.50×10^6	-8.01×10^6	-8.55×10^6
Transport	1.21×10^7	2.16×10^7	0	0	-2.88×10^6	3.09×10^7
Primary	9.20×10^5	1.64×10^6	-1.98×10^6	7.15×10^5	-2.33×10^5	1.06×10^6
Services	8.96×10^5	1.60×10^6	8.44×10^5	1.37×10^6	-2.30×10^6	2.41×10^6
Residential	2.34×10^6	4.16×10^6	0	0	-4.01×10^6	2.49×10^6
2017						
Total	2.16×10^7	4.14×10^7	0	-3.00×10^7	-2.22×10^7	1.08×10^7
Industry	5.01×10^6	9.61×10^6	-1.04×10^7	-3.12×10^6	-8.11×10^6	-7.00×10^6
Transport	1.21×10^7	2.33×10^7	0	0	-3.14×10^6	3.23×10^7
Primary	9.77×10^5	1.88×10^6	-2.03×10^6	7.84×10^5	-1.02×10^5	1.50×10^6
Services	9.31×10^5	1.78×10^6	8.78×10^5	1.41×10^6	-2.24×10^6	2.76×10^6
Residential	2.39×10^6	4.58×10^6	0	0	-3.95×10^6	3.02×10^6
2018						
Total	2.21×10^7	4.29×10^7	0	-3.22×10^7	-2.33×10^7	9.48×10^6
Industry	5.17×10^6	1.01×10^7	-1.05×10^7	-3.49×10^6	-8.66×10^6	-7.38×10^6
Transport	1.23×10^7	2.38×10^7	0	0	-3.51×10^6	3.26×10^7
Primary	1.05×10^6	2.03×10^6	-2.04×10^6	8.52×10^5	-6.11×10^4	1.83×10^6
Services	9.77×10^5	1.90×10^6	8.88×10^5	1.49×10^6	-2.28×10^6	2.97×10^6
Residential	2.44×10^6	4.75×10^6	0	0	-3.85×10^6	3.34×10^6
2019						
Total	2.29×10^7	4.40×10^7	0	-3.51×10^7	-2.43×10^7	7.50×10^6
Industry	5.41×10^6	1.04×10^7	-1.03×10^7	-3.61×10^6	-9.10×10^6	-7.20×10^6
Transport	1.27×10^7	2.44×10^7	0	0	-3.98×10^6	3.31×10^7
Primary	1.11×10^6	2.14×10^6	-2.05×10^6	9.21×10^5	-2.53×10^4	2.10×10^6
Services	1.02×10^6	1.95×10^6	8.84×10^5	1.53×10^6	-2.15×10^6	3.23×10^6
Residential	2.50×10^6	4.81×10^6	0	0	-4.01×10^6	3.30×10^6
2020						
Total	2.35×10^7	2.88×10^7	0	-2.86×10^7	-2.41×10^7	-3.32×10^5
Industry	5.49×10^6	6.73×10^6	-1.03×10^7	-2.08×10^6	-7.49×10^6	-7.65×10^6
Transport	1.30×10^7	1.60×10^7	0	0	-4.07×10^6	2.49×10^7
Primary	1.12×10^6	1.37×10^6	-2.02×10^6	1.47×10^6	5.25×10^4	2.00×10^6
Services	1.03×10^6	1.26×10^6	8.15×10^5	1.56×10^6	-1.94×10^6	2.73×10^6
Residential	2.54×10^6	3.11×10^6	0	0	-4.06×10^6	1.58×10^6
2021						
Total	2.51×10^7	3.94×10^7	0	-2.80×10^7	-2.15×10^7	1.50×10^7
Industry	5.64×10^6	8.84×10^6	-9.90×10^6	-2.89×10^6	-8.16×10^6	-6.47×10^6
Transport	1.43×10^7	2.24×10^7	0	0	-3.71×10^6	3.29×10^7
Primary	1.14×10^6	1.79×10^6	-2.02×10^6	1.22×10^6	-1.52×10^4	2.11×10^6
Services	1.09×10^6	1.71×10^6	8.24×10^5	1.60×10^6	-1.78×10^6	3.46×10^6
Residential	2.54×10^6	3.97×10^6	0	0	-3.94×10^6	2.57×10^6
2022						
Total	2.63×10^7	4.71×10^7	0	-3.78×10^7	-2.05×10^7	1.51×10^7
Industry	5.50×10^6	9.85×10^6	-8.19×10^6	-8.69×10^6	-9.24×10^6	-1.08×10^7
Transport	1.54×10^7	2.76×10^7	0	0	-3.53×10^6	3.95×10^7
Primary	1.16×10^6	2.08×10^6	-2.99×10^6	1.48×10^6	-4.03×10^3	1.72×10^6
Services	1.11×10^6	1.99×10^6	7.74×10^5	1.24×10^6	-2.16×10^6	2.95×10^6
Residential	2.57×10^6	4.60×10^6	0	0	-4.50×10^6	2.66×10^6
2023						
Total	2.74×10^7	4.82×10^7	0	-4.25×10^7	-2.35×10^7	9.70×10^6
Industry	5.76×10^6	1.01×10^7	-9.88×10^6	-7.96×10^6	-9.57×10^6	-1.15×10^7
Transport	1.61×10^7	2.84×10^7	0	0	-5.06×10^6	3.95×10^7
Primary	1.16×10^6	2.05×10^6	-2.26×10^6	1.22×10^5	-1.04×10^5	9.65×10^5
Services	1.14×10^6	2.01×10^6	8.37×10^5	1.04×10^6	-2.46×10^6	2.57×10^6
Residential	2.59×10^6	4.56×10^6	0	0	-4.14×10^6	3.01×10^6
2024						
Total	2.91×10^7	5.19×10^7	0	-4.35×10^7	-2.40×10^7	1.34×10^7
Industry	6.07×10^6	1.08×10^7	-1.07×10^7	-7.25×10^6	-9.95×10^6	-1.09×10^7
Transport	1.72×10^7	3.06×10^7	0	0	-4.62×10^6	4.32×10^7
Primary	1.23×10^6	2.20×10^6	-1.95×10^6	-2.42×10^5	-1.47×10^5	1.09×10^6
Services	1.26×10^6	2.24×10^6	9.07×10^5	1.36×10^6	-2.32×10^6	3.45×10^6
Residential	2.72×10^6	4.85×10^6	0	0	-4.13×10^6	3.44×10^6

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