

**MAJOR SOURCES OF CARBON EMISSIONS IN THE NATIONAL ECONOMY: A  
SECTORAL ANALYSIS AND POLICY IMPLICATIONS**

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**Abstract:** Carbon dioxide and other greenhouse gas emissions from national economic activities represent one of the most consequential challenges of contemporary environmental governance. Despite growing scholarly attention to climate mitigation, a systematic understanding of the sectoral architecture of national carbon emissions—particularly in transitional and emerging economies—remains incomplete. This paper conducts a comprehensive, evidence-based analysis of the principal sources of carbon emissions within national economic frameworks, drawing upon empirical data, input-output modeling, and a systematic review of 98 peer-reviewed studies and institutional reports published between 2012 and 2024. The analysis identifies six dominant emission sectors: energy generation and fossil fuel combustion, industrial manufacturing and heavy industry, transport and logistics infrastructure, agriculture and land use change, waste management systems, and building and construction activities. The study further examines sector-specific emission drivers, including technological lock-in, structural economic factors, and institutional barriers to decarbonization. Findings indicate that energy and industrial sectors collectively account for approximately 62–68% of national GHG emissions across the reviewed economies, yet exhibit the greatest abatement potential through technological substitution and regulatory intervention. The paper concludes with a discussion of sector-differentiated policy instruments and proposes a national carbon accounting framework that integrates production-based and consumption-based emission perspectives.

**Keywords:** carbon emissions; greenhouse gases; national economy; sectoral analysis; decarbonization; fossil fuels; input-output analysis; climate policy; emission accounting

The relationship between economic activity and carbon dioxide (CO<sub>2</sub>) emissions has been a central preoccupation of environmental science, ecological economics, and climate policy since the landmark reports of the Intergovernmental Panel on Climate Change (IPCC) in the early 1990s. The fundamental tension between economic growth imperatives and the atmospheric limits of greenhouse gas (GHG) accumulation has only intensified in the intervening decades. Global average surface temperatures have risen by approximately 1.1°C above pre-industrial levels, with the most severe consequences concentrated in regions that are simultaneously the least responsible for historical emissions and the least equipped to adapt (IPCC, 2023).

Within this global context, the national economy constitutes the primary analytical and policy unit for understanding emission sources, because economic structures, energy systems, industrial compositions, and governance institutions are principally organized and regulated at the national level. Identifying and quantifying the sectoral origins of national carbon emissions is therefore an essential precondition for designing effective, equitable, and economically viable decarbonization strategies. Without a granular understanding of where emissions originate within the national economic system—and why—policymakers risk deploying blunt, poorly targeted instruments that impose economic costs without achieving commensurate environmental benefits.

Despite this evident necessity, the literature on national carbon emission sources remains fragmented across disciplinary boundaries. Energy economists emphasize fossil fuel combustion

and energy system transitions; industrial ecologists focus on material flows and lifecycle emissions; agricultural scientists examine land use and soil carbon dynamics; and urban planners concentrate on building energy performance and transport systems. Integrative, cross-sectoral analyses that situate all major emission sources within a unified national economic accounting framework are comparatively rare, particularly for developing and transitional economies where structural economic transformation is occurring most rapidly.

This paper addresses this gap through a systematic, evidence-based analysis of the major sources of carbon emissions in national economies. The study is guided by four research objectives:

1. To identify and characterize the principal sectoral sources of carbon emissions within national economic frameworks;
2. To quantify the relative contribution of each sector based on available empirical evidence from multiple national contexts;
3. To examine the structural economic, technological, and institutional drivers of emissions within each sector;
4. To evaluate the implications of sectoral emission profiles for the design of differentiated climate policy instruments.

The paper is structured in accordance with the IMRAD format. Section 2 presents the materials and methods, including the literature search strategy, data sources, and analytical framework. Section 3 presents findings organized by emission sector. Section 4 discusses cross-cutting themes, including emission accounting methodologies and policy implications. Section 5 offers conclusions and directions for future research.

This study employs a mixed-methods design combining a systematic literature review with secondary quantitative analysis of national greenhouse gas inventory data. The systematic review component follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor and transparency (Page et al., 2021). The quantitative component draws on publicly available national GHG inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by

Sectoral emissions were analyzed using a modified version of the Kaya Identity framework, which decomposes total CO<sub>2</sub> emissions into the product of population, per capita GDP, energy intensity of the economy, and carbon intensity of the energy supply (Kaya & Yokoburi, 1997). This decomposition allows identification of the relative contributions of demographic, economic, technological, and fuel-mix factors to emission trajectories across sectors and countries. Input-output analysis was additionally applied to assess upstream and downstream emission linkages between sectors, enabling identification of sectors that are both direct and indirect major emitters within national economic systems. Energy generation—encompassing electricity production, heat supply, and the direct combustion of fossil fuels in stationary installations—consistently emerges as the single largest source of national carbon emissions across the reviewed economies. Based on aggregated EDGAR v7.0 and IEA data, power generation and heat supply account for an average of 34.2% (range: 21–52%) of total national GHG emissions, with higher shares observed in economies heavily reliant on coal-fired electricity generation, including China, India, Poland, and several Central Asian republics (Friedlingstein et al., 2022).

The carbon intensity of electricity generation is strongly correlated with the fossil fuel composition of the national energy mix. Coal-intensive electricity systems produce approximately 820–1,050 gCO<sub>2</sub>/kWh, compared to 400–550 gCO<sub>2</sub>/kWh for natural gas combined cycle plants, and near-zero for nuclear, wind, and solar photovoltaic systems (IPCC, 2023). Decarbonization of the power sector through renewable energy deployment, fuel switching, and carbon capture and storage (CCS) therefore represents the highest-leverage opportunity in most national contexts. However, energy transition pathways are constrained by existing capital stock lock-in, grid infrastructure limitations, and the socioeconomic vulnerabilities of fossil fuel-dependent communities and regions (Unruh, 2000).

Fugitive emissions from fossil fuel extraction, processing, and transmission—including methane leakage from natural gas systems and coal mines—constitute an often underestimated component of national energy sector emissions. Methane, with a global warming potential approximately 80 times that of CO<sub>2</sub> over a 20-year horizon, can substantially increase the effective carbon footprint of natural gas relative to its nominal combustion emissions (IPCC, 2023). Improved monitoring and reporting of fugitive emissions represents a significant data gap in many national greenhouse gas inventories. The industrial sector—encompassing manufacturing, mining, construction materials production, chemical processing, and metallurgy—is the second most significant source of national carbon emissions, accounting for an average of 27.8% of total GHG emissions across the reviewed economies (IEA, 2023). Industrial emissions arise from two distinct sources: energy combustion for heat and power within industrial facilities, and process emissions resulting from chemical transformations inherent to production processes.

Process emissions from cement clinker production (arising from the calcination of limestone), iron and steel manufacturing (from coking coal reduction of iron ore), and chemical industry operations (including ammonia synthesis and petrochemical cracking) are particularly significant because they are structurally embedded in the production chemistry and cannot be eliminated through energy system decarbonization alone (Davis et al., 2018). Global cement production alone accounts for approximately 8% of global CO<sub>2</sub> emissions, making it one of the most challenging sectors to decarbonize without radical materials substitution or carbon capture deployment.

The transport sector accounts for an average of 16.4% of national GHG emissions across the reviewed economies, though this share is substantially higher in high-income countries with extensive private vehicle ownership and road freight systems, reaching 28–32% in several Western European nations and the United States (IEA, 2023). Transport emissions are almost entirely attributable to the combustion of petroleum-derived fuels—gasoline, diesel, kerosene, and heavy fuel oil—in road vehicles, aviation, shipping, and rail.

Road transport dominates the sector, contributing approximately 72–78% of transport-related CO<sub>2</sub> emissions in most national contexts. Passenger car use accounts for the largest share of road transport emissions, followed by heavy goods vehicles. The carbon intensity of transport is driven by vehicle fuel efficiency, fleet turnover rates, fuel carbon content, and travel demand patterns, all of which are shaped by land use structures, urban form, income levels, and cultural norms (Sims et al., 2014). The ongoing transition to battery electric vehicles offers a substantial decarbonization pathway, though its effectiveness depends critically on the carbon intensity of the electricity grid used for charging. Aviation and maritime shipping, while representing smaller shares of national emission totals, present distinct decarbonization challenges due to the technological immaturity of zero-carbon propulsion systems and the international jurisdictional

complexities of attributing emissions from cross-border transport activities. The absence of these sectors from nationally determined contributions (NDCs) submitted under the Paris Agreement represents a significant accountability gap. The agriculture, forestry, and other land use (AFOLU) sector occupies a distinctive position in national carbon emission profiles, functioning simultaneously as a significant source of GHG emissions and as the economy's primary carbon sink through managed forest systems. Agricultural emissions average 11.7% of national GHG totals across the reviewed economies but rise to 25–35% in agricultural export economies and developing nations with high dependence on livestock production and traditional land management practices (FAO, 2023).

The waste management sector contributes an average of 3.8% of national GHG emissions across the reviewed economies, primarily through methane generation from landfill decomposition of organic waste and from wastewater treatment processes (IPCC, 2022). While relatively modest in proportional terms, waste sector emissions carry high mitigation value because landfill gas can be captured and utilized for energy generation, and because upstream waste reduction and material recycling generate significant indirect emission benefits across connected industrial and transport sectors.

The sectoral heterogeneity of national carbon emission sources necessitates a portfolio approach to climate policy, in which different instruments are tailored to the specific technological, economic, and institutional characteristics of each sector. Carbon pricing mechanisms—whether through emission trading systems or carbon taxes—are most effective in sectors where competitive market dynamics, price-elastic fuel demand, and technological alternatives are present, particularly power generation and energy-intensive industry (Goulder & Schein, 2013). Regulatory standards, including fuel economy requirements, building energy codes, and appliance efficiency mandates, are more appropriate in sectors where consumer information asymmetries, split incentives, and non-price barriers impede market responses to carbon pricing.

Public investment programs for research, development, and demonstration (RD&D) of breakthrough technologies—including green hydrogen production, industrial carbon capture, sustainable aviation fuels, and next-generation nuclear power—are essential in sectors where technological solutions remain immature and the private sector underinvests due to spillover effects and long development timescales. Agricultural emission mitigation requires a distinct blend of agronomic extension services, incentive payments for ecosystem services, and regulatory frameworks that balance productivity imperatives with environmental objectives. Several significant data gaps were identified in the course of this analysis. First, national GHG inventories vary substantially in quality, completeness, and temporal currency across countries, with many developing nations reporting inventories with significant time lags and methodological uncertainties. Second, process emissions from industry, particularly in the chemical sector, are underreported in many national inventories due to measurement complexity and confidentiality constraints. Third, AFOLU emissions carry the highest inherent measurement uncertainty of any sector, owing to the spatial heterogeneity of soil carbon stocks and the methodological challenges of estimating biomass changes from satellite data. Fourth, the interaction effects between sectors—particularly the emission implications of electrification of transport and heating for the power sector's emission trajectory—are rarely captured in static sectoral accounting frameworks. This study has presented a systematic, cross-sectoral analysis of the major sources of carbon emissions within national economies, synthesizing evidence from 98 peer-reviewed studies, national greenhouse gas inventories, and international institutional

databases. Six principal emission sectors were identified and characterized: energy generation, industrial manufacturing, transport, agriculture and land use, waste management, and buildings. Energy and industry together account for approximately 62–68% of national GHG emissions on average, but each sector exhibits distinct emission drivers, decarbonization challenges, and policy leverage points that demand tailored analytical and governance approaches.

The analysis underscores three overarching conclusions. First, no single instrument or sectoral strategy is sufficient to achieve the deep decarbonization required by science-based climate targets; a coordinated, cross-sectoral policy portfolio is necessary. Second, the structural composition of national economies is a primary determinant of emission profiles, and decarbonization strategies must be adapted to the specific economic, technological, and institutional context of each country rather than applied uniformly. Third, current national GHG accounting frameworks, while improving, remain inadequate to capture the full complexity of emission sources, particularly with respect to consumption-based emissions, fugitive releases, and AFOLU carbon dynamics.

Future research should prioritize: longitudinal analysis of emission trajectory drivers across economic development stages; improved integration of consumption-based and production-based accounting perspectives; methodological advances in measuring and verifying agricultural and land use emissions; and systematic evaluation of the co-benefits and trade-offs of sector-specific mitigation policies for economic productivity, employment, energy security, and distributional equity. Progress on these fronts is essential to transforming the understanding of national carbon emission sources into actionable, just, and economically viable decarbonization pathways.

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