Industry on the road to 2050

A report prepared for the Climate Club

Reflections on key steps towards inclusive and accelerated industrial decarbonisation

CLIMATE CLUB

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Foreword

This year marks the tenth anniversary of the Paris Agreement: a milestone that reminds us both of how far we have come and how much more remains to be done. In this pivotal decade, the Climate Club has emerged as a vital force in translating global ambition into action. Our shared goal of achieving net-zero emissions by mid-century depends more than ever on the successful decarbonization of industry, which is both the foundation of our economies and a significant driver of global emissions.

Reflecting on our journey, the Climate Club has provided a unique high-level platform for dialogue and has made remarkable progress over the past two years. We have strengthened cooperation on a multitude of challenges, always keeping guiding principles of ambition and fairness at the center. The launch of the *Voluntary Principles for Action to Address Carbon Leakage and Other Spillovers* reflects our commitment to ensuring that climate action and competitiveness advance hand in hand, while our *Global Pledge to Grow Near-zero and Low-emissions Steel and Cement Markets* demonstrates members' shared resolve to transform production systems while fostering innovation and economic opportunities.

Industry on the road to 2050: A report for the Climate Club represents a critical synthesis of ideas by leading authors. It was our extreme privilege to convene a diverse group of globally-renowned scientists, economists, policy experts and practitioners to offer key insights on how Climate Club members and beyond could shape their policies to achieve the twin, complementary, goals of decarbonization and economic development. We are deeply grateful to the authors for their enthusiasm to take part in this project, and we are equally sure that their ideas will inspire governments, organizations, and thought leaders around the world to achieve our shared objectives.

As we reflect on the decade since COP21, I am proud of what we have contributed through the Climate Club, even as I remain motivated by the challenge that lies ahead. With shared purpose and collective action, we can make the vision of a decarbonized, competitive industry that incentivizes economic development and security a reality.

Michael Apicelli

Head of Climate Club Secretariat

Acknowledgements

This report was developed with the support of the Co-Chairs of the Climate Club (Chile and Germany) and funded by the Government of Germany.

The report was edited, reviewed and co-ordinated by Stephan Raes, *Head of OECD Structural and Industry Policy Division*, Deger Saygin, *Team Lead and Senior Policy Analyst at the OECD,* and Antonella Pasetto, *Project Manager at the Climate Club Secretariat,* with support from Mara Felice and Julia Gaus. Editorial support was provided by Anna Lockwood and Lizzie Sayer.

Chapter 1 was authored by Stephan Raes, Deger Saygin, and Antonella Pasetto, with support from Mara Felice and Julia Gaus. It benefited from valuable contributions from Michael Alonzi, Joseph Cordonnier, Isabel Geppert, Andrew Ruttinger, Valeria Sinisi Garcia and Tiffany Vass.

Chapters 2 to 12 were authored respectively by Joseph E. Stiglitz; Ketan Ahuja and Ricardo Hausmann; Frank Jotzo; Laurence Tubiana, Richard Baron, Samuel Leré, and Matthew Langdon; Kimberly Clausing, Axel Ockenfels and Catherine Wolfram; Carolyn Fischer and Michael Mehling; Marcelo Mena; Patricia Espinosa Cantellano; Mercedes Maroto-Valer; Damilola Ogunbiyi, Alvin Jose, Divyam Nagpal, Anant Wadhwa and Pavel Tereshchenko; and Elena Cima. The authors contributed voluntarily and did not receive financial remuneration for their contributions.

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List of acronyms

ACCTS	Agreement on Climate Change, Trade and Sustainability
AGMS	Africa Green Minerals Strategy
AGTP	Absolute Global Temperature Potential
AI	Artificial Intelligence
BCA	Border Carbon Adjustment
bcm	Billion Cubic Meters
BF-BOF	Blast Furnace–Basic Oxygen Furnace
BNDES	Brazilian Development Bank's
BTU	British Thermal Unit
CBAM	Carbon Border Adjustment Mechanism
CBDR-RC	Common but Differentiated Responsibilities and Respective Capabilities
CCfDs	Carbon Contracts for Difference
CCS	Carbon Capture, and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation, and Storage
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Conference of Parties
CPI	Carbon Pricing Instrument
DT	Digital Twins
EAF	Electric Arc Furnace
ECI	Economic Complexity Index
EFTA	European Free Trade Association
EIA	Energy Information Administration
EMDE	Emerging Market and Developing Economy
ESM	Energy Systems Model

ETS	Emission Trading System
EU	European Union
EUDR	European Union Regulation on Deforestation
EV	Electric Vehicle
FTA	Free Trade Agreement
GATT	General Agreement on Tariffs and Trade
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GMP	Global Matchmaking Platform
Gt	Gigatonnes
GWP	Global Warming Potential
IAM	Integrated Assessment Model
ICJ	International Court of Justice
IEA	International Energy Agency
IEEFA	Institute for Energy Economics and Financial Analysis
IFCMA	Inclusive Forum on Carbon Mitigation Approaches
IDRI	Industrial Decarbonisation Research and Innovation Centre
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	Intergovernmental Panel on Climate Change Sixth Assessment Report
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
JETP	Just Energy Transition Partnership
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard
LNG	Liquified Natural Gas

MCDA	Multi-Criteria Decision Analysis
MDB	Multilateral Development Banks
MFA	Material Flow Analysis
MFN	Most Favoured Nation
MMRV	Measurement, Monitoring, Reporting and Verification
MRV	Monitoring, Reporting and Verification
Mt	Million Tonnes
MTPA	Million Tonnes Per Year
NAICS	North American Industry Classification System
NDC	National Determined Contribution
Net ECR	Net Effective Carbon Rates
NGFS	Network for Greening the Financial System
NOC	National Oil Company
OECD	Organisation for Economic Co-operation and Development
OGDC	Oil and Gas Decarbonization Charter
OGMP 2.0	Oil and Gas Methane Partnership 2.0
OLADE	Latin American Energy Organization
PPP	Purchasing Power Parity
PROINFA	Programme of Incentives for Alternative Electricity Sources
PV	Solar photovoltaic
PVOUT	Photovoltaic Output
RCA	Revealed Comparative Advantage
R&D	Research and Development
SADC	South African Development Community
SCORE	Sarawak Corridor of Renewable Energy
SDR	Special Drawing Rights
SLO	Social Licence to Operate
T-MACC	Temperature-based Marginal Abatement Cost Curve

TrCM	Trade-Related Climate Measure
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UAE	United Arab Emirates
UK	United Kingdom
UKRI	United Kingdom Research and Innovation
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USD	United States Dollars
WDR	World Bank World Development Report
WTO	World Trade Organization

1 Reflections on the key next steps towards inclusive and accelerated industrial decarbonisation

I. Introduction

Imagine an offshore wind turbine. Its operation supports the transition to a secure and affordable energy system and could imply a reduction in carbon dioxide (CO_2) emissions. Up to 80% of the turbine is made of steel. The production of that steel fosters economic growth and job creation, both in the local economy and globally throughout its value chain. At the same time, the production of steel contributes significantly to global CO_2 emissions. This creates a challenge for governments, which acknowledge the importance of steel, cement and other bulk industrial materials like aluminium, fertilisers and plastics for economic development, jobs and the energy transition, while remaining committed to reducing CO_2 emissions. Importantly, this all occurs within highly interconnected markets, where policies in one country—or the absence of them—could affect what happens in others. Some countries with ambitious mitigation policies may see their industrial activity relocate elsewhere, which helps neither economic growth nor CO_2 reduction. Meanwhile, other countries may struggle to make progress on their much-needed industrial development in markets that could become fragmented as a result of industrial decarbonisation moving at different paces.

The challenge of combining economic growth with the achievement of ambitious climate goals is at the core of this report prepared for the Climate Club, a high-level international government forum launched in 2022 with the aim of accelerating industrial decarbonisation and thus contributing to achievement of the Paris Agreement. This first chapter sets the stage for those that follow, in which distinguished authors share their perspectives on how to address the challenge of industrial decarbonisation. The Climate Club has convened this group of experts on industrial decarbonisation to prepare chapters for this report with the goal of collecting their independent views on the key aspects that governments should consider as they design and implement industrial decarbonisation policies, and on the possible approaches they could take through international co-operation.

II. The importance of the industry sector

Manufacturing industries form the backbone of economies around the world, with strong societal significance

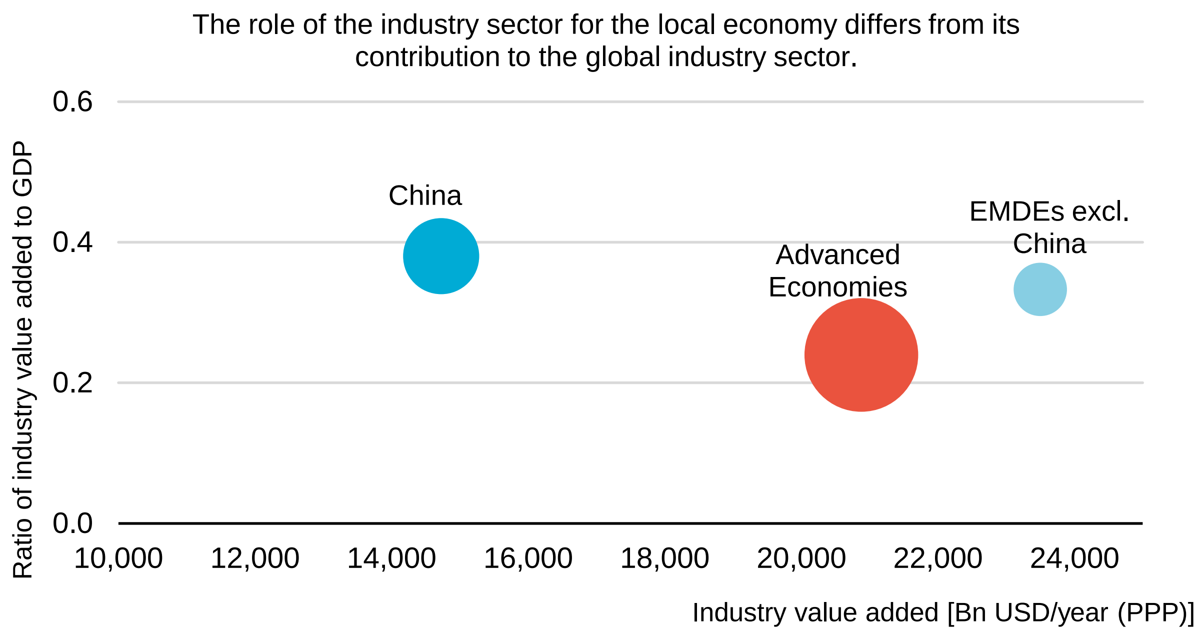
This report is about industry—its importance for economic development and for the people who work in it—and ways to decarbonise industry that are both efficient and inclusive. Societies around the world would not be the same without the strong basis of materials and goods the industry sector provides, particularly for infrastructure, buildings and vehicles. In particular, the heavy industry sector, including its subsectors such as cement, steel, petrochemicals and aluminium, is critically important for facilitating economic growth, catalysing innovation and spurring job creation across the world. The manufacturing sector alone represents 15% of the world economy and employs 14 out of 100 workers globally (World Bank 2024; United Nations Statistics Division 2023). The economic impact of the sector globally is further amplified by the high tradability of industrial products, as shown, for example, by the 25% of global steel and more than 10% of global ammonia production that is exported (Saygin et al. 2023).

Yet, from a supply-side perspective, wide differences emerge across economies

Industrialisation has been critical to economic development and prosperity in many countries, from the first industrial revolution in 18th century Europe, to the rapid industrialisation of Asian economies since the 1960s, and the ongoing industrialisation in emerging markets and developing economies (EMDEs) around the world today. Differences in the timing and circumstances of industrialisation explain the different roles played by industry in each country's socio-economic configuration and the share of those countries in industrial value added globally. For instance, East Asian economies contribute the most to the industrial value added globally, and the importance of industry in these economies is also reflected in the high share of regional GDP accounted[1] by the sector. Meanwhile, some EMDEs are characterised by an industrial base that is relatively moderate in comparison, but that represents a significant share of the country's GDP, reflecting a high dependency on industrial activities (Figure 1). Various advanced economies account for a significant share of industrial value added globally but have seen a decline in the share of industrial value added within their economies over the past decades.

[1] During the 1950s and 1960s, Hong Kong, Taiwan, Singapore, and South Korea experienced very high economic growth driven by the industrial sector in a phenomenon known as the "East Asian Miracle" (Lane, 2025).

Figure 1: Economic importance of the industry sector at the local and global scale, 2024 (data: IEA Global energy and Climate model, 2025). Bubble size reflects GDP per capita [USD/capita (PPP)]



Differences also emerge from a demand-side perspective

These differences are also evident from a demand-side perspective. The apparent consumption[2] of industrial materials—for example, 219 kg of steel per capita per year (World Steel Association 2023) and 471 kg of cement per capita per year (World Cement Association 2024) at the global level—is much higher in advanced economies. Economic development is often associated with a rise in apparent consumption of industrial goods (OECD 2019), although this stabilises once economies reach a certain level of maturity. Note that this rise in apparent consumption is increasingly becoming less pronounced as a result of measures promote efficient consumption levels and circular economies.

Manufacturing industries are of critical importance for reaching climate objectives

Industries are vital to the clean energy transitions so urgently needed today. Materials and goods such as steel, cement, aluminium and plastics are essential for renewable energy technologies like solar photovoltaic (PV), wind turbines, electric vehicles (EVs), electrolysers, batteries and heat pumps, as well as many other components and equipment. The establishment of strong industrial development strategies for near-zero and low-emissions materials could therefore also help countries participate in the low-emissions production of these key technologies.

[2] The physical production of a good, corrected by its trade balance and divided by the total population that consumes that good within a year.

At the same time, industry also significantly contributes to CO_2 emissions

While the industry sector is extremely important as a supplier of necessary inputs for energy transitions, and as a driver of economic growth more broadly, it is also a key source of CO_2 and other greenhouse gas (GHG) emissions. Industry accounts for about 25% of final energy consumption and up to 40% of total global CO_2 emissions—including both emissions from burning fossil fuels during industrial production processes, and those from the generation of electricity supplied to industrial plants, as well as industrial process emissions (IEA 2024c). Without advancing on industrial decarbonisation, achieving the climate objective of the 2015 Paris Agreement will remain out of reach.

There are large differences in industrial emissions across economies

As noted, the industrial profiles of different economies differ significantly, including with regards to the size of different sectors, technologies used, production processes, fuel mixes and the resulting emissions intensity. While countries face some common challenges in addressing industrial decarbonisation, differences across them mean that there is significant heterogeneity in how this could be achieved (OECD 2023).

Figure 2: Emissions from the industry sector 2024 (data: IEA Global Energy and Climate model 2025). Bubble size reflects the total annual CO_2 emissions from the industry sector in 2024 [Mt CO_2/year].

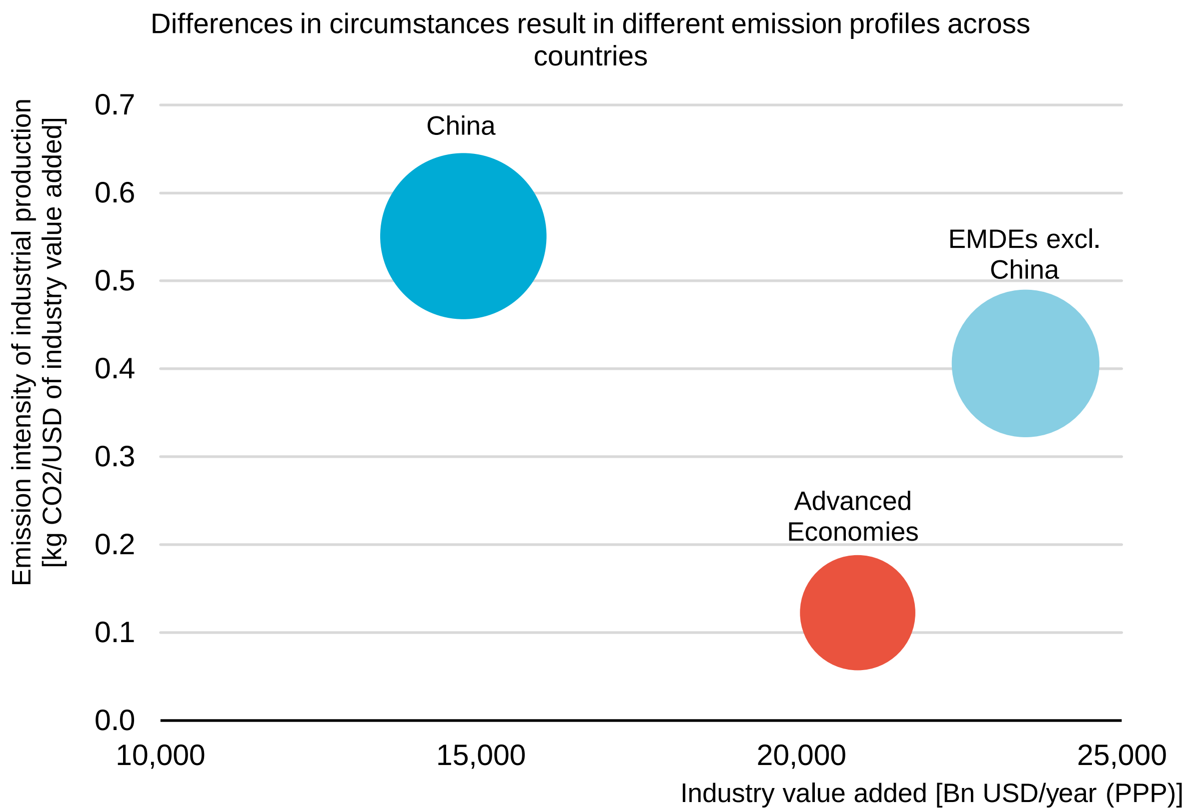
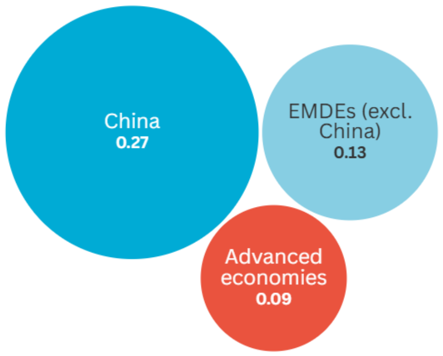
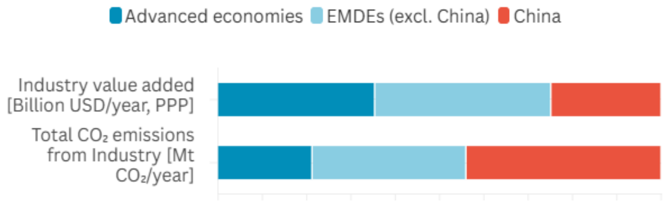


Figure 3: The heterogenous starting points of countries in terms of the industry sector's relevance for the national economy, its emission profile and global relevance. All values are for 2024 (IEA Global Energy and Climate model 2025).

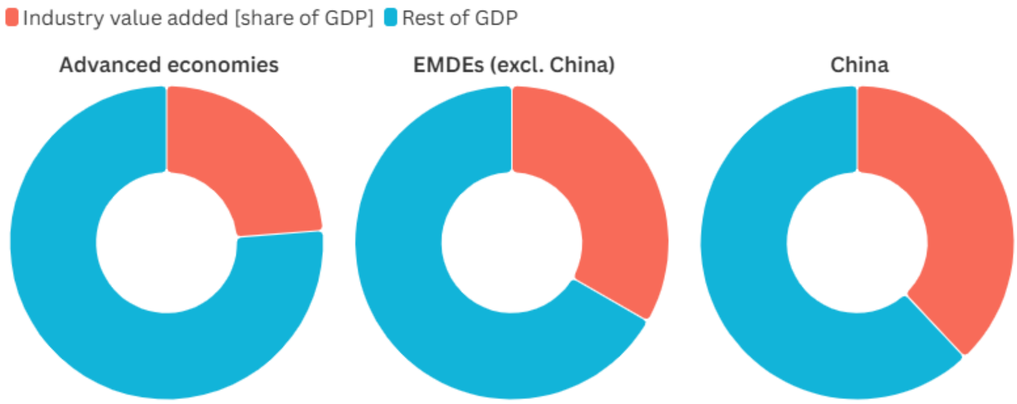
b) Emissions per unit of value added (Unit: kg CO_2/USD industry value added PPP)



a) Share of industry value added and total emissions per country grouping



c) Share of industry value added in each country grouping



III. The urgent need to accelerate industrial decarbonisation

The good news is that industrial decarbonisation is advancing

Encouragingly, various studies show that industrial companies are increasingly taking steps to reduce their emissions. For instance, analysis shows that most major steel producers worldwide have set decarbonisation targets (88%) and 65% of them have set net-zero targets. In addition, analysis of 65 announced near-zero and low-emissions steel projects by the end of 2022 shows that such projects are growing in number; the European Union accounted for about 60% of the project portfolio, China accounted for almost 15%, and North America and Asia (excluding China and India) for 8% each (OECD 2024a). A similar trend can be seen in the cement sector. According to the LeadIT Green Cement Technology Tracker (2025), the industry's emission reduction efforts are progressing, with over 75 announced projects globally involving Carbon Capture and Utilisation (CCU) and Carbon Capture, Utilisation and Storage (CCUS), alongside 35 projects focused on clay calcination kiln units to reduce the carbon intensity of cement by enabling the use of calcined clay as a partial substitute for clinker.

Advances are increasingly supported by governments

Governments also increasingly acknowledge that to accelerate industrial decarbonisation, they need to step up their actions. Research by the Climate Club Secretariat shows that all major steel-producing economies have introduced steel decarbonisation policies. However, almost half of all policies analysed (232 policies in 15 jurisdictions) are non-binding (48%) and focus on incentives rather than regulation (Climate Club 2025). In addition, while various mitigation policies effectively reduce emissions, the significant heterogeneity across policy instruments, sectors and regions—which reflects differences in policy design, implementation and other contextual factors—can limit their impact (OECD 2025c).

Yet, these efforts urgently need to be stepped up

At the same time, it is widely acknowledged—including throughout the chapters in this report—that the current pace of industrial decarbonisation is insufficient to achieve climate objectives. While emissions from heavy industries would need to fall by over 90% by 2050 from the current level to achieve net-zero objectives (OECD 2022) announced capacity for near-zero emissions iron-based steel production and cement production by 2030 amounts to only about 10 million tonnes (Mt) and 35 Mt, respectively, equivalent to 10% of the capacity required in the same year on a pathway to net-zero emissions by mid-century (IEA 2025a). In this context, there is a significant need for the private and public sectors to jointly accelerate their decarbonisation actions.

Industry decarbonisation can offer significant opportunities

Without underestimating the complexities of the transition, the various contributions in this report demonstrate that industrial decarbonisation can, in many ways, also provide opportunities. It creates possibilities for new markets and products that could potentially generate employment and economic growth, and can also produce innovations that can help spur productivity growth.

In past decades, growth in new industrial capacity has shifted from today's developed economies to China, and it is now shifting to India and other EMDEs, mainly in Asia, Africa and Latin America and the Caribbean (OECD 2022). While growth in industrial capacity can be a driver for those economies to achieve their development goals, investment in decarbonised industries could also give them a competitive edge. There are already many examples of new industrial plants employing the state-of-the-art technologies in EMDEs, such as for the production of aluminium, for which some plants in Africa or Asia now require less electricity than the global average (IAI 2024)—which has strengthened their competitiveness and resilience. Many EMDEs can use their ample available raw materials and clean energy resources required for industrial production to reap the benefits of these opportunities. Choices about plant location will also determine the wider prospects for global supply chains.

With the right policies in place, industry decarbonisation can create considerable returns for its financiers

The prospect of attractive returns on investment can give investors and financiers a significant incentive to invest in industrial decarbonisation. In the IEA Net Zero Emissions by 2050 Scenario, the market value of near-zero emissions steel and cement reaches USD 300-650 billion by 2035 (IEA 2025a). In order to mobilise private capital (which will account for the largest share of the investment needed for the industrial decarbonisation required), an enabling environment needs to be created. This should be accompanied by appropriate risk mitigation actions, as well as tailored financing and market instruments that are essential to develop project pipelines.

However, this comes with significant challenges

Firstly, **markets and technologies** for near-zero and low-emissions industrial materials are currently in various stages of development. As a consequence, the high market premiums for those goods mean they cannot yet compete with conventional products. Clarity on **definitions and standards** on what constitutes a near-zero or a low-emissions product is needed to provide the market signal for such markets to develop, and for private and public actors to produce, procure and trade these products (IEA 2024a).

Insufficient market development is also a result of **knowledge gaps**, as data and emission measurement methodologies are currently not readily available, nor are they consistent and robust enough to allow for adequate comparison that could create market signals. This challenge particularly relates to carbon intensity metrics (OECD 2025a). In addition, there is an urgent need for better insights into which mitigation policies are the most effective, requiring a stronger knowledge base in this area.

Furthermore, given the interconnectedness of markets for industrial products and the differences in countries' mitigation approaches, **carbon leakage and other negative spillovers** (OECD 2025a) could complicate the transition to net-zero aligned industries. These spillovers may both hamper the effectiveness of mitigation policies and lead to competitiveness disadvantages for climate-ambitious countries and industries. The current lack of a governance structure to address these issues—and the resulting collective action problem—constitutes a further challenge. Additionally, the lack of a level playing field, with some countries using vast amounts of market-distorting government support to enhance or maintain production capacity within their domestic industries, constitutes a further impediment to market-driven industrial decarbonisation (OECD 2025b).

Fourth, the issue of **financing** looms large. Data suggests that annual global investments in near-zero and low-emission technologies for industry decarbonisation need to increase by a factor of three to five by 2030 compared to current levels in order to align industrial emissions with net-zero pathways (Cordonnier and Saygin 2023). The lack of maturity of some of the required technologies adds another challenge, as more than half of emissions reductions required in the heavy industry sector in the IEA Net Zero Emissions by 2050 Scenario result from technologies (e.g. low-emissions hydrogen and CCUS) that are not yet commercially available for heavy industry applications at the scale needed for widespread deployment (IEA 2023). This raises risks, and therefore costs – which constitutes a particular challenge for EMDEs, where the costs of capital tend to be higher from the outset. While public finance offers significant opportunities, it is limited and also affected by competing public spending priorities. Concessional loans, for instance, can finance only a few multi-billion-dollar large-scale industrial plants. Investing at the required scale will therefore only be possible by enhancing the enabling conditions for investment, at the same time as mitigating risks.

The complexity of moving forward on industrial decarbonisation also derives from the fact that governments have **various underlying objectives** in pursuing this aim, which may not always be perfectly compatible. Governments may have legitimate policy objectives to foster industrialisation (at the lowest cost possible) as part of their development strategies, and/or to ensure that low-emissions industrial activities take place (or continue to take place) in their countries. Similarly, they may want to ensure that critical components of the supply chains for their energy transition and decarbonisation are not jeopardised by trade or industrial policy actions elsewhere. At the same time, such actions may lead to undesirable policy competition and inefficient mitigation outcomes from a global perspective, and may hamper efforts by EMDEs to move forward in this domain. Building competitive industries and value chains is also a challenge since decarbonisation comes at a cost. Countries are therefore confronted with a question that may appear simple but is inherently complex: whether to take action today to support industrial decarbonisation via ambitious policies, or to wait until technology costs come down. Any decisions will require careful accounting to assess the true costs: as carbon markets expand, delaying action may come at a higher price for industries, and early action can thus mitigate the risks of stranded assets.

Last but not least, in the short and medium term, industrial decarbonisation can create **transition challenges** for the workers, firms, regions and countries affected. The new jobs created via industrial decarbonisation may not benefit workers currently employed in these industries or the regions where they are located. Nevertheless, industrial decarbonisation provides opportunities in the longer term, and so effective and inclusive transition measures are essential for a transition that works for all (IEA 2024b; OECD 2024b).

These challenges require joint efforts from industry, policymakers and the financing community

To address these challenges and to benefit from the opportunities industrial decarbonisation provides, joint efforts by policymakers, industry and the financial sector are essential. IEA and OECD analysis, including for the Climate Club, shows the importance of effective and ambitious policy frameworks to support industrial decarbonisation (IEA 2025b; OECD 2025n.d.).

These efforts also require close international collaboration

One aspect of industrial decarbonisation is crystal clear and highlighted in every chapter of this report: no country will be able to achieve it on its own. There are at least three reasons for this.

The first is **scale**. Given the magnitude of the industrial decarbonisation challenge, there is a need for an 'all (or many) aboard' approach towards ambitious and determined steps by both industries and governments across the world to accelerate industrial decarbonisation. In some cases, concerted efforts can also enable economies of scale in working towards the innovations needed to advance industrial decarbonisation. Concerted efforts can also help avoid harmful policy competition that could otherwise lead to suboptimal outcomes in mitigation action from both an effectiveness and efficiency perspective. Scale and co-operation can also enhance policy learning.

The second reason is related to **interconnectedness**. As indicated, manufacturing industries are global and connected through trade and investment relations. Given the differences in mitigation approaches across countries, in particular, such interconnectivity means that what happens in one country may affect what happens elsewhere. International collaboration can help countries to benefit from the positive impacts of such spillovers while at the same time mitigating potential negative consequences. It can help overcome the collective action problem on a level that no single country can address by itself.

Third, international collaboration is essential from the perspective of **effectiveness and inclusiveness**. As discussed above, not only do circumstances in countries differ, but countries also have differing abilities to move forward on industrial decarbonisation. For EMDEs, in particular, industrial decarbonisation cannot be achieved without a massive scale-up in support that could be facilitated by their increased co-operation with advanced economies. Recent OECD analysis for the Climate Club shows that the decarbonisation of the industry sector in EMDEs has to date not received the necessary attention in terms of technical and financial assistance (OECD 2024b). Many donor governments, as well as an increasing number of international finance institutions and philanthropies, have taken notice of this gap. Closing it, however, will require capacity-building to strengthen the institutional and technical capacities across governments, industry actors and local financial institutions such as commercial and national development banks. Assistance will also be needed to increase technological capacities in EMDEs, and to contribute to the creation of new value chains and the development of carbon markets and policy frameworks to address carbon leakage and other spillover effects.

Together, the challenges for industrial decarbonisation and the reasons for international co-operation outlined above constitute the crux of what the Climate Club aims to contribute.

IV. The role of the Climate Club

Why a Climate Club?

As outlined above, the decarbonisation of industry is essential to achieving global climate objectives as established under the Paris Agreement. However, the topic has not received sufficient attention in existing mitigation approaches (from governments, industry and financial sectors), nor has it been deeply discussed at a multilateral level. Moreover, national governments can only provide part of the solution for goods that are often heavily traded internationally. This is where the Climate Club comes into play—providing solutions that can only be achieved with international co-operation.

The 46 members that are currently part of the Climate Club share the view that an inclusive approach is needed—one that brings together countries at different stages of industrial development and decarbonisation, incentivises the development and adoption of deep decarbonisation technologies, and enables all countries and industries to join in.

What are the objectives of the Climate Club?

Finding common ground on how, at what pace and under what rules to advance industrial decarbonisation is not easy. The Climate Club creates an enabling environment for high-level strategic political dialogue among its diverse membership in order to build such common ground. In a landscape where there are many public and private initiatives looking to advance these topics from a technical and research point of view, the Climate Club is the only high-level, strategic intergovernmental forum dedicated exclusively to industrial decarbonisation. It aims to support the acceleration of climate action and an increase in ambition to achieve global net-zero GHG emissions by or around mid-century.

The Climate Club membership spans countries with different starting points and transition pathways, which are considering different levels of development of their industrial sectors, in the context of competing policy priorities, varying resource endowments, and differing needs for financial and technical assistance. The premise that underlies the dialogue among Climate Club members is that both advanced countries and EMDEs can partake in industrial decarbonisation and reap its economic benefits.

How does the Climate Club contribute to industry decarbonisation?

Through its high-level intergovernmental meetings, including senior official meetings at the sidelines of major international climate events and leaders' events, for example during the annual United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP), the Climate Club looks to move up discussions on industrial decarbonisation in governments' agendas. The approach is to elevate relevant technical challenges, such as carbon leakage or common industry standards, to the political level. To do so, the Secretariat convenes exchanges at which Climate Club members discuss technical aspects and are exposed to relevant work from external experts in the field, in order to discuss concrete solutions to the challenges related to decarbonising industries.

Some key topics the Climate Club aims to advance include (1) how to manage unintended cross-border effects of ambitious climate mitigation policies (including carbon leakage), (2) how to grow markets of near-zero and low-emissions materials, and (3) in what way financial and technical assistance can help mobilise the necessary investments for this transformation.

What has the Climate Club achieved so far?

Thanks to the commitment and hard work of its members, the Climate Club is successfully helping place industrial decarbonisation on the international and national mitigation agendas.

In terms of advancing common understandings on key topics and concepts, Climate Club members have articulated an improved shared understanding of carbon leakage in the 2024 Climate Club Statement, agreed on voluntary principles for action to address carbon leakage and other spillovers, and affirmed the IEA's principles for definitions of near-zero and low-emissions steel and cement. Members have further agreed on the need of making carbon accounting approaches more transparent and interoperable in the 2025 Climate Club Statement, while also launching a Global Pledge to grow near-zero and low-emissions steel and cement markets, committing to voluntary actions crucial to achieving the goals of the Paris Agreement.

With regards to technical and financial aspects necessary for this transition, a key milestone for the Climate Club was the launch of its Global Matchmaking Platform (GMP) during COP 29 in Baku. The GMP constitutes the Climate Club's main support mechanism for EMDEs and operates by connecting requests sent by governments with technical and financial assistance providers. As of October 2025, the GMP, whose Secretariat is hosted by the United Nations Industrial Development Organization (UNIDO), has successfully engaged with 24 EMDEs, received 22 expressions of interest, matched 19 requests, and is currently assisting another 8 countries.

Table 1: Basic information on the Climate Club

Goal	Accelerating climate action and increasing ambition in the field of industry decarbonisation
Format	Open, inclusive, high-ambition intergovernmental forum for discussions and enabling framework for increased co-operation, improved co-ordination and potential collective action across diverse geographies
Initial sub-sectoral focus	Steel and cement
Membership	46 members at time of publication: Argentina, Australia, Austria, Bangladesh, Belgium, Canada, Chile, Colombia, Costa Rica, Croatia, Denmark, Egypt, European Union, Finland, France, Germany, Greece, Indonesia, Ireland, Italy, Japan, Kazakhstan, Kenya, Korea (Republic of), Luxembourg, Malaysia, Morocco, Mozambique, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Singapore, Slovak Republic, Spain, Sweden, Switzerland, Thailand, Türkiye, Ukraine, United Kingdom, Uruguay, Uzbekistan, Vanuatu.
Co-Chairs	Chile and Germany
Secretariat	Hosted in tandem by the OECD and the IEA
Foundation	• **Terms of Reference** adopted by G7 leaders in Dec 2022 • Launch at Leader level at COP 28 (Dec 2023)
Website	climate-club.org

V. Building on key findings: report contributions and next steps towards industrial decarbonisation

There is an urgent need to accelerate action

A clear message permeates across all the chapters in this report: There is an urgent need to take action to accelerate industrial decarbonisation. This is not only because the current pace of industrial decarbonisation is insufficient to reach climate objectives, as all chapters underline. It also results from the assessment that current policy endeavours do not sufficiently tackle the challenges underlying industrial decarbonisation, and, additionally, that multilateral co-operation to advance climate objectives, including in industrial sectors, is increasingly disputed.

How to accelerate action?

The question that all chapters in this report try to answer is what the possible solutions and the steps forward are. While all chapters explicitly or implicitly suggest that pluralist co-operation is essential, the proposals for advancing such co-operation differ by author. The discussion of these suggestions can be grouped around three key issues underlying industrial decarbonisation.

The first centres on the question of how to advance industrial decarbonisation in such a way that it contributes to climate mitigation while prioritising industrialisation in EMDEs and taking the specific circumstances of each country into account.

The second relates to the traded nature of industrial goods and, as such, the interconnectedness of mitigation efforts across countries—and the importance of international co-operation in taking this into account. This includes aspects relating to scaling up financial and technical assistance as well as carbon leakage and other spillovers.

The third is concerned with policymaking itself and the most effective, inclusive and efficient ways for policymakers to advance industrial decarbonisation, both domestically and through international co-operation.

Across all three issues, authors make suggestions about how the Climate Club could support these efforts.

Balancing the need to advance industrial decarbonisation with development, and the different starting points and transition pathways across countries

The chapters in this second part of the report all emphasise one common point: industrial decarbonisation can be advanced in a way that takes into account development needs in EMDEs.

In Chapter 2 (***"Development and Industrial Decarbonisation"),*** **Joseph E. Stiglitz** examines the global challenge of reducing GHG emissions, especially in EMDEs where industrial processes are often more energy- and carbon-intensive. Stiglitz advocates for "green partnership agreements" between advanced economies and EMDEs that integrate investment, research, technology-sharing and fair market access, ahead of carbon border adjustments and protectionist industrial policies that exclude EMDEs from industrial decarbonisation. He warns against a resurgence of global economic fragmentation.

In Chapter 3 (**"Catalysing Economic Growth Through Powershoring"**) **Ketan Ahuja** and **Ricardo Hausmann** argue that "powershoring"—the relocation of energy-intensive industries to renewable-rich regions – will reshape global industrial geography as economies decarbonise. Since renewable energy is difficult to transport, proximity to abundant, cheap electricity will again become a key source of comparative advantage. The authors argue that renewable-rich regions should focus on highly energy-intensive industries like green steel or aluminium, while knowledge-rich but energy-poor regions should specialise in advanced, less energy-intensive sectors.

Similarly, **Frank Jotzo** in Chapter 4 (**"Efficient global industrial decarbonisation: economic opportunities with trade and carbon pricing"**) argues that for industrial decarbonisation to succeed, a shift in the economic geography of heavy industry is required towards geographies with abundant cheap renewable energy potential, which would also entail changes in trade flows between countries for energy-intensive products. Many countries that currently export fossil fuels could become competitive exporters of "green" base commodities (such as iron), while the high value-added elements of the supply chain (such as high-grade steel) remain in the traditional industrial centres. This would cushion the economic impact of declining fossil fuel exports over time. Australia is positioned as an example. Jotzo proposes that the Climate Club can help create a level playing field for clean industry globally by providing a framework for carbon pricing coalitions to emerge and supporting harmonised rules and technical assessments for border carbon adjustments.

Fostering international co-operation and dealing with co-ordination challenges given international connectedness

The chapters in this part of the report propose ways in which pluralist co-operation can help overcome industrial decarbonisation challenges. The importance of pluralist approaches was underlined in a recent paper by Allan (2025), who states that: "Plurilateral climate clubs can build close co-operation at the sectoral level. This would enable small groups of states with shared decarbonization and industrial policy objectives to work together to integrate supply-push and demand-pull policies to secure markets in opportune areas like steel, critical minerals or rare earth magnets."

Laurence Tubiana, **Richard Baron**, **Samuel Leré**, and **Matthew Langdon** in Chapter 5 (**"Embodied carbon: Understanding our trade and climate co-dependency"**) argue that global trade is a major but under-addressed source of GHG emissions, with nearly a quarter of global emissions embodied in traded goods. As countries intensify their domestic climate efforts, their imports often shift emissions abroad, creating a climate "co-dependency." Tubiana et al. call for international co-operation to measure, regulate and reduce these embodied emissions. They advocate for new co-operation through fora like the G20 or Climate Club to develop shared carbon accounting standards, targets for imported emissions, and fairer trade policies. for new co-operation through fora like the G20 or Climate Club to develop shared carbon accounting standards, targets for imported emissions, and fairer trade policies.

Kimberly Clausing, Axel Ockenfels and **Catherine Wolfram**, in Chapter 6 (**"A Path to a Heavy-Industry Climate Coalition"**), propose such a coalition to accelerate global decarbonisation in emissions-intensive sectors. Traditional climate agreements struggle with free-riding and weak enforcement, while unilateral actions like the EU Carbon Border Adjustment Mechanism (EU CBAM) risk fragmentation and trade disputes. The coalition would instead co-ordinate carbon pricing with border adjustments, ensuring reciprocity and protecting competitiveness, while incentivising membership through technology-sharing, climate finance and market access. The framework is built on six principles: self-reinforcement, efficiency via a carbon price floor, fairness through differentiated obligations, pragmatism by starting with heavy industry, integrity via border adjustments, and credibility through rigorous monitoring.

In Chapter 7 (**"Counting on Carbon Pricing: Determining a Carbon Price Paid in Third Countries and Coalitions"**), **Carolyn Fischer** and **Michael Mehling** discuss trade-related climate measures—which limit or condition trade on the basis of carbon intensity and climate performance—and which have been on the rise recently. For several reasons, including fairness, compliance with international legal obligations, and a desire to incentivise climate action abroad, these measures often seek to account for a carbon price (or some other form of cost) incurred in the country of origin of traded goods. The EU CBAM is one such example. Similarly, an agreement for a carbon pricing coalition of industrial emitters would have to grapple with the terms for qualifying carbon pricing systems. While conceptually compelling, determining the carbon price "effectively paid" is far from straightforward in practice. This chapter systematically dissects alternative options for determining such a price, identifying their respective economic, legal and environmental implications and trade-offs.

In Chapter 8 (**"A Global Buyers Club for Lower-Emission Oil and Gas to accelerate methane mitigation"**), **Marcelo Mena** broadens the discussion on mitigating industrial emissions to methane emissions from the fossil fuel sector. He argues that leakage of methane in certain processes can more than triple the warming impact per unit of output, negating the climate benefits of switching from coal or oil to natural gas in many applications. He therefore proposes the creation of a Global Buyers Club for Lower-Emission Oil and Gas, launching in 2027, to drive rapid methane reductions in liquefied natural gas (LNG) and broader oil and gas supply chains.

Effective, efficient and inclusive industrial decarbonisation policies

The chapters in this last part of the report all reflect on the policy settings required to advance industrial decarbonisation, with various experts calling for a systematic approach that also includes capacity support in EMDEs. They also discuss how instruments like carbon pricing can be adapted to account for the differences across countries.

In Chapter 9 (**"New Roles, New Rules. Industrial Decarbonisation through Policy and Partnership"**), **Patricia Espinosa Cantellano** argues that while technologies for low-carbon steel, cement and petrochemicals are advancing, heavy industry remains capital-intensive, trade-exposed and slow to change. The central barrier is not innovation, but the lack of durable, credible and internationally consistent policy signals. Markets alone cannot drive transformation; governments must provide certainty to mobilise private capital. The chapter proposes five catalysts for systemic change: strategic policy frameworks, budget credibility, finance mobilisation, climate-aligned fiscal regimes and institutional capacity. They must operate together to reduce risk and scale investment.

Chapter 10 (**"Whole-System Frameworks for Advancing Industrial Decarbonisation"**) by **Mercedes Maroto-Valer** argues that advancing industrial decarbonisation requires a **whole-systems approach** that integrates technology, policy, economics, environment and society. Unlike the power sector, heavy industry involves complex, interconnected processes, requiring co-ordinated transformation rather than isolated technological fixes. Whole-systems thinking enables stakeholders to identify interdependencies, avoid lock-ins, and design coherent pathways combining hydrogen, carbon capture, electrification and circular economy measures. Maroto-Valer takes the UK's Industrial Decarbonisation Research and Innovation Centre (IDRIC) as an example of such an approach through collaborative work across industrial clusters, linking over 240 partners in academia, industry and government to co-create low-carbon solutions. IDRIC's framework integrates governance, finance and community participation, ensuring social legitimacy and a just transition. She argues that globally, the Climate Club can advance a systemic approach by harmonising carbon standards, co-ordinating cross-border infrastructure, and promoting joint investments and technology-sharing.

In Chapter 11 (**"Inclusive Industrial Decarbonisation Policies to Effectively Integrate Energy, Climate, and Development Goals in Emerging and Developing Economies"**), **Damilola Ogunbiyi**, **Alvin Jose**, **Divyam Nagpal**, **Anant Wadhwa** and **Pavel Tereshchenko** argue that industrial decarbonisation is critical to achieving global net-zero goals, given that industry accounts for over one-third of global energy use and GHG emissions. The article calls for shifting the perception of heavy industry from "hard-to-abate" to "priority-to-abate", emphasising opportunities for energy efficiency, electrification with renewables, hydrogen use and carbon capture. EMDEs face challenges in accessing affordable clean technologies, financing, and capacity, risking long-term dependence on carbon-intensive production. The chapter proposes inclusive industrial policies that integrate energy, climate, and development priorities, enabling EMDEs to leapfrog to green industrialisation.

In Chapter 12 (**"Repurposing Fossil Fuel Subsidies: Enabling Decarbonisation through Trade and Investment Law Reform"**), **Elena Cima** examines how international trade and investment law can be reformed to support the global phase-out of fossil fuel subsidies and accelerate decarbonisation. Scientific consensus, including Intergovernmental Panel on Climate Change (IPCC) findings, show that subsidy removal would cut emissions, improve public revenues, and aid sustainable development. Reform is needed on two fronts: World Trade Organization (WTO) rules should distinguish between "good" ("green") and "bad" (fossil fuel) subsidies, and investment treaties should limit protection for projects that are harmful to the climate.

Inspiration for the Climate Club agenda in the coming years

All the chapters of this report make important reflections on the role the Climate Club could further play in advancing industrial decarbonisation. This takes different forms.

Various chapters suggest that forms of pluralist co-operation could help advance the industrial decarbonisation agenda, notably through the proposed Global Buyers' Club, heavy industry coalition and global partnerships. The Climate Club could either be a catalyst of such initiatives or could even provide the platform through which such pluralist co-operation could take shape.

In other instances, the chapters raise questions on further topics the Climate Club could consider. Should reducing methane emissions from the industrial sector be a more direct objective of Climate Club activities? Given the importance of existing fossil fuel subsidies that distort the playing field for the renewable energy needed for industrial decarbonisation, should the Climate Club play closer attention to such issues?

The chapters also include examples of how the Climate Club could help deliver on the issues underlying the ideas proposed. For instance, the emphasis on capacity-building raises the question to what extent the Climate Club—through its Global Matchmaking Platform (GMP) and other activities—can further contribute to such capacity building. Should issues regarding technology transfers and patenting be a further topic for Climate Club activities? In the context of the discussion on powershoring and the issues around carbon embedded in traded goods, could the Climate Club, having formulated voluntary principles on carbon leakage and other spillovers, play a similar role in developing additional principles that establish common ground between countries on how to address such developments through international co-operation?

All these issues require further discussion and further analysis to articulate the ideas more precisely—and, of course, further co-operation across countries. As this report makes abundantly clear, the coming years will be critical for developing and implementing concrete ideas to advance industrial decarbonisation. The Climate Club could be a key initiative to help deliver on the next steps.

Appendix

Data supporting Figure 1 and Figure 2 (IEA's Global Energy and Climate model, 2025)

Region	GDP per capita [USD (PPP)]	Industry value added [Billion USD (PPP)]	Industry value added [share of GDP]	Total CO_2 emissions from Industry [Mt CO_2/year]	Emission intensity of industrial production [kg CO_2/USD industry value added (PPP)]
Advanced economies	61,087	20,880	0.24	1,919	0.09
EMDEs (excl. China)	13,438	23,500	0.33	3,147	0.13
China	27,364	14,726	0.38	3,991	0.27

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Part I: Decarbonisation and economic development

2 Development and industrial decarbonisation

Joseph E. Stiglitz

Abstract

The article presents a number of proposals for advancing industrial decarbonisation in a way that helps development: reducing greenhouse gas (GHG) emissions can be good for growth. It describes the flaws in current approaches that advanced countries use to induce developing countries to undertake a faster green transition, and emphasises the importance of sharing technology. It identifies the distinct aspects facing emerging markets, arising from their greater technological prowess and advanced countries political resistance to their successes. Global co-operation is necessary—co-operation that the Climate Club, as a plurilateral platform, might facilitate. The multilateral development banks (MDBs) will play a critical role, as will new green partnership agreements, narrower with a more limited number of countries and more limited sectors than the comprehensive agreements of the past, but deeper, going beyond trade to include technology development and transfer, and investment.

I. Introduction

Developing countries contribute a disproportionately large share of global greenhouse gas emissions *relative to their gross domestic product (GDP),* though not relative to their population. In virtually all of these countries, production processes are less efficient across multiple dimensions—requiring more labour per unit output, but also more energy per unit output; and the energy production itself generates more emissions per unit output. Further, China and many other emerging markets and developing economies (EMDEs) have become the centre of industrial production, making goods that are then consumed within the advanced countries; and because industrial production is more emissions-intensive, overall GDP is more emissions-intensive. Indeed, because the share of services in spending in richer countries is higher and services are typically less emissions-intensive, many developing countries' consumption emissions intensities may be larger than that of advanced countries.

Finally, the developmental transition typically entails rapid urbanisation, which requires the construction of infrastructure and housing, and when these projects use steel and cement, there will be a heavy burden on emissions.

Climate change is a global problem and mitigating it must accordingly be a global effort. Because of the high emissions intensity of production in EMDEs, prospects of doing so by curbing their emissions, including those specifically associated with industrial decarbonisation, might seem especially opportune. The question is, how can this best be done, and in ways that would not stifle the rise of living standards in these countries? Many developing countries have been reluctant to put emissions mitigation at the top of their policy agenda, arguing that the current level of atmospheric concentrations of GHG emissions is the result of profligate policies of the advanced countries. Why should they now be asked to sacrifice their standards of living?

II. Why reducing greenhouse gas emissions can be good for growth

Stern and Stiglitz (2023) have argued that aggressive actions to reduce energy requirements in production, and thus emissions, can be growth-enhancing. The reason is obvious: lowering *any* input requirement in the production process is efficiency-enhancing and therefore can stimulate growth. It makes the countries' goods more competitive.

Moreover, today, the most efficient energy production relies heavily on renewable energy—a marked change from a quarter century ago. Energy systems relying largely on solar and wind are much less expensive than energy produced with fossil fuels, even taking into account the costs of storage (batteries or reservoirs) (IRENA 2025; Lazard 2025; IEA 2024).

Further, developing countries have an advantage by being at an earlier stage of development: they can design industrial production to reflect the comparative advantage of renewable energy, using production technologies that allow more variability in efficient production, reflecting the nature of renewable technologies. This may be advantageous with the less capital-intensive technologies that are more appropriate for less developed countries.

III. Flawed approaches to inducing a faster greener transition

As Europe and other like-minded countries work hard to push the green transition, it is understandable that they worry that with international trade, production of emissions-intensive goods will leave their country and move to places where emissions are less well-regulated and/or not taxed. As Stiglitz (2006) argued, the absence of taxes and regulations was akin to a subsidy. In these countries, firms did not have to pay the full costs of what they were producing, just as would be the case if the government subsidised labour or capital costs. A longstanding pillar of international trade is that subsidies should not be allowed—there can be no level playing field with subsidies. This has motivated the demand for cross-border adjustments (imposing taxes, effectively countervailing duties, on imports to reflect the value of the subsidy, or simply banning the importation).

(In the context of Trump's trade war, were such policy to be implemented fairly on *all* countries, including the US, almost surely, it would be met by countervailing action by the US. It would be another step in the move away from open borders).

Developing countries have rightly argued that the way these cross-border adjustments are designed is likely to significantly disadvantage them, and thus, rather than facilitating the kind of co-operation required to achieve global carbon reductions, may have just the opposite effect. For them, the cost of compliance is very high, many of the low carbon technologies are protected by patents, so adopting such technologies will require them to pay companies in the North large amounts of money, and many of the low carbon technologies are capital intensive, and developing countries face a scarcity of capital. This is especially the case given that the terms were not the result of dialogue and discussion of how best to achieve a shared goal but were imposed on them. There are significant worries that the costs of compliance will be high, and judgments about the carbon price equivalence of certain regulations and other actions will be biased and the methodologies for calculating the emissions associated with their production flawed. Moreover, many of the new technologies that would have lower emissions are capital intensive, and global financial markets charge developing countries high interest rates, well in excess of their actuarial risk (Pontifical Academy of Social Sciences 2025).

IV. Sharing technology

For developing countries, the development of and access to affordable technologies that would successfully and significantly reduce emissions is crucial. But there are two problems.

First, research capacities are overwhelmingly located in advanced countries and have been directed at innovation appropriate to the circumstances of advanced countries, with low cost of capital, high costs of labour, and an abundance of highly skilled labour—circumstances that are markedly different from those in developing countries. Thus, new technologies appropriate to their circumstances have to be developed. This can best be done if there are investment/research partnerships between advanced countries and companies located in them and developing countries, partnerships that enhance the research capacities of developing countries and make use of their local knowledge.

Second, the technologies that have been created in advanced countries are protected by strong patent laws, and for developing countries to make use of them requires the payment of high fees (or the appropriation of quasi-rents when the production is done in developing countries by firms from advanced countries). This generates flows of funds out of developing countries to the advanced countries—exactly the opposite of what is needed if the gap between developing countries and advanced countries is to be narrowed. Recognising that there will be these "colonial" flows that will impair development makes developing countries reluctant to agree to aggressive emission reductions. Antipathy towards the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement that was part of the World Trade Organization (WTO), resulted in vaccine apartheid during the COVID-19 pandemic makes payments of onerous royalties (hidden or open) even more noxious.

There is an obvious solution—contained in the original Rio Climate Agreement of the 1992 Earth Summit in Rio de Janeiro—compulsory licenses, in which developing countries would have access to all climate-related technologies upon the payment of a "fair" competitive (not monopolistic) royalty. But this provision has rarely, if ever, been invoked; and the provision of TRIPS providing for compulsory licenses in the event of an epidemic or pandemic has not been effectively enforced, and, indeed, pharmaceutical companies have worked hard to make sure that this is the case. That was why a call for a vaccine waiver during the COVID-19 pandemic was launched, something that the pharmaceutical companies, with the assistance especially of the UK, Germany, and Switzerland, beat back (Stiglitz and Wallach 2021). The lesson is clear: there needs to be a climate waiver. The planet is sick. There is an urgent need for all available technologies that have the prospect of reducing emissions to be used as extensively as possible.

And that means that all firms, in all countries, have to have access to the relevant technologies, and the advanced countries have to take an active role in the transfer of technology.

V. New global agreements

There has been turmoil in international trade in recent years. The blatant disregard for WTO agreements as the US expanded its industrial policy, with spending estimated at more than a trillion US dollars, and the refusal of the US to allow the appointment of appellate judges at the WTO, meant that the WTO was in trouble even before Trump arrived (Guzman and Stiglitz 2024; Schneider-Petsinger 2020). But now the post-World War II era of trade liberalisation appears to be over. The US has even abandoned the most fundamental principle, which is also required for market efficiency, the most favoured nation principle, as it has attempted to appropriate for itself more and more of the surplus value of global supply chains. In the process, it has destroyed those chains and transformed the world into a place in which borders do matter, once again, and matter a lot.

The comprehensive trade agreements that marked the post-World War II era are a thing of the past. The Uruguay Round, which ended in 1994, is likely to be the last for a long time. Even the more modest Development Round, initiated in Doha in 2001, in a moment of global solidarity following the 9/11 attacks, was a failure. The US and the EU refused to rectify the imbalances between developing countries (including the least developed) and advanced countries that marked the Uruguay Round that preceded it (see Stiglitz and Charlton 2005).

The future will lie in narrower agreements with a more limited number of countries and more limited sectors, but possibly broader reach. I am particularly optimistic about the possibility of *green* agreements, in industrial areas like steel or broader areas of industry, going beyond just trade to embrace investment and research, recognising the common interest in reducing carbon emissions, and the necessity of doing so in ways that raise living standards in both advanced and developing countries and lower the size of the divides. (The Climate Club could be a starting point for such green agreements.) If the advanced countries have industrial policies to help develop greener technologies, creating a fair global architecture implies that doing so should not be (and not be seen as) grabbing these "good" jobs of the future, and especially not grabbing them away from developing countries. Developing countries simply do not have the resources to provide comparable subsidies. Accordingly, those advanced countries undertaking these policies must commit to working with developing countries to develop *their* technologies, in many cases providing explicit subsidies to them for technological development.

As the 1998/1999 World Bank World Development Report (WDR) emphasised, what separates developed and developing countries is as much knowledge as a gap in resources. An agenda that seeks co-operation on climate must simultaneously seek to close the gap in knowledge, and especially knowledge that is relevant to the green transition.[3]

[3] For a broader discussion of how today's intellectual property rules impede development, and correspondingly, the green transition, see Stiglitz 2006, Baker *et al* 2017, and Cimoli *et al* 2014.

An essential part of such agreements is access to the markets of advanced countries. But what happened in the US, with its patent abrogation of international law, meant that developing countries can no longer rely on access to any one country, and in particular to the US.

VI. Emerging markets

While the knowledge gap is smaller for emerging markets like Brazil and China—in fact, in some aspects of the green transition, they have been at the forefront of knowledge development—there are some distinctive challenges they face in decarbonising their economies. Though their own role in carbon emissions today is often large, many of the issues raised in previous paragraphs concerning less developed countries' reluctance to fully engage in industrial decarbonisation still apply to the emerging market economies—for instance, the cost of capital is higher than in advanced countries, and they may be reluctant to pay the royalties and licensing fees demanded by those in the advanced countries who control the relevant technologies to address a problem that they feel was caused by the advanced countries. Moreover, they may not have the administrative capacity to demonstrate compliance with the rules for carbon emissions of cross-border trade.

In addition, protectionist sentiment is typically directed more at emerging markets, which are a more serious competitive threat to the more advanced countries. Even as the US and EU have undertaken massive green industrial policies, they have long criticised emerging markets like Brazil and China for undertaking such policies. The US has argued that Brazil should be subjected to countervailing duties, even when its intervention is focused on lowering the cost of capital in its dysfunctional financial markets (Zeidan 2018), where real interest rates have often been extraordinarily high (see US Department of Commerce 2016, 2025.)

Still, the technological prowess of emerging markets like China and Brazil holds particular promise for a green industrial transformation. These countries have invested heavily in engineers and science; in some domains they are competitive with the advanced countries. There are some who are very optimistic that advances in artificial intelligence (AI) will enable striking advances in technology, enabling marked reduction in emissions. The successes that China seems to have achieved (with DeepSeek) open up the possibility that AI might be directed at doing so, giving China a competitive advantage not just in solar panels, EV and batteries, but in a host of other industries. These advances could be instrumental in a green industrial transition. But we have also seen how protectionist sentiment has been strong in each of these areas, in the EU and even more so in the US, precluding the world from taking full advantage of the emission reductions that these advancements would have allowed. Political leaders in the US and EU seem to have put protecting jobs today—something that should be a matter of sound macroeconomic policy, not trade policy—over saving the planet for our future.

VII. Instruments

Economists have rightly focused on the question of the appropriate set of tools for bringing about a green transition. No economy today is centrally planned. Governments have to induce industrial firms to change their technologies. There has been a heated debate about how best to do that. It is understandable that many economists, observing that firms that pollute do not pay the full cost associated with their production, argue that a tax on carbon emissions is *the* solution. It is part of the solution, but only part, and this is especially true in developing countries. Whenever there are other market failures (besides those associated with climate), such as capital and risk market imperfections, or when there are limited instruments for dealing with the distributive consequences of a carbon tax (as there are), one cannot rely on just a "carbon price." One needs other interventions, such as regulations or government provided loans.[4]

Unfortunately, developing countries do not have the resources to provide loans to the private sector to enable them to make the investments needed to facilitate industrial decarbonisation or to make the public investments that would complement private investments. The multilateral development banks (MDBs) could provide some of the necessary financial resources, but more is needed. Ann annual emission of special drawing rights (SDRs) be the International Monetary Fund[5] (IMF), to the order of several hundred billion dollars, would be enormously helpful.

VIII. Concluding comments

There is a mutual interest around the world in industrial decarbonisation. It is an essential part of the green transition. I have argued that policies that advance this may even enhance economic growth. A successful global agenda has to recall the old refrain, "Common but differentiated responsibilities," reflecting the differentiated circumstances of developing countries and the advanced economies, including the gap both in knowledge and institutional capacities.

Climate change is a global problem, and advanced countries need to do what they can to facilitate industrial decarbonisation *globally.* In this article I have outlined several ways in which they have actually put impediments in the ways of developing countries (in trade and intellectual property rights). Their failure to live up to their commitments in providing resources (finance) means these poorer countries do not have the resources that would facilitate a faster path of decarbonisation.

The chapter presents a number of clear proposals for advancing industrial decarbonisation in a way that helps and not hinders development. These proposals include:

- Develop carbon border adjustment measures in dialogue between developing and advanced countries, taking into account the legitimate concerns from EMDEs.
- Technology sharing, including opening up patents for clean technologies to developing economies.
- The provision of additional resources to developing countries for green investments, both through additional lending by the MDBs and through annual emissions of SDRs.
- Working towards green partnership agreements, for instance with a sectoral focus, that combine trade, technology, finance and research. Agreements of a narrower scope than

[4] See, in particular, Stiglitz 2019 and Stern *et al* 2017

[5] With recycling of unused SDR's to developing countries and development banks for green investments.

earlier comprehensive trade agreements like those that emerged at the end of the Uruguay Round (limited in the sectors or range of products covered), but deeper and more politically sustainable.

This path forward requires global co-operation—co-operation that the Climate Club, as a plurilateral platform with varied membership, might facilitate. While all countries should have an interest in decarbonisation, there are special interests at play in some countries. It may be possible to achieve agreement among different sets of countries in different arenas.

In an era when the international rule of law is being brutally abrogated by the US, global co-operation and co-ordination, including through green partnership agreements, is necessary if we are to move towards a world that is environmentally sustainable.

Joseph E. Stiglitz

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3 Catalysing economic growth through powershoring

KETAN AHUJA AND RICARDO HAUSMANN

Abstract

In a trend called powershoring, energy-intensive industry will locate closer to renewable energy sources, driven by cheap renewable energy (which is difficult to transport), and the need to decarbonise. Regions' renewable energy resources and industrial capabilities shape the types of energy-intensive industries they can attract: some regions are best placed to produce very energy-intensive commodities (like green steel and green ammonia), while other regions are best positioned to host more complex industries that still require good clean energy supplies (like battery manufacturing or datacentres). Similarly, some powershoring industries have many spillovers and open up new pathways for regional economic growth, while other energy-intensive industries have fewer spillovers or open up fewer development pathways. This contribution explores these trends to help policymakers develop contextually aware powershoring strategies that can catalyse their best opportunities for economic development.

I. Introduction

For most of human history, industry has located nearby energy sources: farmers used to bring their grain to windmills, and water wheels powered early industrial manufacturing sites, before the steam engine was invented.

This relationship broke down in the 19th and 20th centuries as we learned to harness fossil fuels as our primary sources of energy. Fossil fuels such as coal, oil, and (more recently) natural gas are relatively easy to transport. As a result, we could bring energy to our industry rather than having to locate our industry next to our energy sources. This enabled places that were rich in industrial know-how and engineering innovation to become today's industrial powerhouses, even when they lacked local sources of energy. With fossil fuels, the world became energetically 'flat', as local energy sources did not make a place more competitive in industrial production.

As we decarbonise and electrify our economies, energy-intensive industries will likely have to move closer to the best sources of renewable energy, because renewable energy (generally captured as electricity or heat) is much harder to move than fossil fuels (Samadi et al. 2023). This will resurrect the age-old relationship between heavy industry and energy sources, and will bring the energy-flat world to an end. Going forward, places' renewable energy resources will become critical determinants of comparative advantage in energy-intensive industries; this trend is called 'powershoring'. Powershoring is, of course, not a totally new idea. Aluminium and other electricity-intensive industries have often located near hydropower dams for the cheap electricity that they provide, for example. But powershoring will become a much more important trend that economic policymakers have to take account of, as solar and wind begin to substitute fossil fuels as sources of energy to a much greater degree.

Industrial know-how, expertise and capabilities will continue to matter: even the most energy-intensive industries need a skilled local workforce, engineering capabilities, industrial research capabilities, and a supportive ecosystem of suppliers, partners and customers to thrive. But local industrial capabilities will no longer solely determine competitiveness, as the need to locate industry close to energy sources reasserts itself.

This suggests that industries fall on a spectrum: on one end those that are more energy-intensive and on the other end those that are more know-how-intensive. Some industries are extremely energy-intensive, but relatively simple, producing the basic commodity materials that our economy demands. Other industries are very know-how intensive: they require energy inputs, but advanced manufacturing expertise forms the critical determinant of comparative advantage. And some industries are both, demanding both energy and advanced manufacturing know-how.

Places, too, fall on this spectrum. Some places have tremendous renewable energy resources. Some places have a depth of industrial know-how and expertise in different advanced manufacturing industries. And some places are blessed to have both.

Industrial know-how, of course, comes in many flavours. It is not just a question of more or less know-how. Some places are specialised in making vehicles, other places are specialised in making textiles, while other places are specialised in making pharmaceuticals. A place's know-how shapes how many and which industries it can engage in. Economic development is a process of places purposefully acquiring new capabilities by diversifying into more, and more complex, industries.

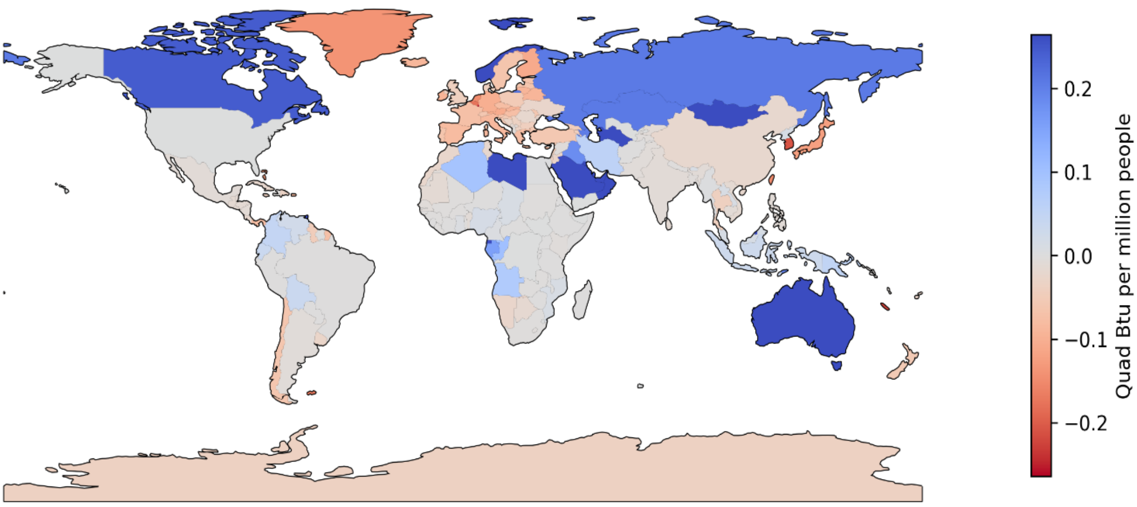
Policymakers need to plan for this 'powershoring' trend, helping their regions specialise in the right mix of industries to match both their energy resources and their industrial capabilities. For some renewable-rich regions with limited industrial capabilities, this trend offers a generational opportunity to develop, letting them attract investment in energy-intensive industry, aggressively develop new capabilities, and move up the industrial value chain. For other regions rich in know-how but poor in energy resources, this means coming up with smart strategies to maximise the value of their industrial base, while staying within the envelope of their energy resources. Regions blessed to have both renewable energy resources and capabilities to specialise in advanced manufacturing industries should pursue the most complex, energy-intensive industries.

This article aims to guide policymakers on how to steer their regions through these trends, outlining how they can assess where their region falls on the powershoring 'spectrum', and how this shapes which opportunities offer their best paths for development.

II. The energy-flat world

Trade in energy powers the modern world economy. Some regions, primarily fossil fuel exporters, run persistent energy surpluses, while other regions with developed, energy-hungry economies, but few local energy resources, run persistent, large energy deficits. Figure 1 shows these global energy surpluses and deficits.

Figure 1: Global energy surpluses and deficits by country (Source: see 'Methods')



This global trade in energy has made the world energetically 'flat': local energy resources have little bearing on a region's competitiveness in energy-intensive industries, because fossil fuels can be shipped around the world easily.

Figure 2 demonstrates this relationship. It shows, for each country, their energy surplus or deficit in trade per billion USD gross domestic product (GDP), plotted against their specialisation in energy-intensive products. We derive countries' specialisation in energy-intensive products from the coefficient of a regression of countries' revealed comparative advantage (RCA) in internationally traded goods on the energy content of those goods. More details on this regression can be found in the methods section of this article.

Figure 2: Country-level energy surpluses and specialisation in energy intensive products (Source: see 'Methods')

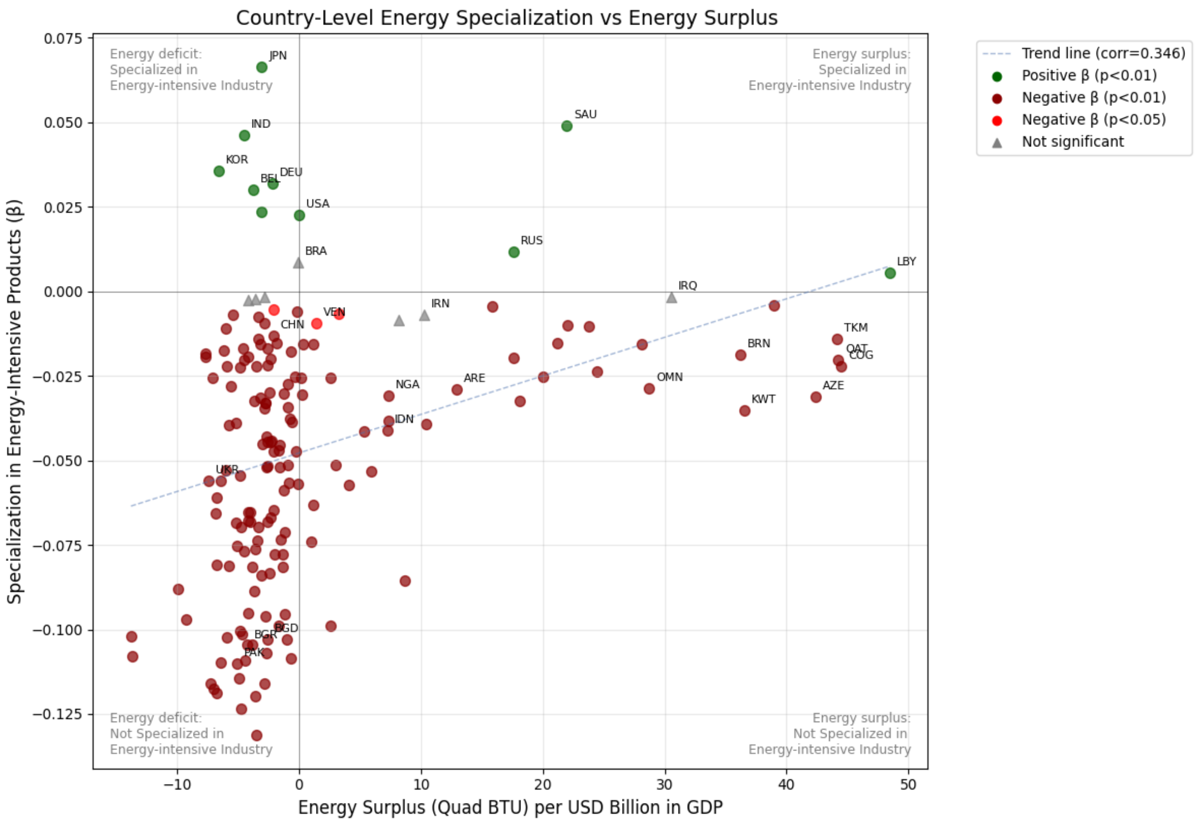


Figure 2 shows that there is little relationship between countries' specialisation in energy-intensive industries and whether they run an energy surplus or deficit. While there is some correlation in a basic regression between these two variables, it is driven largely by many countries that import substantial amounts of both energy and energy-intensive industrial goods, and country characteristics other than energy surplus mostly drive specialisation in energy-intensive industries. See Methods for more details.

This energy-flat world has accordingly meant that regions that are poor in energy, but rich in industrial know-how and capabilities have been able to specialise in energy-intensive industries. Regional energy resources have not been a determinant of comparative advantage, for the most part.

III. The end of the energy-flat world

But this energy-flat world is coming to an end, in a trend called 'powershoring'. Renewable solar and wind power have, in many places, become the cheapest forms of electricity on the grid. As modular technologies, they are also often the fastest to build. And grid constraints mean that it is often not possible, in the short term, to move this renewable energy closer to demand.

Industries that are intensive in electricity have therefore already started to move to places with abundant renewable energy. Texas in the United States (US) (Carbon Credits 2025), and Scotland in the United Kingdom (UK) (Williams 2025), have attracted huge investments in datacentres that seek to use their cheap, abundant wind energy. Sweden has attracted billions of dollars of investment in green steel manufacturing because of its plentiful hydropower (Devlin et al. 2023) and green steel manufacturers have also invested in building plants in Arizona (World Steel Association 2025) because of its market leading solar energy resources. Energy-intensive silicon casting for use in solar panels takes place mostly within China, but even there, it is moving from regions with substantial coal fired electricity to regions that have excess solar capacity (Ellichipuram 2022). Gulf states such as the United Arab Emirates (UAE) have become leaders in producing green aluminium, using their abundant sunshine (The National News 2022). Globally, anticipated and announced investment projects suggest there is an emerging sunbelt of countries rich in solar energy that are attracting investments into heavy industry (Eldridge et al. 2025).

Regions with abundant renewable energy are attracting investment not just in basic commodities like steel and aluminium, but also in advanced manufacturing industries that are energy intensive. Northvolt in northern Sweden attracted EUR 9 billion of investment to fund its plans to build a battery manufacturing hub that used Sweden's abundant hydropower (Milne 2025).

Having appropriate know-how to host an industry will continue to be important, even as the energy-flat world comes to an end. Energy costs matter in many industries, but in no industries are they all that matter. Northvolt failed in part because of the challenges of scaling a battery manufacturing industry in a region without any industrial ecosystem (Milne 2025): northern Sweden had the energy for battery manufacturing, but not the industrial capabilities. Northvolt's failure was to select northern Sweden only for its energy resources, without paying attention to the industrial know-how that it needed—i.e. without considering both axes of the powershoring spectrum. The lesson: places with cheap, clean energy *and* a good industrial manufacturing ecosystem may succeed in attracting complex, energy-intensive industries over capable manufacturing hubs with poor or expensive renewable energy.

Of course, international trade in energy in a world with powershoring is still substantial. But instead of trading energy directly, we will trade energy embodied in products and services, such as aluminium, iron, and data processing. In each case, tricky determinations need to be made around whether it is cheaper to move the electrons, or products made with those electrons. Assessments will depend on the relative cost of energy in different places, grid and transport infrastructure, and other industry-specific economic parameters. In many cases, however, moving products like aluminium and iron is likely to be cheaper and easier than moving electricity itself.

The end of the energy-flat world means that many energy-intensive industries need to locate in places that not only have a supportive industrial ecosystem, but also have good clean energy resources. So far, these changes have been marginal. But the recent European energy crisis brought on by Russia's invasion of Ukraine, and the termination of gas supplies to Europe, is a harbinger for what might be coming down the line (Hollinger et al. 2022). This energy crisis rendered many European energy-intensive industries uncompetitive, shifting production and investment to regions with better energy resources.

IV. Drivers of powershoring

Powershoring trends are not just, or even mostly, a creature of climate policy. Renewable energy, and particularly solar, is now often cheaper and faster to build than fossil fuel-powered generation, and cheap batteries are making renewables' intermittency easier to manage. Renewables dominate deployment of new generation capacity, not just in environmentally-conscious rich countries, but also in cost-conscious developing countries. In an age of electricity shortages, grid constraints, and booming electricity demand to fuel datacentres and electric vehicles, renewables' cost and speed to market are huge advantages.

Of course, policy can greatly speed up or slow down deployment of renewables, with rules around permitting, and support for developing electricity grids and training workforces (for example) serving as critical accelerants for renewable deployment. For the most part, the sorts of policies required are not subsidies, as solar and wind are often the cheapest forms of electricity to deploy on the margin today. Instead, 'enabling' policies are critical. Nations that make it easy to deploy renewable generation at scale set themselves up well to take advantage of powershoring trends. The Climate Club can play an important role here, through providing technical assistance, facilitating policy co-ordination and sharing best practices in ways that help countries develop the ability to deploy renewable energy at scale.

Deploying renewables is very capital intensive, and the cost of capital is a critical policy lever that shapes how easily countries can deploy renewables. Many developing countries have a high cost of capital: policy co-ordination to reduce the cost of capital through the Climate Club and other bodies can really help places with good renewable capacity but underdeveloped capital markets deploy renewables at scale and thereby access powershoring growth opportunities. Some countries with very high capital costs may need subsidies to help them bring down the cost of capital.

Industry is also electrifying for performance benefits of electrification (and not just climate reasons), as electricity offers many advantages over fuels in many advanced manufacturing techniques (US Department of Energy 2025). Processes powered by electricity are often more energy efficient, more precise, involve higher productivity and faster production times, are safer and have lower maintenance costs, and result in higher quality products with lower scrap and wastage. Advanced manufacturing techniques, like 3D printing metal parts with electrically-powered lasers, are therefore dominating legacy manufacturing techniques, like casting the same metal parts using fuels.

Climate policy and the need to decarbonise do of course help powershoring trends, with policies like the European Union's Carbon Border Adjustment Mechanism (EU CBAM), and trading of industrial carbon credits, turbocharging efforts to electrify and decarbonise energy intensive-industrial products around the world. In the short term, climate policies are hard to predict, politically contested, and occasionally face reversal. But in the long term, the need to decarbonise will become ever more pressing, as people increasingly feel the harms of a changing climate. Sooner or later, policymakers will have to consider how their local energy resources shape their potential industrial base, regardless of the short-term climate policies they or their trading partners adopt.

Policy co-ordination among several dimensions that are at the core of the Climate Club's mission could do much to help places realise powershoring opportunities. Powershoring trends require open trade in low-carbon intermediate products—green steel, aluminium, ammonia, and other decarbonised materials must trade freely across borders to where they are needed for further processing or final use. Trade protectionism targeting these products could undermine the economic logic of locating energy-intensive production near renewable resources, misallocate resources, and generally raise the costs of industrial decarbonisation. The Climate Club, through its strategic dialogues and work on harmonising methodologies and standards for green industrial products, can help establish common frameworks that facilitate rather than hinder trade in these critical materials. More generally, the Climate Club can help co-ordinate investments and policies, for example through its focus on partnership development, and its financial and technical assistance mechanisms.

V. Diagnosing powershoring context

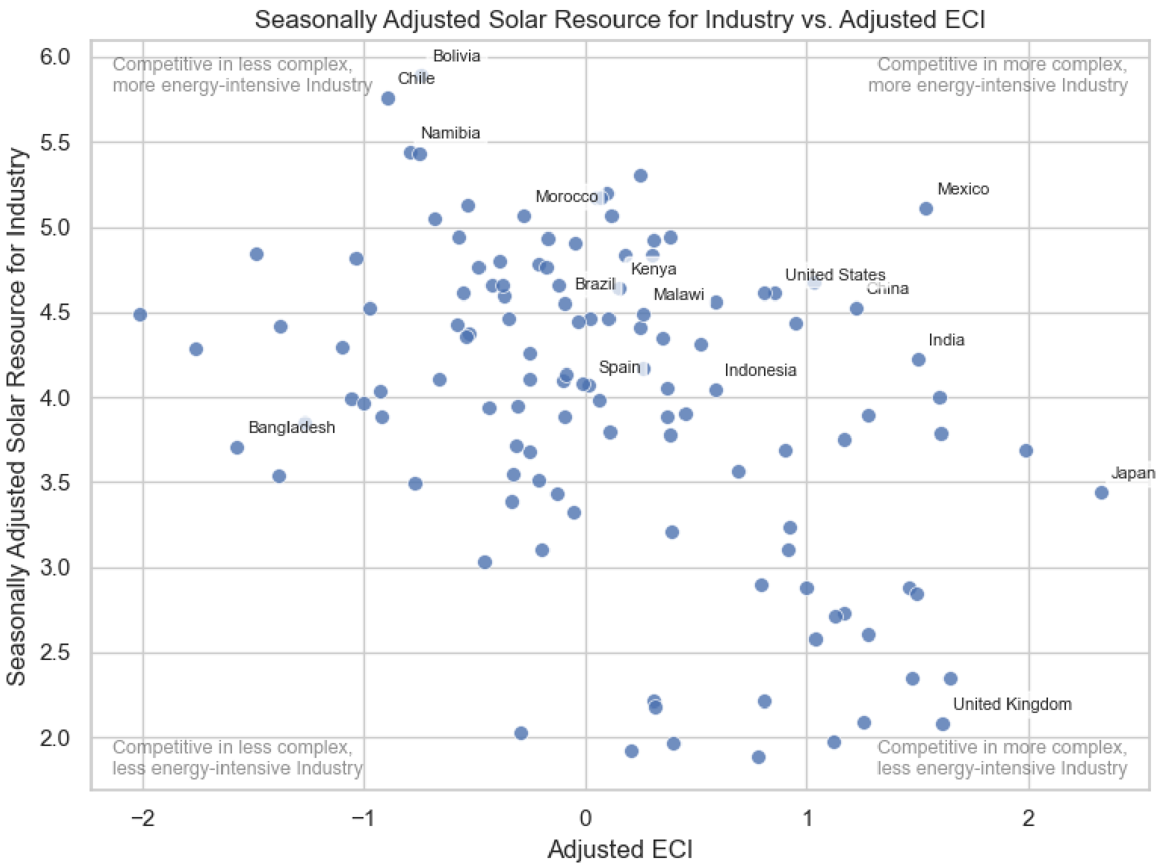
Policymakers who hope to steer their regions through this powershoring trend need to start by diagnosing their powershoring context—what are their region's local clean energy resources, and how do these resources map to the energy demands and productive capabilities of their industrial base?

For the most energy-intensive clean industries, like green steel, strong solar resources with minimal seasonal variation are important determinants of competitiveness, with wind, hydro, and other resources playing a more marginal role. This is because solar energy has become very cheap. Solar resources adjusted for seasonal variation therefore offer policymakers a good starting point.

Policymakers also need to evaluate the productive capabilities, and energy demands of their region's industrial base. Tools from economic complexity can help policymakers efficiently assess their region's productive capabilities (Hausmann 2013). The Economic Complexity Index (ECI), for example, ranks countries on the average complexity of their export industries, and provides a simple metric to assess a region's ability to support a complex industry. Policymakers can assess the energy demands of their industrial base using input-output tables (see Figure 1 and Methods).

Figure 3, below, therefore offers a starting point for national policymakers who seek to diagnose their country's powershoring context. It charts countries' economic complexity index ranking against their seasonally adjusted solar energy resources (see Methods for details). Countries to the top right of the graph are potentially competitive in (green) energy-intensive and complex industries. Figure 3 suggests, for example, that Namibia has excellent solar resources, but lacks strong productive capabilities for complex industries, while the UK has poor solar resources but excellent capabilities for hosting complex industries.

Figure 3: Seasonally Adjusted Solar Resource for Industry versus Adjusted ECI (Source: see 'Methods')



Of course, much will depend on diving deeper into local nuances and energy systems, which will adjust countries' relative positioning for specific industries. Energy systems are highly complex: some places can offset poor or middling solar resources with strong hydro, wind, or geothermal resources, such as Iceland, Sweden, and Brazil. Other places have excellent electricity grid connections, which can, to some extent, reduce system costs by reducing the need for energy storage and managing intermittency. And great sunshine matters little if places cannot also develop the ability to cheaply build and finance extremely capital-intensive solar, wind, and infrastructure projects. Policymakers need to evaluate all these nuances and complexities of their local energy systems.

There is, similarly, much more complexity involved in assessing a region's industrial capabilities than one metric (such as the ECI) can capture. Policymakers would want to assess how related their industrial ecosystem is to particular industries, alongside their research strengths, workforce skills, transport links, existing infrastructure, and plant capital, for example.

Once policymakers understand their energy resources and industrial capabilities, they become empowered to chart a path for regional economic development that best fits their region's context. They can know, for example, whether they are operating in a binding envelope of energy resources, and can accordingly support specialisation in appropriate industries, build grid infrastructure to import more renewable energy, or develop trading relationships that harness comparative advantages for mutual benefit.

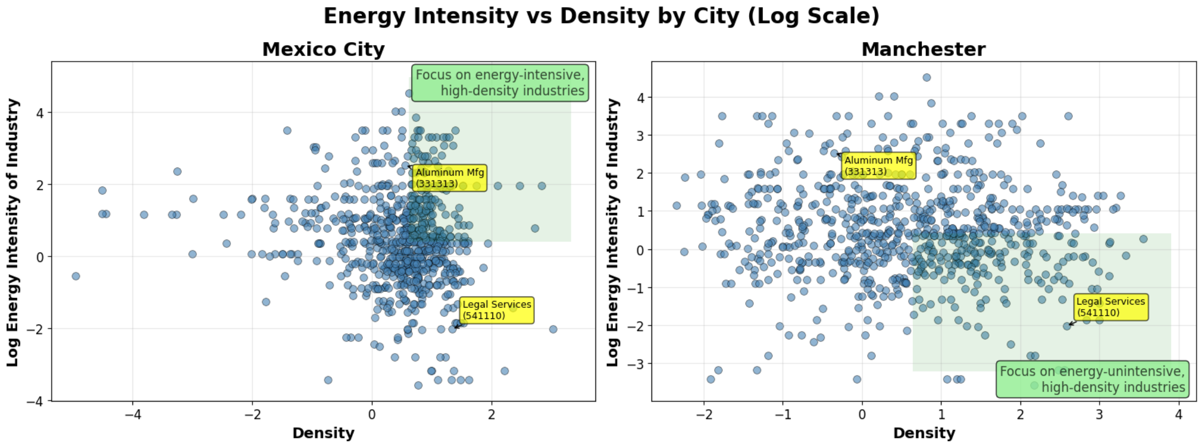
VI. Evaluating regional powershoring opportunities

Empowered with knowledge of regional powershoring context, policymakers can support development of their region's industrial base in ways that leverage their regional comparative advantages. Regions rich in energy resources can try to diversify into industries that are energy intensive, and that also leverage regional industrial capabilities. Regions poor in energy resources can try and diversify into industries that are less energy intensive and are related to local industrial capabilities.

Figure 4 below charts industrial opportunities for Mexico City and Manchester. Each dot in Figure 4 represents an industry (under the North American Industry Classification System (NAICS)). The X-axis in Figure 4 plots 'density', a metric from the economic complexity literature that calculates how related various industries are to Mexico City and Manchester's industrial capabilities (respectively), with higher values indicating that the industry is a better fit for each city's local economies. The Y axis represents the energy intensity of each industry, with higher values suggesting the industry is more energy-intensive (see Methods for more information). We have highlighted aluminium manufacturing and legal services in these graphs.

As a place with excellent solar resources, Mexico City can focus on industrial opportunities to the top right of its graph. Manchester, on the other hand, has poor solar resources and may accordingly want to focus on industrial opportunities on the bottom right of its graph, and on compensating for its poor solar resources with appropriate policy measures. These respective quadrants are shaded green for Mexico City and Manchester.

Figure 4: Comparing energy intensity of industrial opportunities with industrial capabilities for Mexico City and Manchester (Source: see 'Methods')



VII. Using powershoring as a stepping-stone

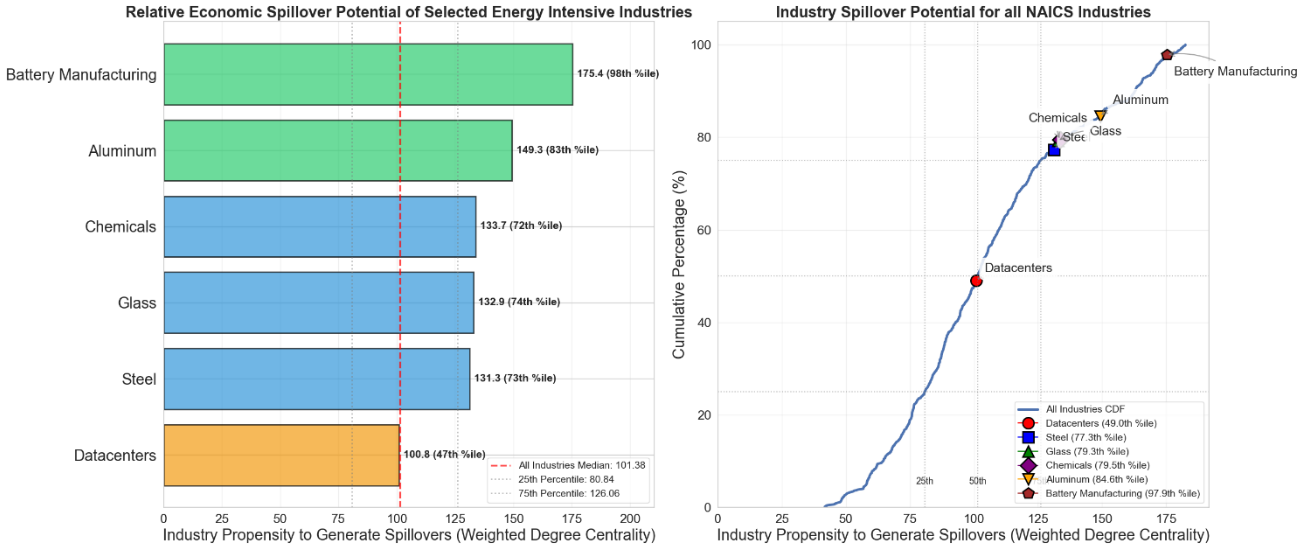
Industries matter to places not just in their own right, but also for the development pathways that they open up. Attracting a new industry to a place can bring new productive capabilities to that place's local economy, allowing it to diversify further into a wider range of industries. This process of progressively diversifying into more, and more complex, industries by accumulating new capabilities drives regional economic growth.

Some places with natural resources have been able to capture spillovers from these natural resources and develop more complex industries that rely more on human capital agglomeration and know-how accumulation. Capturing spillovers led some hard-scrabble frontier towns that were seeded during the Gold Rush in the American West one hundred and fifty years ago to become thriving metropolises, like Denver and Los Angeles, long after they exhausted their gold resources.

Places that want to maximise the value of their powershoring strategies will design them around industries that offer maximal spillovers. Not all energy-intensive industries are equal in this regard. Some allow a place to develop a more capable workforce, and stimulate local supply chains, such as battery manufacturing. Others use lots of energy but employ few people and do little to stimulate any local supply chain, workforce, or spillovers, such as datacentres.

Figure 5 below compares six energy-intensive industries based on their propensity to generate spillovers. The bar graph on the left of Figure 5 shows that industries such as battery and aluminium manufacturing generate relatively more spillovers than datacentres. The line graph on the right of Figure 5 ranks these six industries against all other NAICS industries based on each industry's relative propensity to generate spillovers. We use co-location of different industries in a region, which, with a few assumptions, is a reasonable proxy for economic spillovers (see Methods for details).

Figure 5: Economic spillover potential of energy-intensive industries (Source: see 'Methods')



VIII. Conclusion

As we change our sources of energy, we reshape fundamental determinants of comparative advantage across a wide swathe of industries. Policymakers need to contend with the opportunities and risks these changes present for their regional economies, or risk being left behind.

For some regions, powershoring represents a generational growth opportunity—to leverage nature's gifts to attract industries that can become fundamental building blocks of an economy. Other regions must play defence, building out an energy system, industrial base, and trading relationships that make the most of their limited regional energy resources, and smooth industrial adjustment over a long period of time.

The transition to migrate regional industries to live within their energy envelope will not be costless. Traditional industrial powerhouses with limited renewable resources face particular challenges, as they must migrate workers and communities to less energy-intensive industries, and pre-empt political backlash that may lead to protectionist policies or a delayed transition. The Climate Club can play a vital role in both enabling powershoring, and in smoothing industrial transitions, by helping members share best practices, co-ordinating demand- and supply-side industrial policy, and developing mechanisms to support workers in regions affected by industrial change.

This submission outlines how policymakers can navigate these changes, charting a path to local prosperity that makes the most of their industrial context and energy system.

Ketan Ahuja

Ketan Ahuja leads Harvard Growth Lab's green growth research agenda, which helps countries leverage the energy transition to transform their economies and generate economic growth. He's investigating how decarbonisation will transform global production by creating new industries, markets, and paths for economic development. He writes on various topics in industrial and competition policy.

Prior to the Growth Lab, Ketan worked on commercialising solar energy technologies at the US Department of Energy, and on competition policy and competitive strategy in the public and private sectors. His work has been published by, among others, Cambridge University Press, Harvard Kennedy School, the Financial Times, MSNBC, ProMarket, Bruegel and the Roosevelt Institute.

Ricardo Hausmann

Ricardo Hausmann is the founder and Director of Harvard's Growth Lab and the Rafik Hariri Professor of the Practice of International Political Economy at Harvard Kennedy School. Under his leadership, the Growth Lab has grown into one of the most well regarded and influential hubs for research on economic growth and development around the world.

Before joining Harvard University, he served as the first Chief Economist of the Inter-American Development Bank (1994-2000), where he created the Research Department. He has served as Minister of Planning of Venezuela (1992-1993) and as a member of the Board of the Central Bank of Venezuela. He also served as Chair of the IMF-World Bank Development Committee. He was Professor of Economics at the Instituto de Estudios Superiores de Administracion (IESA) (1985-1991) in Caracas, where he founded the Center for Public Policy. He holds a Ph.D. in economics from Cornell University.

Annex

Data Sources

Data on energy intensity of traded products is derived from US Environmentally-Extended Input-Output (USEEIO) data, using input-output methodologies, and concordance tables from the US Bureau of Economic Analysis and the "R" Concordance Package with manual adjustments. We are grateful to James McNerney for his work assembling this dataset, and to Sophia Henn and Yang Li for their work on concordance tables. Units for energy intensity of products are in MJ of energy per dollar of output.

Data on International Trading Products is taken from the United Nations (UN) Comtrade data set and is published in the Atlas of Economic Complexity at https://atlas.hks.harvard.edu/data-downloads. Data on countries' GDP is computed from the GeoPandas world dataset.

Data on each country's energy production and consumption is derived from the US Energy Information Administration's (EIA) International Energy Statistics.

Data on industrial specialisation of cities in different regions, as used in Figure 4, is taken from Metroverse, and is based on Dunn and Bradstreet's dataset on companies' locations globally. Our assessment of economic spillovers similarly uses this Dunn and Bradstreet dataset.

Methods

Figure 1

Figure 1 maps countries' energy surpluses and deficits, taking into account their primary energy production and consumption, in quadrillion British thermal unit (BTU). It is based on US EIA data. Energy surplus amounts to energy production minus consumption.

Figure 2

Figure 2 maps countries' energy surplus as a proportion of GDP (on the x axis) against the energy content of its export basket (on the y axis). We calculate energy surplus as a proportion of GDP by dividing a country's energy surplus in quadrillion BTU by its GDP in billions of dollars. We calculate the energy content of a country's export basket as the coefficient of a regression of countries revealed comparative advantage in different products (computed from trade data) against the energy content of those products (computed from USEEIO data). The regression specification is (for each country):

$\text{Log(RCA)} = \beta_0 + \beta_1 \times \text{energy content of products} + \varepsilon$

The coefficient on the y-axis of Figure 2 is the β_1 value from this regression for each country. The coefficient represents, for each country, its specialisation in energy-intensive products in its trade basket. We have removed Timor-Leste and Mongolia as outliers from this regression (both have very high energy surplus for their GDP), and excluded natural resource exports (HS codes beginning with 25, 26, 27, 41 and 71).

Figure 3

Figure 3 charts countries' adjusted economic complexity index score on the x axis against countries seasonally adjusted solar resource for use in industry on the y axis. Adjusted economic complexity is taken from the Atlas of Economic Complexity: See here for more information https://atlas.hks.harvard.edu/glossary.

Country's seasonally adjusted solar resource is calculated by taking the 90th percentile in practical solar resources for each country from the Global Solar Atlas (measured in kWh/kWp), and curated by the World Bank. It is available at https://www.worldbank.org/en/topic/energy/publication/solar-photovoltaic-power-potential-by-country. We choose countries' 90th percentile solar resources ('P90_solar') because we assume countries will prioritise areas with the most insulation.

We adjusted this score by seasonal variation because published studies indicate that seasonal variation in solar resources is one of the main determinants of the cost of solar power for industrial use. Seasonal variation in electricity output requires large plant overbuilding and involves low utilisation factors for industrial plant and equipment (much more so than short-term intermittency).

To quantify the impact of renewable energy seasonal variation on green steel production costs, we replicated a published machine learning model on green steel production in various countries.(Devlin et al. 2023) The model identified solar Coefficient of Variation (CoV) as the most important predictor of the cost of green steel (43.8% feature importance), with a strong linear relationship ($R^2 = 0.89$) indicating that each 0.1 increase in monthly solar CoV increases levelised cost of steel (LCOS) by $28.44/ton. CoV is a country's standard deviation divided by its mean in monthly Photovoltaic Output (PVOUT) solar resources.

We use this model to develop a Solar Industrial Competitiveness Index (SICI) that combines resource quality with economic penalties from seasonal variation: SICI = P90_solar × (1 - 0.61 × CoV). The penalty factor of 0.61 reflects that each 0.1 increase in CoV represents a 6.1% cost increase relative to the model's baseline Levelised Cost of Steel of $466/ton.

Figure 4

Figure 4 charts, for Mexico City and Manchester, each city's specialisation in different industries as measured by employment density on the x-axis, against the log energy intensity of industrial goods for a range of different NAICS industries. Employment density measures how related any given industry is to a city's capabilities, by looking at the industries in which that city's employees work. A higher employment density score for an industry in a city indicates that industry is a better fit for that city's economic structure. Calculations are based on Dunn & Bradstreet data and taken from Metroverse according to the methodology outlined in Metroverse: https://metroverse.hks.harvard.edu/.

Calculations of log energy intensity of industrial goods are derived from USEEIO data and mapped to NAICS Industries as set out above.

Figure 5

Figure 5 measures, for six energy-intensive industries, their propensity to generate economic spillovers. As a proxy for spillovers, we use co-location of different industries within a metropolitan area based on Dun & Bradstreet and Metroverse data. This is a proxy for spillovers, rather than a quantification of spillovers, because although we calculate which industries tend to co-locate, we do not calculate directionality of which industries lead to the development of other industries in a location. Calculating directionality is beyond the scope of this article, and it is not clear that patterns of directionality are stable across time and place.

To calculate spillovers, we construct an industry network where nodes represent NAICS industry codes and edges connect industries based on their co-location patterns derived from Dun & Bradstreet business establishment data. We are grateful to Karan Daryanani for constructing this network. We then calculate a weighted degree centrality metric for each industry, which ranges from 0.2274 to 1.0000 (mean: 0.5871) in our sample. This measure captures both the number and strength of inter-industry connections, where higher values indicate industries that are both connected to more industries in our network, and connected more strongly with other industries (based on edge weights derived from colocation patterns).

Acknowledgements

We are grateful to James McNerney for his work in constructing a dataset on energy intensity of industries while at the Growth Lab, and for substantially producing the visualisation in Figure 1. We are grateful to Karan Daryanani for constructing the network used for analysis of spillovers in Figure 5.

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4 Efficient global industrial decarbonisation: Economic opportunities with trade and carbon pricing

Frank Jotzo

Abstract

Decarbonisation of global heavy industry is necessary for effective climate action, and it will mean a change in the economic geography of heavy industry if done efficiently. Geographies with pronounced low-cost renewable energy potential, along with a range of enabling factors, can become producers and exporters of energy-intensive base commodities. This includes developing countries and fossil fuel-exporting developed countries. Supply-side policies to make green industry production cheaper are important to start new industries, but may be limited in scope and fiscal sustainability, and could bias the global location of green industries. An efficient policy approach would be a uniform global carbon price or equivalent policies. In a world of incomplete carbon pricing, border carbon adjustments can incentivise the emergence of green commodity production. The Climate Club can help create preconditions for an international coalition on industrial carbon pricing, support the development and implementation of harmonised rules for border carbon adjustments that support trade, and foster other approaches that create green premiums in product markets.

I. Introduction

Heavy industry and resource processing account for a sizeable share of global greenhouse gas (GHG) emissions. They can and must be largely decarbonised in a net-zero emissions world economy, to a large extent by replacing fossil fuel with renewable power as the energy input.

Effective and efficient decarbonisation of global heavy industry means a change in the economic geography of heavy industry, towards locations with abundant cheap renewable energy potential allowing low-cost clean electricity-based production. This also implies changes in trade flows between countries, for energy intensive base commodities such as iron and steel, aluminium, ammonia, and others.

Geographies with pronounced low-cost renewable energy potential, abundant land, port access and stable access to low-cost supplies of raw materials, suitable workforces and conducive institutional environments could become producers and exporters of processed and semi-processed energy-intensive commodities such as iron and other metals, base chemicals and carbon neutral fuels. These would be exported to the world's traditional industrial centres, keeping high value-added elements of the supply chain (such as steel and chemicals) there, while alleviating the need to procure very large amounts of clean energy for base processing.

Countries with such potential for green commodity exports include a number of developing countries, as well as a few developed countries. Several of the countries that could become competitive exporters of 'green' base commodities currently are developing countries, and/or large producers and exporters of fossil fuels. Establishing green export industries would cushion the economic impact of declining fossil fuel exports over time. This in turn could help with the political economy of climate policy in fossil fuel-exporting countries.

Green industrial production is typically more expensive than conventional high-emissions production. Policy is needed to make them competitive, in particular at early stages of deployment. Policy can also be a determinant for the location of future green heavy industries. If policy approaches favour other outcomes than least-cost industrial decarbonisation, then achieving global emissions outcomes could come at unnecessary cost in the industry sector, risking delay.

The currently rising policy approach, alongside traditional industry policy support of various kinds, is supply-side support to make green industry production cheaper. This holds promise to help establish green industries but is limited in scope and fiscal sustainability. It may also bias the location of industries towards countries that are most willing to subsidise rather than where clean production is cheapest.

An efficient policy approach would be a uniform global carbon price, or equivalent policies. To be fully effective, carbon pricing needs to apply in most of the major industrial economies, with border adjustments until and unless there is full coverage at comparable price levels.

In a world where only some countries price carbon, and/or at differing levels, border carbon adjustments (BCAs) can achieve a similar effect. They can not only prevent 'carbon leakage' but incentivise the emergence of green commodity production. BCAs can effectively extend domestic carbon prices to imports from jurisdictions where production is not subject to emissions constraints, or to lower effective carbon prices. They create green premiums in product markets that can cover higher production costs of green materials, available to any producers irrespective of location. A web of carbon pricing coupled with BCAs in different countries could greatly amplify this effect. Other policy approaches, for example offtake agreements or government procurement, can also help create green premiums in product markets.

The Climate Club can help create preconditions for an international coalition on carbon pricing for industry to emerge. It can support the development and implementation of harmonised rules and technical assessments for BCAs, and help promote insights among member countries.

II. The role of heavy industry decarbonisation in global climate change action

Heavy industry accounts for around a quarter of GHG emissions, or about a third if counting its share of indirect emissions for electricity generation (IPCC 2022). Industry sector emissions have grown faster than those in any other sector globally, in line with ever-rising production of base industrial products and resource processing to serve rising deployment of infrastructure, housing, and various forms of equipment. Demand for such products is set to continue rising as developing countries raise material standards of living, and as people in developed countries continue to have greater means to afford more material goods. However, the expectation is that with technological changes in the production processes and the adequate policies, the production of these goods becomes less emissions-intensive over time. As an illustration, the International Energy Agency (IEA)'s "stated policy scenario" has global industry carbon dioxide emissions flatlining from now until 2050, while overall emissions would fall by approximately a quarter (IEA 2024).

The high and likely rising share and of industrial emissions makes it imperative to address them effectively as part of the global climate change mitigation effort. Making deep cuts to industrial emissions will be necessary to ultimately achieve net zero emissions.

Most heavy industry production is energy intensive, and the combustion of fossil fuels is the dominant source of industrial GHG emissions. A small number of resource processing and production activities are particularly emissions intensive. Among these are iron and steel, various other metals, cement, ammonia and plastics. Fossil fuels are by far the dominant energy source and feedstock in these production chains.

Options to reduce emissions from heavy industry production include substitution to clean energy, reduced material use, greater energy efficiency, carbon capture and storage (CCS), and others. Among these options, substituting to zero-carbon energy, and specifically clean electricity (typically renewable energy, though also nuclear power), has the greatest emissions-reduction potential. This can take various forms depending on the product and processes used, including switching to clean electricity generation; switching from fossil fuel combustion to clean electricity (electrification); and producing low- or zero-emissions synthetic feedstock (using clean electricity as the energy input) to replace fossil fuel feedstocks. Depending on the process, relevant technologies are either already commonly used, ready to deploy, or in development.

The single largest example is iron and steel production, which accounts for around 7% of global emissions. The conventional process of primary steel production uses coal both as a chemical reactant to reduce iron ore to iron, and a heat source for smelting. "Green" steel processes can use hydrogen (or potentially electricity) for iron ore reduction and (clean) electricity as the energy source for heat. The required hydrogen in turn can be produced via electrolysis, using clean electricity as the energy input.

If the electricity used is fully renewable (or nuclear), then the emissions intensity of the whole process can be reduced towards zero. The process can be split into iron production, which is the energy-intensive part, and steel production, which is the high value-added part. In this way, steel production can remain in the traditional industrial centres, allowing for continued access to the local workforce and proximity to customers, and minimising economic and social adjustment pressures.

Heavy industry is often seen as among the "hard-to-abate" sectors: areas of the world economy where it will be particularly difficult to reduce emissions, whether because of the absence of deployable technologies or because of cost. However, the dramatic reduction in renewable energy supply costs, particularly the cost of solar and wind power, has reduced the cost of decarbonising many industrial activities. At the same time, efforts to develop commercial low- or zero-emissions heavy industry production technologies have intensified and are bearing fruit. Such technology development has been precipitated by cheaper renewable energy in tandem with policy incentives, present and expected for the future.

III. A changed global geography of heavy industry and its political economy

The current location of heavy industries is shaped largely by historical factors, proximity to markets and workforces, and access to fossil fuels or transportation routes for fossil fuels. A shift to renewable energy as the dominant energy source will imply a change of the economic geography of the world's heavy industry. The most energy intensive aspects of industrial production will then be most cost-effectively located in geographies that have plentiful low-cost clean energy potential. The reason is that renewable energy is costly to transport; this is also true for hydrogen.

Regions with high insolation rates, high wind speeds or other clean energy potential, combined with low opportunity costs of land and port access, will generally be the favoured locations for energy-intensive heavy industries in a decarbonised world economy. Another feasible combination of factors is plentiful cheap fossil fuel (especially gas) availability combined with suitable and low-cost options to sequester carbon dioxide (CO_2).

Such conditions exist in a number of developing countries, notably in Africa, South America, and the Middle East; as well as in some developed countries including Australia, Canada and the United States (U.S.), all of which are large fossil fuel exporters. By contrast, the high population density, high latitude regions of Europe and North-East Asia, where much of the world's traditional heavy industry is still located, are by large much more constrained in their clean energy opportunity. The upshot is that re-organisation of global industrial supply chains, including their resource and energy inputs, can be of palpable economic benefit to some developing countries, as well as some fossil fuel-exporting developed countries that will be exposed to falling fossil fuel revenues.

Stable access to low-cost supply of relevant raw materials is also a crucial factor. This may be optimally selected on the basis of raw materials (such as iron ore) co-located with clean energy resources, or otherwise by shipping resources to processing centres. Additional factors will be availability of skilled workforces, conducive institutional frameworks, stable investment climate, and supportive domestic policy frameworks.

This implies that while much hinges on factors of resource endowment and geography, governments can help advance the prospects of having future clean industries locate in their jurisdictions by creating conducive environments. Of particular importance are favourable institutional frameworks including security of tenure to underpin the very large private sector investments that will be necessary, provisions of infrastructure, and technical or vocational training. Supportive industry policy and creating enabling environments could also be major factors; however, there may be pitfalls as discussed below.

A changing landscape of base industry implies changes in trade flows between countries, which would happen alongside very pronounced reductions in fossil fuel trade. Countries that become new locations for clean industrial production would see (potentially substantially) increased value add in industrial processing and exports of energy-intensive products. For some countries, this could help offset the negative economic effects of declining fossil fuel production and exports, which could to some extent ease the difficulties of the transition.

This dynamic is already evident in Australia, where a vision of the nation as a future "renewable energy superpower" has been established (Garnaut 2019). The country's potential as a producer and exporter of green hydrogen or ammonia, and more importantly green iron and other green metals, is seen as a chance to maintain and potentially expand resource and energy production for export. The opportunity for green iron is particularly pronounced. As the world's largest iron ore exporter, and with ready access to abundant renewable energy resources as well as land, ports, infrastructure and a resource industry workforce, Australia is potentially very well placed as a supplier of green iron to Asian steel mills (OECD 2025).

The expectation is that export revenue from coal, and later gas, will fall as a result of reduced fossil fuel use in the global transition to net zero. This politically and economically uncomfortable reality could to some extent be addressed by building up green export industries. Importantly, this can also be seen as a sizeable contribution to global climate action: by exporting green commodities and energy, Australia could potentially help reduce emissions in other countries by an extent that is greater than its national emissions, or the embodied emissions in exports (Burke 2022).

Similar opportunities exist for some other fossil fuel-exporting nations, including some developing countries. A more positive political economy for decarbonisation could make a difference in countries' stances toward climate change mitigation, including on co-operative international approaches. Policymakers and civil society in relevant countries have agency in this, by investigating and communicating the opportunities that future green export industries may bring. A salient way of communicating the concept may be to make an illustrative assessment of the potential emissions reductions in other countries as a result of a country's green exports, and of the achievement of the crossover point with embodied emissions in exports (Jotzo and Zou 2025; Australian Treasury 2025).

III. Carbon pricing with border adjustments to support efficient green industry development

Green industrial production is generally more expensive than conventional high-emissions production. Costs will generally decline with commercialisation and mass deployment of equipment such as electrolysers, as has been evident in the dramatic cost declines of solar panels, wind turbines and battery technology. But cost gaps will likely remain longer term.

Policy instruments will be necessary to provide an enabling environment for green industries, and to bridge remaining cost gaps by either reducing the effective cost of production, and/or by creating a 'green premium' for low-emissions products in markets, in the form of higher market prices without the need to pay a carbon penalty. Policy may also be a major factor determining the location of future green heavy industries.

An efficient policy approach would provide the same implicit or explicit policy support level across all jurisdictions, ideally in line with the extent to which emissions are reduced. In the theoretical ideal, this would be achieved by a uniform global carbon price. This would increase market prices of conventionally produced commodities in line with their emissions intensity, while green products would not face carbon costs but enjoy higher market prices (green premium). Similar effects can also be achieved through other economic policy instruments.

In a world where only some countries price carbon, and/or at differing levels, BCAs can broaden the reach of industrial climate policy and make sufficiently strong policy settings feasible. BCAs, such as the EU CBAM, are conventionally seen as instruments to prevent 'carbon leakage' in traded emissions-intensive industries. However, they may also serve the purpose of incentivising the emergence of green commodity production and trade, and would provide these incentives irrespective of the location of the green industries.

Consequently, industrial carbon pricing with BCAs can be an effective way to promote industrial decarbonisation efficiently through open trade, at least in some sectors and product categories. To fulfil the goal of overall economic efficiency of clean industrial production, BCAs need to be designed and implemented to mirror domestic climate policy settings onto imports, providing the same carbon reduction incentive to producers in any location. This would result in a level playing field between domestic and international producers, without trade distortions or and protectionist effects (DCCEEW 2024).

BCAs can then help foster efficient location of low-emissions industries anywhere in the world, by extending incentives from any country's domestic carbon pricing scheme to imports, making green premiums in product markets available to any producers irrespective of location.

A web of carbon pricing coupled with BCAs in different countries could greatly amplify this effect. A proposal for a 'climate alliance' centred on carbon pricing with border adjustments features in climate policy discussions at COP30 (Global Climate Policy Project 2025). Such an alliance could feature reciprocity in treatment, shared benefits of green industry development and trade, and benefits of extra fiscal revenue.

There are other policy instruments that can create green premiums in product markets. Among them are government-underwritten offtake agreements, and government procurement programs. Although less universal in nature and typically limited in scope and/or scale, they may be effective in providing the demand for green commodities needed to underpin initial investments.

At present, most green industry policy takes the form of supply-side support to make green industry production cheaper, such as subsidies, tax credits, offtake agreements, preferential financing and others. These policies can play an important role in establishing new industries, and in particular, in establishing the first installations in any relevant jurisdictions. However, they are intrinsically limited in scope and fiscal sustainability.

Selective, nationally-based industry policy may be motivated by the desire to realise dynamic advantages in emerging industries, safeguard established industrial production, or strategic supply security. Industry policy with these and other motivations is widely in place and rising (Evenett et al., 2024). National supply-side policies carry the risk of extra costs in green industry development, by creating a bias for the location of industries towards countries that subsidise them, rather than where clean production is cheaper. This would make achieving net zero emissions more difficult because of higher costs, and could delay reaching global climate goals.

Just as for any type of industry policy, benefits of subsidising emerging green industries need to be weighed against fiscal outlays and opportunity costs of the activities that are promoted as well as drawbacks such as potential adverse local environmental effects. For commodity exporting countries, supply-side support to make green industry production cheaper will tend to be particularly costly. Governments of resource-exporting countries vying for green industries also need to consider that the benefits of lower supply costs will accrue largely to customers overseas.

Policymakers are well-advised to focus on the creation of demand-side policies, especially carbon pricing, limit the extent of supply-side policy (and especially subsidies) to specific identified instances of high promise, and focus such policies to support the emergence of new green industries and technologies.

IV. What the Climate Club can do

The Climate Club can help create common ground on green industry development between member countries and work collaboratively to advance efficient policy approaches. Specifically, the Climate Club can provide a framework for carbon pricing coalitions to emerge. A key element of this would be to support the development and implementation of harmonised rules and technical assessments for BCAs.

For BCAs to work efficiently, with minimal transaction costs and maximum trust, a shared set of principles, assessments of emissions intensity of production, and assessments of the effective carbon price levels that apply in the country of production is needed. The Climate Club can help work towards these objectives by facilitating dialogue about desired policy and design settings and by promoting consensus about protocols and procedures. It may also promote a durable institutional structure for the required assessments. This work can start with a select group of the most important and prospective commodities, likely including green iron and ammonia.

At a higher level and longer term, the Climate Club may be able to help its members promote an improved understanding of the opportunities inherent in efficient green industry development, and support policy approaches that can maximise economic efficiency in the transition to a low-emissions global industrial system.

Two opportunities stand out. One, the Climate Club could champion approaches that support open trade frameworks for green commodities, including through trade efficiencies inherent in carbon pricing with BCAs. Two, the Climate Club could be a setting where other policies to create green premiums in product markets are explored or co-ordinated, such as offtake agreements and government procurement. In both options, the Climate Club could support analysis and exchange, with a view to adoption of internationally compatible or harmonised policy approaches.

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Acknowledgements

This article draws on ideas developed in many exchanges with academic colleagues, policymakers and business stakeholders. Climate Club secretariat members made suggestions in the drafting process.

AI statement: This article was written without use of large language models (LLMs).

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Part II: Decarbonisation in an interconnected world: co-ordination challenges

5 Embodied carbon: Understanding our trade and climate co-dependency

LAURENCE TUBIANA, RICHARD BARON, SAMUEL LERÉ, AND MATTHEW LANGDON

Abstract

Countries trigger each other's greenhouse gas (GHG) emissions through imports and exports of manufactured goods and commodities: emissions embodied in trade represent nearly a quarter of the global total. Recognising this co-dependence ("my imports are your emissions") can be an avenue for international co-operation on mitigation, and there is now data showing where efforts would be productive. In the meantime, countries take unilateral measures that can contain and even lower imported emissions, although not without frictions. A group of countries could, each individually, commit to reducing imported emissions and seek co-operation on mitigation to that effect. The Climate Club and Brazil, Russia, India, China, and South Africa (BRICS) show signs that developed and developing countries may be ready to grapple with the contentious topic of embodied emissions.

I. Introduction

Trade has emerged as a new source of tension in climate negotiations, with developing countries' recriminations over unilateral measures like the European Union Carbon Border Adjustment Mechanism (EU CBAM) or Regulation on Deforestation (EUDR). These measures are presented as attempts to reduce, respectively, carbon leakage and the growth of countries' foreign "carbon footprint". Yet there is little objective discussion over the magnitude of these potential problems; indeed, sources of reliable data have been hidden in technical papers.

For a long time, trade and climate talks were kept separate. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have been careful to consistently exclude international trade from their deliberations: Article 3.5 of the Convention states that "*measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade*." Parties left international debates on trade where they belong, at the World Trade Organisation (WTO). This did not preclude domestic debates on how any imbalance in climate policy ambition, however justified by the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), would grant undue competitive advantage to less ambitious countries and undermine national efforts to reduce emissions (IPCC 1996).[6] It is only natural that trade

[6] The notion of carbon leakage is already present in the Second Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, 1996.

gathered much more attention in the climate policy community at the time where various regions have been putting ever more ambitious policies in place to reduce their emissions. The above-mentioned EU CBAM and EUDR have led to heated discussions between the European Union (EU) and several of its partners. It must be acknowledged that even before these measures were implemented, certain economic sectors had already begun to change their practices as a result of them. The same applies to the Inflation Reduction Act (IRA), which gave rise to a great deal of opposition, including between the United States (US) and its European and Asian allies, led by Japan and Korea.

The later introduction of tariffs on electric vehicles from China imposed by the US (from 25% to 100%), Canada (100%), the EU (up to 35%), Turkey (40%) and India (as high as 100%) also illustrates the growing importance of the ecological transition in trade and geopolitics. At the same time, climate has been entirely absent from recent tariff negotiations with the US, which is jarring: the country has decided to withdraw from the Paris Agreement and the EU has committed to acquire vast amounts of gas and oil from the US, which tops the list in terms of embodied greenhouse gas (GHG) emissions (Howarth 2024). It is yet another illustration of the importance of embodied emissions. It is high time that large emitters and importers of embodied emissions take a more detailed look at their external carbon footprint and explore policy implications. Given their size and responsibility in global emissions, G20 countries are the focus of this paper.

For many, imported emissions are essentially associated to EU CBAM, whereas the current scope of the mechanism accounts for less than 9% of EU's total imported emissions. The direct impact of CBAM on reducing these emissions will therefore be limited. This should not be a surprise as the main objective of CBAM is to prevent carbon leakage in sectors facing a carbon price in the EU, and not in exporting jurisdictions. It applies to a small set of products imported in the EU, and which would otherwise benefit from a significant and immediate cost advantage as carbon emissions become priced in the EU. Foreign producers may decide to reduce their emissions to gain a competitive advantage through a lower carbon cost in the EU market, and it is only then that CBAM can claim additional mitigation outside the EU. It would be restrictive to focus on the sectoral scope of a single jurisdiction (the EU) for a small set of traded products (aluminium, iron and steel, cement, fertilisers, hydrogen and electricity) as an entry point to explore international co-operation on "traded emissions".

The aim of this paper is to initiate a discussion on the possibilities of reducing embodied emissions in a co-operative manner to accelerate the global transition. No country has committed to reducing their imported emissions so far,[7] and very few countries report on their carbon footprint, i.e. emissions beyond their borders, let alone engage in bilateral conversations with trade partners on reducing imported emissions.

[7] Countries could also consider mitigation objectives on their carbon footprint, i.e. their territorial emissions less their exported emissions plus their imported emissions.

II. Latest data on embodied emissions show their importance

A. Embodied emissions: an extended definition

Embodied emissions are understood here as GHG emissions that are released in one country or sector to produce goods and services consumed in another country. For instance, the embodied emissions of Indian steel are all the direct emissions generated by the Indian steel sector to fulfil the total final demand of other economies.

In this article, we report all emissions occurring in the Indian steel industry caused by foreign final demand, including steel exported by India in machinery, cars, appliances, etc. It is a more comprehensive representation of embodied sectoral emissions than one focussing on the GHG content of India's exports of steel products. More simply put, "embodied emissions", unless indicated otherwise, represent all emissions in a country's sector triggered by another country's total demand.[8]

B. The main emitters are also the main importers of embodied emissions

The GHG emissions from the production of goods and commodities traded internationally have been growing for some time. They accounted for approximately a quarter of global emissions, nearing 12.8 billion tonnes of CO_2 equivalent ($GtCO_2e$) in 2021 (Carbone 4, European Climate Foundation 2024).

The volume of traded GHG emissions has been increasing by 1.4% per year on average over the last 15 years, albeit more slowly than the value of global imports (+3.4%/year). The share of GHG emissions embodied in trade in the total of global emissions has been hovering around 23% in the last 25 years. Looking at CO_2 from fossil fuels alone, embodied emissions grew from 6.5 $GtCO_2$ in 1995 to 7.9 $GtCO_2$ in 2019, which is higher than the US total GHG emissions that year (Carbone 4, European Climate Foundation 2024).

The major emitting countries also happen to be major importers of embodied emissions, with the G20 accounting for 81% of traded emissions, a reflection of their prominence in international trade. The three largest emitters (China, the US and the EU) with 2.5, 2.0 and 1.8 $GtCO_2e$, respectively, account for the largest imports of embodied emissions. Imports from India and Japan also represent significant emissions, with 0.8 and 0.7 $GtCO_2e$, respectively. What could be the implications of these countries' interest in mitigating the carbon footprint of their imports? A sectoral look at embodied emissions gives further indications.

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[8] Using the EXIOBASE database for 2022, we estimated embodied emissions for EU27, 16 major economies and remaining five world regions, for eight sectors: iron and steel (including without electricity-related emissions); aluminium (including electricity related emissions); chemicals; meat and fish products; other agriculture; textiles; mining (excluding fossil fuels); and electricity-related emissions from traded manufactured goods. Dugast, 2025.

C. A sectoral look

Latest data combining trade and GHG emissions indicate how countries and regions influence each other's emissions through trade, which we refer to as co-dependence on GHG mitigation. Briefly put, a country's imports drive other countries' emissions. This could open a space for co-operation on mitigation.

The co-dependences identified here may appear intuitive to trade experts. They are, however, striking both for the magnitude of embodied emissions and the countries engaged in "high embodied carbon" trading. The heaviest sectors combining trade and embodied emissions are iron and steel, chemicals, agriculture and animal products, or aluminium (Table 3). *Table 1* shows the sectoral "heat map" of embodied carbon for the steel sector, including indirect emissions from electricity used in steelmaking.[9]

Table 1: Heat map of GHG emissions embodied in traded iron and steel products ($MtCO_2e$). Source: Dugast 2025

Consuming countries →

Producing countries ↓

	Austr	Brazil	Cana	Switz	China	EU27	UK	Indo	India	Japan	S. Kor.	Mex	Norw	Russ	Turk	US	O As	O Eur	O Afr	O Lat	Mid. East	S. Afr.	TOT
Austr	0,3	0,0	0,0	0,0	0,1	0,1	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,3	0,0	0,0	0,0	0,0	0,0	1,3
Brazil	0,1	10,3	0,6	0,0	3,9	1,3	0,2	0,1	0,3	0,2	0,2	0,7	0,0	0,1	0,2	5,7	0,9	0,1	0,4	4,8	0,9	0,0	31,0
Cana	0,1	0,1	5,8	0,0	0,5	0,4	0,1	0,0	0,2	0,1	0,1	0,5	0,0	0,0	0,1	7,0	0,3	0,0	0,1	0,3	0,3	0,0	15,9
Switz	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1
China	10,1	8,1	9,0	1,9	1859	58,6	9,9	8,8	24,7	22,5	22,7	9,8	1,2	5,9	5,0	106,1	167,2	3,3	25,0	35,6	62,0	1,6	2460
EU27	0,7	0,9	1,1	1,8	10,3	71,0	4,5	0,4	2,1	1,1	1,2	1,3	0,8	1,3	3,2	11,1	5,0	1,8	2,7	2,4	6,5	0,3	131,6
UK	0,0	0,0	0,1	0,0	0,3	1,8	1,8	0,0	0,2	0,1	0,0	0,0	0,1	0,0	0,2	0,6	0,4	0,0	0,2	0,1	0,4	0,0	6,4
Indo	0,4	0,3	0,3	0,1	21,6	2,5	0,4	24,3	1,5	0,8	1,7	0,3	0,0	0,3	0,4	3,5	7,2	0,1	0,7	0,6	2,4	0,1	69,3
India	1,2	1,0	1,3	0,4	16,0	13,2	1,9	2,2	223,5	1,6	1,1	1,8	0,2	1,0	1,3	13,1	19,2	0,5	5,0	3,1	14,0	0,5	323
Japan	0,8	0,4	0,6	0,1	12,2	3,0	0,5	1,2	1,6	65,5	2,6	1,0	0,1	0,4	0,3	7,4	10,6	0,1	1,1	2,0	3,5	0,1	115
S. Kor.	0,4	0,3	0,5	0,1	6,2	2,9	0,4	0,6	1,7	1,6	13,5	0,8	0,1	0,4	0,5	5,0	5,6	0,1	0,6	1,1	2,0	0,1	44,8
Mex	0,1	0,2	0,8	0,0	0,9	0,6	0,2	0,0	0,2	0,1	0,1	6,7	0,0	0,1	0,1	8,6	0,4	0,0	0,1	2,0	0,5	0,0	21,7
Norw	0,0	0,0	0,0	0,0	0,1	0,5	0,1	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,1	0,1	0,0	0,0	0,0	0,1	0,0	1,6
Russ	2,1	1,8	1,8	0,9	31,8	35,2	3,3	3,3	6,3	3,7	3,2	5,0	0,5	75,3	13,6	22,7	41,2	10,7	9,6	5,6	19,1	0,4	297
Turk	0,1	0,1	0,1	0,1	0,8	3,6	0,5	0,1	0,3	0,2	0,1	0,1	0,0	0,1	18,5	1,2	1,3	0,3	1,9	1,1	3,4	0,0	34,0
US	0,4	0,4	4,2	0,1	2,9	2,8	0,5	0,2	0,7	0,6	0,6	3,9	0,1	0,1	0,6	47,5	2,2	0,1	0,5	2,2	1,9	0,0	72,6
O As	1,2	0,3	0,6	0,1	15,4	3,6	0,6	3,3	2,5	1,5	1,0	0,7	0,1	2,1	0,4	5,4	12,6	0,2	1,2	0,9	2,4	0,1	56,2
O Eur	0,1	0,1	0,1	0,1	2,2	3,4	0,4	0,3	0,3	0,2	0,1	0,1	0,0	0,5	0,8	1,8	1,4	4,8	1,4	0,9	3,2	0,0	22,1
O Afr	0,0	0,0	0,0	0,0	0,2	1,1	0,1	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,2	0,0	13,1	0,1	0,3	0,0	15,9
O Lat	0,0	0,5	0,1	0,0	1,2	0,5	0,1	0,0	0,2	0,1	0,1	0,2	0,0	0,0	0,1	1,8	0,4	0,0	0,1	11,8	0,4	0,0	17,8
Mid. East	0,3	0,2	0,3	0,1	4,8	1,9	0,3	1,1	1,4	0,4	0,3	0,2	0,0	0,1	0,3	2,4	3,6	0,1	1,5	0,3	2,8	0,1	22,3
S. Afr.	0,1	0,1	0,1	0,0	0,7	2,1	0,3	0,1	0,7	0,1	0,1	0,1	0,0	0,1	0,1	1,2	0,6	0,0	4,0	0,3	0,5	7,3	18,8
TOT	18,8	25,2	27,5	6,0	1991,1	212,4	26,1	46,2	268,7	100,5	48,7	33,2	3,8	88,1	46,0	252,8	281,5	22,3	69,4	75,4	126,6	10,8	3800

Note: Emissions reported here include emissions from the production of iron and steel, including for steel traded in other manufactured goods. Numbers also include emissions in power and heat generation used by the iron and steel sectors. "O As": Asian countries other than China, India, Indonesia, Japan, South Korea; "O Eur": other European countries; etc. Deeper red cells indicate a high level of traded emissions.

[9] For more data: https://www.netzerotrade.org/s/Publication_embodied_emissions_carbon-intensive_compressed.pdf

Iron and steel. More than a third of iron-and-steel related GHG emissions end up traded (1,322 $MtCO_2e$ out of 3,800 $MtCO_2e$). China leads in exported emissions, mostly to neighbour Asian economies (167 Mt), the US (106 Mt), the Middle East (62 Mt) and the EU (58 Mt). Russia is also a non-negligible “GHG exporter”, accounting for 20% of the total.

The data reflects the GHG emissions triggered abroad by trade in both finished and unfinished goods. For example, many markets outside of Asia are relatively closed to imports of Chinese steel. Since 2018, the US has applied tariffs on imports of Chinese steel consistently in the range of 25%, in addition to targeted anti-dumping tariffs and countervailing duties. All measures combined, EU tariffs on imports of Chinese steel can be as high as 74%. Nonetheless, both continue to import manufactured goods from China containing steel, thereby triggering Chinese production and emissions.

Chemicals display a higher share of embedded emissions, at 45% (525 $MtCO_2e$) with China still in the lead, but with the Middle East as another important producer and exporter of fertilisers.

Embodied emission flows show a different, more diverse pattern on **animal food products** and **other agricultural products** with nearly a quarter of emissions embodied in imports, amounting to a staggering 1.7 $GtCO_2e$ of emissions embodied in trade *(Table 2).* A group of countries and regions tops the list of imported emissions: China, the Middle East, the US, Japan and South Korea. Lead exporters are Brazil, the rest of Latin America, India, or Australia.

Table 2 : Heat map of GHG emissions embodied in traded animal food products ($MtCO_2e$). Source: Dugast 2025.

Consuming countries →

Producing countries ↓

	Austr	Brazil	Cana	China	EU27	UK	Indo	India	Japan	S. Kor.	Mex	Russ	Turk	US	O As	O Eur	O Afr	O Lat	Mid. East	S. Afr.	TOT
Austr	19,4	0,3	0,6	22,0	3,0	0,5	8,0	0,8	8,7	6,3	0,2	0,7	0,2	9,4	13,2	0,1	0,3	0,4	3,7	0,1	**98**
Brazil	0,3	298	0,2	95,3	5,7	0,5	0,3	1,5	1,2	0,7	0,3	1,7	2,5	4,3	24,7	0,3	2,0	10,9	29,0	0,2	**480**
Cana	0,1	0,1	32,7	2,0	1,2	0,2	0,1	0,1	1,8	0,7	0,7	0,1	0,1	15,6	1,4	0,1	0,1	0,3	0,5	0,0	**58**
China	0,3	0,2	0,3	352	2,4	0,4	0,2	0,5	1,5	0,6	0,2	0,2	0,1	2,5	4,8	0,1	0,4	0,6	1,1	0,1	**369**
EU27	1,3	1,2	1,3	12,7	289	16,6	0,5	1,8	2,9	1,9	1,0	1,7	2,7	10,2	8,8	2,3	7,9	2,6	13,4	0,4	**384**
UK	0,3	0,1	0,2	0,8	8,9	32,3	0,0	0,2	0,3	0,1	0,1	0,1	0,1	1,2	1,0	0,1	0,3	0,3	0,9	0,1	**47**
Indo	0,0	0,0	0,0	0,3	0,5	0,1	57,8	0,1	0,2	0,1	0,0	0,0	0,0	0,3	0,5	0,0	0,0	0,1	0,1	0,0	**60**
India	0,6	0,9	0,5	4,8	7,1	1,3	0,4	229	1,0	0,7	0,6	0,4	0,5	9,8	32,0	0,3	2,4	1,8	44,2	0,2	**340**
Japan	0,0	0,0	0,0	0,2	0,1	0,0	0,0	0,0	14,6	0,0	0,0	0,0	0,0	0,1	0,4	0,0	0,0	0,0	0,0	0,0	**16**
S. Kor.	0,0	0,0	0,0	0,2	0,1	0,0	0,0	0,0	0,1	12,8	0,0	0,0	0,0	0,1	0,2	0,0	0,0	0,0	0,0	0,0	**14**
Mex	0,1	0,1	1,3	1,1	1,4	0,2	0,1	0,1	2,7	1,6	50,8	0,1	0,1	36,8	1,4	0,1	0,1	1,1	0,3	0,0	**99**
Russ	0,1	0,0	0,1	1,9	1,1	0,1	0,0	0,1	0,2	0,5	0,0	78,1	0,1	0,4	3,5	1,0	0,2	0,1	0,5	0,0	**88**
Turk	0,1	0,1	0,2	0,8	4,9	0,8	0,1	0,5	0,3	0,2	0,1	0,8	32,0	1,5	1,8	0,4	1,7	0,3	7,7	0,1	**54**
US	0,6	0,6	8,7	8,0	7,0	1,6	0,8	0,8	11,2	12,5	9,3	0,2	0,3	306	10,6	0,2	0,6	6,2	4,1	0,1	**391**
O As	2,2	0,4	2,1	45,0	7,7	1,9	1,2	3,4	6,8	3,1	0,4	0,9	0,5	24,2	423	0,2	1,9	1,2	11,1	0,1	**539**
O Eur	0,1	0,1	0,1	2,1	3,1	0,4	0,1	0,3	0,2	0,1	0,1	9,4	0,2	0,6	4,1	22,2	0,3	0,2	1,6	0,0	**45**
O Afr	0,4	1,3	0,5	4,7	16,7	1,7	0,4	2,2	0,8	0,6	0,4	0,6	0,6	5,3	2,6	0,5	903	0,8	10,5	3,5	**959**
O Lat	0,4	10,2	1,9	75,2	15,5	1,3	0,4	1,9	2,0	1,1	2,5	6,6	3,6	24,5	5,1	0,3	5,4	234	17,9	0,3	**411**
Mid. East	0,1	0,2	0,1	1,4	1,6	0,4	0,1	0,8	0,2	0,2	0,1	0,3	0,2	1,3	1,5	0,1	2,5	0,2	92,1	0,1	**103**
S. Afr.	0,1	0,0	0,0	0,9	0,9	0,1	0,0	0,1	0,1	0,0	0,0	0,0	0,0	0,3	0,3	0,1	2,8	0,1	1,3	26,4	**34**
TOT	**26**	**314**	**51**	**632**	**379**	**61**	**70**	**244**	**57**	**44**	**67**	**102**	**44**	**455**	**541**	**28**	**932**	**261**	**240**	**32**	**4600**

Aluminium is another very heavily traded and highly GHG-intensive product, including through its intensive use of electricity; about half of its 1 $GtCO_2e$ of emissions end up in traded products. The main exporters are China, the Middle East, Australia, Russia, India and South Africa, with most of other countries of the world being net importers of emissions from aluminium. Some countries that are important aluminium producers are off the radar because their low-carbon electricity significantly lowers the carbon footprint of their production and exports. Provided they have flexibility to increase volumes, these producers could be winners once a GHG premium is applied to aluminium products—and notably to cleaner electricity sources.

Table 3: Share of emissions embodied in traded products–key sectors. Source: Dugast 2025.

Sector	Total GHG (Mt CO_2e)	Embodied in trade (Mt CO_2e)	Share
Iron and steel (incl. Electricity)	3 800	1 322	35%
Aluminium (incl. Electricity)	1 002	513	51%
Chemicals	1 173	525	45%
Animal food products*	4 600	1 084	24%
Other agricultural products*	3 083	696	23%
Textiles	138	73	53%
Mining	70	22	31%
Electricity	12 314	2 483	20%

* Emissions in land-use sectors do not include possible emissions from land-use change.

The traded emission heat maps reflected here provide an immediate picture of regions' co-dependences on a sectoral basis. The question is whether this become the basis for a conversation on mitigation action that goes beyond what individual parties are ready to do. At the very least, it should help countries understand how much their mitigation efforts are also tied to the rest of the world, because a country's surge in demand for GHG-intensive product is a trigger for higher emissions somewhere else. Obviously, the interest of two trading partners to engage in a mutual effort to reduce emissions will also take into consideration their respective competitive positions, their ability to mobilise resources for mitigation or regulatory change, and implications for domestic markets.

III. Towards an international discussion on how to abate embodied emissions

One can envision several steps, showing different levels of political commitment, to co-operate on the abatement of embodied emissions.

A. Sharing data

First and absolutely central to this and many other policy questions is the measurement of embodied emissions. The data we showed here should be shared and fully owned by trade partners to ensure a mutual understanding of the magnitude of embodied emissions, and of a possible common interest in mitigation. Only then can partners share policy insights on how to best contain emissions from, say iron and steel, or chemicals. This can re-open the door of sectoral approaches that were briefly considered around the Copenhagen COP 15 (2009). A common and objective look at the data could also serve to alleviate other concerns, for instance on the question of carbon leakage. It is encouraging to hear that Climate Club members have looked at this important dimension of climate ambition. At this stage, a pool of statistical information and research on trade flows and policies could go a long way into either confirming or demystifying carbon leakage risks. We do not have time to encourage and then hamper carbon pollution havens: it is high time for an independent international carbon leakage observatory.

Precisely on this topic, the BRICS group of countries launched a "Laboratory for Trade, Climate Change and Sustainable Development"; it seeks to facilitate, among others "strategic, evidence-based collaboration to maximise the benefits and minimise drawbacks of [hybrid trade and climate] measures" and "assessments of the cross-border impacts, implications and costs of unilateral trade measures [...]" Further, the BRICS Lab will be "supporting the use of modelling tools for identifying, quantifying, analysing and projecting the economic, social and environmental impacts of hybrid measures". The BRICS Lab should primarily inform its member countries. Tracking actual carbon embodied in trade maybe of interest to the BRICS members, including to understand their climate co-dependence with the rest of the world, from carbon leakage risks to possible areas of co-operation (BRICS 2025).

B. Setting targets on embodied imported emissions

Second, some countries could decide to set mitigation targets that include their imported emissions, with the ambition to engage trading partners in the conversation, including to provide technical, regulatory or financial assistance to facilitate their mitigation actions. A group of countries bound by international trade flows would need to sit down and go through their co-dependences to be able to adjust each other's mitigation goals to their partners' efforts. Without going through such complexity from the start, individual countries, presumably the more economically advanced, could approach their trade partners with an offer to support mitigation in their most carbon-intensive exporting activities. This would also help "exporting" countries to meet or surpass their NDCs. The embodied emissions heat maps used in this paper can jumpstart such an effort by guiding countries in the identification of their most GHG-intensive trade partners.

The EU and China could take the leadership of this effort, together with other willing countries or regions. Given their combined weight in terms of imported and exported emissions and their climate ambition, joint action could create an international momentum to contain emissions embodied in trade. A strong signal in this direction would be a joint announcement on mitigation objectives pertaining to their imported emissions for 2030 or 2035, and a roadmap to tackle this issue.

IV. Policies and measures targeting embodied emissions

The question of embodied emissions can appear abstract up to the point where we ask: how can countries effectively abate these emissions? Assuming there is political will for such a move, what policy instruments could be brought to bear, and what issues could they raise?

A. Co-operation on policy approaches

Two trading partners with similar sectoral interests could share mitigation policy practices, with a few of facilitating trade in decarbonised products. Note that this should not imply similar levels of mitigation effort.

The policy spectrum could go from common measurement of products emission intensity to facilitate trade and allow a better monitoring of mitigation actions, to common policies. These can include sectoral GHG-intensity performance objectives, with varying degrees of intensity, and different tools to get there—from mandatory performance requirements or standards to cap-and-trade.

In pursuing this path, partners will need to take stock of whether their pre-existing commitments and agreements allow them to implement policies to reduce embodied carbon. Bilateral investment treaties, for instance, can sometimes contain prohibitions on performance requirements that make it harder for governments to enact policies that promote pollution control, environmental preservation, or social progress.[10]

There are multiple fora, from academic to more official, that promote ambitious mitigation action, including the Climate Club, the OECD Inclusive Forum on Carbon Mitigation Approaches, the World Bank Partnership for Market Implementation, the International Energy Agency, the many co-operative initiatives formed under the Glasow Breakthrough Agenda or the above-mentioned BRICS Lab. All can provide essential information on good policy practice to implement sectoral or cross-sectoral policies.

Taking this a step further, countries could also decide to allocate part of their international climate finance towards mitigation in sectors that are highly emitting and account for much embodied carbon. There certainly will be instances where a country's official development assistance could not be used to subsidise another country's competing industry: it is hard to imagine the EU financing China's steel industry decarbonisation effort, but it is conceivable—and probably already happening—that the two governments would compare notes on monitoring carbon emissions in steel and on their respective emissions trading systems.

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[10] See for instance: 5.4.3 Performance Requirement Prohibitions – A Sustainability Toolkit for Trade Negotiators

B. Unilateral measures

Countries worrying about their carbon footprint and in particular emissions embodied in imports have different policy measures at their disposal to mitigate these. Article 3.5 of the UNFCCC issues a warning, however: "Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade". They should also not contravene the rules of the WTO, recognising that not all countries are committed to their observance and that there are voices that question the adequacy of its rulemaking with our collective sustainable development goals.[11]

There is a range of policies that inadvertently or explicitly impact embodied emissions.

- A jurisdiction can adopt a GHG-performance standard for products sold on its market, in the same way that it would apply a minimum energy performance standard to electric appliances. Imported products in this category would have to report on their GHG performance to gain access. Performance standards could be introduced first in public procurement to create a lead market, and stem competition for innovative producers in need of a "green premium" to be able to invest in low-carbon production. While this should lead to lower embodied emissions, it need not lower imports, provided the market remains open to foreign innovators—one can think of producers in the US which no longer benefit from incentives to reduce emissions at home. Standards are also important if they allow other jurisdictions to identify the carbon content of imported goods, even if they have not yet adopted measures to limit them. It would make the embodied carbon dimension of goods more visible to governments and private sector actors, even before a certain level of GHG performance is demanded. A country that does not produce steel could still have precise information on embodied carbon in steel imports, thanks to trade partner's labelling obligation. Under its Clean Industrial Deal, the European Commission proposes to adopt GHG performance labelling to accelerate low-carbon product uptake. This could be a promising area for bilateral or plurilateral technical co-operation.

- Border Carbon Adjustments (BCAs), like the EU CBAM, are distinct from performance standards in the way they regulate embodied carbon—through a price and not a performance constraint. A priori, the legitimacy of the instrument rests on 1) the use of an actual carbon pricing instrument to curb domestic emissions, and 2) on a concrete risk of carbon leakage. Jurisdictions with substantial trade flows in the covered sectors can team up to harmonise their approach, essentially through, again, a common method to assess embodied emissions. Beyond, an adjustment may still be necessary if domestic carbon prices differ.[12] We can only encourage countries that intend to use them to co-operate and set a common standard on the measurement of carbon embodied in

[11] See for instance: The Villars Framework for a Sustainable Global Trade System — Remaking the Global Trading System for a Sustainable Future Project

[12] While we should not dismiss efforts to link carbon markets and apply a single carbon price, it is easy to see how different levels of ambition in NDCs can lead to heterogenous carbon prices, and that individual jurisdictions may want to remain in control of their own.

products. The Climate Club can help progress in this area by encouraging policy harmonisation.

- A sectoral look beyond heavy industry indicates other areas for co-operation. Large importers of embodied carbon food products like China and EU could work with other importers (India, Japan, South Korea for instance) that have a correspondingly high GHG footprint in their partners in Latin America or the rest of Asia. Other groups of countries may follow the lead of the Climate Club on industry to create similar conversations on land-use related emissions in trade.

All of the above policy initiatives will have to address countries' different starting points, respect the CBDR-RC principle, and ensure that least developed countries that need to implement new policies and measures can be equipped to take part equitably, or receive support to build capacity.

Overall, it is important to reiterate that so-called unilateral measures, provided they are not mere protectionist manoeuvres, intend also to strengthen domestic mitigation measures and give a robust signal to economic actors about the country's low-carbon pathway. At the time where the US, a major GHG emitter, has left the Paris Agreement but subnational governments and private sector entities want to continue their efforts to reduce emissions, it is important that international markets be left open to them. Setting clear and fair conditions for market access is therefore essential. Further, sub-national entities, including US states, who wish to do so, can play an important role in their imported emissions by reinforcing policies they have already put in place (law on imported deforestation for public procurement in the State of New-York, "mirror measures" in California on livestock, or carbon pricing of industrial emissions).

V. Are current trade instruments fit for purpose?

Embodied emissions are an important part of the global climate mitigation challenge, but also critical markers of countries co-dependences. Unfortunately, bilateral discussions on trade agreements or investment protection to date contribute more to increasing embodied emissions than the opposite.

Free trade agreements (FTA) aim to facilitate trade in all goods and services regardless of their carbon intensity, and even though chapters on environmental aspects have appeared in recent years, they remain largely non-binding. Further, FTAs create a space for dialogues to facilitate trade by removing barriers, which may affect environmental regulations. At the very least, there is no example to date of an FTA that would facilitate trade while reducing embodied carbon at the same time. The Agreement on Climate Change, Trade and Sustainability is a first and commendable attempt to combine trade co-operation with ambition on climate and sustainability, even if its geographical reach is still limited.

Reducing embodied emissions necessarily requires revisiting these bilateral agreements to avoid having them increase embodied emissions that would later need to be undone through stronger climate action. The time to bring emissions to zero is too short, and lowering tariffs on GHG-intensive products does not help in that regard.

VI. Setting a pragmatic way forward

Current Nationally Determined Contributions (NDCs), countries' emission pledges under the Paris Agreement, are not on track with limiting the global temperature increase to 1.5°C. No stone can be left unturned in our efforts to curb emissions, all the more so as the second largest emitter is rolling back its climate policies. Trade is one stone that needs turning now. Emissions related to traded products represent nearly one quarter of global GHG, excluding deforestation. Because of this co-dependency across economies ("my imports are your emissions"), I posit that co-operation on trade and climate could facilitate further mitigation. The recent EU-US trade framework sends a different signal, however, that a trade agreement can be a trojan horse to undo our climate ambition. It is high time we look at how we can use our trade relations for a better, not worse, climate outcome.

Combining the latest trade and GHG data draws an interesting map of the main cross-country flows of embodied emissions. The threat of carbon leakage and the product coverage of the EU CBAM put the focus on trade in energy and carbon-intensive industrial goods. Our data shows an even larger footprint of heavy industry through the steel, aluminium, etc. content of other manufactured products once they are traded. As an example, in 2022, the EU27 and Japan's overall imports from China triggered 58 and 22 million tonnes of $MtCO_2e$ in China's iron and steel making (including from electricity use in that sector). And China's demand for meat and agriculture products led to 107 $MtCO_2e$ and 84 $MtCO_2$ of direct emissions in Brazil and the rest of Latin America, respectively – excluding land-use change emissions, difficult to attribute to specific activities (Dugast 2025).

As countries implement more stringent mitigation measures, they are becoming aware of their international greenhouse gas footprint, and it may not be long before we see countries adopting mitigation goals that encompass traded emissions. Countries have a number of options to engage their trade partners, from a mutual understanding of embodied emissions to regulatory co-operation, or the targeting of climate finance to sectors with high domestic and international footprints. Under more auspicious skies, the G20 would be an ideal place to discuss "embodied emissions". At this point in time, the Climate Club could lead by example with such a co-operative agenda. The EU and China, both leaders in climate action, could set the tone in this area, notwithstanding present trade tensions. China is a large exporter of embodied carbon to its Asian neighbours, the United States, the EU27, or Japan, but also a large importer of embodied carbon.

As a first step, bilateral or plurilateral co-operation, with the potential for strong leadership by the Climate Club, can seek to gather a critical mass of countries interested in measuring and understanding the magnitude of carbon embodied in traded goods. Initiatives in carbon accounting abound now and major economies could provide the co-ordination that seems needed to bring a universal carbon accounting standard across the finish line.

Co-operation is also needed on so-called unilateral measures, i.e. policy instruments that change the conditions of market access for foreign producers as a country takes certain climate action. A new CO_2 standard on cars should apply to domestic and foreign car manufacturers in the same way; and should a label on the carbon content of steel products, aluminium, cement or chemicals—provided it pursues GHG mitigation and is not a hidden trade barrier. On the contrary, the sharper market-making measures like labels are, the more they should attract foreign low-carbon innovations. A common "language" on GHG-content of traded goods would only help the global mitigation effort.

An important step towards reducing embodied emissions would be for a group of countries to commit individually to curb their imported emissions, an effort that would also support trade partners mitigation efforts at home. Such commitment could be a voluntary addition to countries' NDCs or to their long-term strategies. The Climate Club could be a platform that encourages its members to act in this area, and Europe could take the lead on this, alongside other countries.

At this stage, trading partners would gain objectivity and serenity in sharing analysis on the reality and risk of carbon leakage: What do they trade and what is the magnitude of embodied carbon in trade? What is driving changes in trade flows? Can these changes be tracked back to climate policies or other competitive advantages? Are their policies to prevent carbon leakage legitimate? It is a good sign, when more countries consider carbon pricing and border carbon adjustments in the same breath, that both the Climate Club (Climate Club 2024) and the BRICS Laboratory for Trade, Climate Change and Sustainable Development (BRICS Brazil 2025) work on this topic.

If global co-operation on climate policy approaches appears to be complicated by the ongoing race to compete on low-carbon products and technologies, a carbon content lens on trade has the potential to bring policymakers together to achieve mutual mitigation gains. The Climate Club is an ideal forum to identify topics for progress in this area.

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6 A path to a heavy-industry climate coalition

Kimberly Clausing, Axel Ockenfels and Catherine Wolfram[13]

Abstract

The U.S. decision to leave the Paris Agreement highlights the challenges of advancing collective climate action through consensus alone. Recognising the limitations of existing international frameworks, such as their susceptibility to free-riding and lack of enforcement, our contribution discusses how to establish a targeted "Heavy-Industry Climate Coalition." This coalition would focus on emissions-intensive industries such as aluminium, iron, steel, cement, and fertilisers. It would encourage participation through co-ordinated carbon pricing and carbon border adjustments, paired with mutual agreements on technology sharing, market access, climate finance and measurement, reporting and verification.

I. Introduction

Domestic economic challenges, geopolitical shifts, and mounting trade disputes are shrinking the political space for effective national climate policies. Moreover, while individual nations bear the full costs of their climate policies, including the expenses associated with energy transitions and the effects of higher energy prices on their competitive industries, most of the benefits of these policies accrue to the global community. Current international climate agreements, which are based on collective targets and Nationally Determined Contributions (NDCs), do not adequately address the free-rider challenge (UNFCCC 2023). An action by a group of countries willing to make progress together—a climate coalition—is essential in this regard (Nordhaus 2015; Cramton et al. 2017). This chapter proposes a "Heavy-Industry Climate Coalition" as a complementary approach to the Climate Club described in Chapter 1 of this report; indeed, the Climate Club could be a useful forum for furthering this type of international collective action.

The coalition would bring together countries willing to co-ordinate on carbon pricing. Initially, the focus would be on a few key industrial sectors, with the intention of expanding over time. Member

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countries would commit to pricing industrial carbon emissions within their borders and applying Border Carbon Adjustments (BCAs) to imports from non-member countries. Additional countries would be incentivised to join through complementary incentives, such as access to low-carbon technologies, climate finance, regulatory capacity support, and preferential market access.

The Global Climate Policy Project has convened a working group of global thought leaders representing many of the world's major emitting countries to help governments develop and implement a climate coalition. The working group's deliberations build on earlier discussions regarding multilateral co-ordination on carbon pricing, including the Climate Club, international organisations such as the International Monetary Fund (IMF), World Trade Organisation (WTO) and the Organisation for Economic Co-operation and Development (OECD) (IMF et al. 2024; IMF and OECD 2021), and the Coalition of Finance Ministers for Climate Action (www.financeministersforclimate.org). They also reflect growing interest in regional carbon pricing and BCA initiatives beyond Europe, such as the Asia-Pacific (Climate Energy Finance 2025; Rahut et al. 2025). This chapter summarises the working group's proposal, as described in Global Climate Policy Project (2025).

II. Climate coalition design principles

According to the framework developed by the working group, coalition members would agree on and implement a carbon price floor for emissions from the most trade-exposed heavy industries. Unlike current international climate agreements, which are based on collective emissions targets and NDCs that do not adequately address the free-rider challenge, a common price agreement offers several advantages, including effectiveness, comparability of efforts, flexible implementation as tax and Emission Trading Systems (ETSs), and relatively straightforward measurement and monitoring. Incentives to join and remain in the agreement are buttressed through mechanisms such as BCA and other incentives including technological transfer and the use of international climate funds (Clausing and Wolfram 2023; Cramton et al. 2017; Kornek and Edenhofer 2020).[14] The reciprocity inherent in the common price agreement is essential for co-operation and has indeed been a helpful factor in the success of other international agreements, ranging from minimum corporate taxes to trade and disarmament (Ostrom 1990; MacKay et al.

[14] Emissions trading systems (ETS) are designed as quantity-based instruments that control aggregate emissions through a fixed cap, allowing prices to fluctuate naturally. Within the framework of an international carbon price agreement, these systems require explicit mechanisms to adjust the emissions cap in response to price signals to maintain agreed-upon price floors. Although economic analyses have identified theoretical advantages of direct carbon taxation over quantity-based cap-and-trade systems, particularly regarding price certainty and minimising policy errors under uncertainty (Goulder and Schein 2013), emissions trading can retain distinct advantages such as political feasibility. An ETS also provides a mechanism for implicit transfers to developing countries through differentiated initial allowance allocations that do not distort the marginal price signal. A key strength of carbon price agreements is their institutional flexibility to accommodate both pricing approaches. Moreover, a growing body of theoretical and empirical literature suggests that international negotiations focused on harmonised carbon price floors are substantially more feasible than negotiations that attempt to allocate country-specific emissions budgets (Weitzman 2014, Nordhaus 2019, Schmidt and Ockenfels 2021, Miettinen and Ockenfels 2025).

2015; Clausing 2024). Reciprocity protects co-operators from potential exploitation and fosters an environment conducive to co-operation.

The proposed climate coalition can leverage the substantial global momentum of carbon pricing implementation. Current pricing mechanisms have achieved remarkable geographic and economic coverage. Currently, 80 carbon tax and ETSs operate across 50 jurisdictions. These systems encompass approximately 28 percent of global greenhouse gas emissions and generate revenues exceeding $100 billion (Global Climate Policy Project 2025). Jurisdictions implementing carbon pricing mechanisms now represent nearly two-thirds of global gross domestic product. All major middle-income economies have either operationalised or initiated the development of pricing schemes. For heavy industries, over 80 percent of emissions are covered by either an existing or a planned carbon price.

The variety of existing national approaches shows the adaptability of carbon pricing to different economic situations and the potential benefits of harmonisation; both flexibility and comparability are important. Selected design variations include: Australia's baseline-and-credit mechanism for industrial facilities, Brazil's integrated national market combining industrial emissions coverage with forest-based offset provisions, Canada's hybrid federal-provincial framework establishing minimum stringency standards while preserving subnational implementation flexibility, and China's output-based ETS, which is currently the world's largest by coverage; India's emissions intensity trading scheme, which is calibrated to accommodate continued economic growth; Indonesia's sectoral approach, which links power-sector emissions trading with a planned economy-wide carbon tax; Thailand's transition from narrow fuel excise taxation to comprehensive industrial coverage; and emerging African initiatives, which explore carbon pricing as an instrument for enhanced fiscal sustainability and climate resilience.

While this proliferation development of diverse pricing mechanisms demonstrates political feasibility and institutional innovation, it also underscores the efficiency losses and some downsides from fragmentation. A climate coalition could transform these disparate national experiments to allow a more co-ordinated and much more effective pricing regime that would capture the efficiency gains from harmonisation, mitigating leakage and free-riding, while still preserving the design flexibility that enabled broad adoption across diverse economic contexts.

That said, co-operation and enforcement mechanisms evolve incrementally. Initially, the focus of a climate coalition will be on carbon-intensive industries such as iron and steel, aluminium, cement, and fertilisers, with the intention of expanding over time. These industries offer a combination of large, measurable emissions from concentrated production in large plants, acute trade exposure, existing (yet fragmented) pricing regimes and data infrastructure, and politically palatable consumer impacts (discussed below). This makes heavy industry a natural starting point for the climate coalition. Coalition members would commit to pricing carbon emissions from these industries within their borders and applying BCAs to imports from non-member countries. They would also offer incentives to encourage broad participation, such as support for low-carbon technologies, climate finance, and market access.

To summarise, the overall framework is guided by six coalition design principles, which are listed briefly here and described in more detail in Global Climate Policy Project (2025).

The first is *self-reinforcement*. A reciprocal, common agreement ensures that membership is in each country's economic interest and robust to changes in domestic politics.

A carbon-price floor, negotiated and agreed upon by coalition members, delivers *efficiency*. The floor aligns economic incentives with climate goals by internalising the environmental cost of emissions and steering investment toward low-carbon processes. It also generates fiscal revenue that can be recycled into transition assistance or general budgets.

Fairness is incorporated through obligations and incentives that reflect common but differentiated responsibilities. Low- and middle-income participants could be offered a lower entry-level price floor that increases over time to reach the common price, or they could receive a higher share of free allowances during an initial transition period.

Pragmatism guides the launch strategy. Rather than starting with economy-wide coverage, the coalition initially targets four upstream, emissions-intensive, and highly traded materials (iron and steel, aluminium, cement, and fertiliser).

To ensure *integrity*, similar carbon-related costs must apply to firms in member countries and to goods imported from firms in non-member countries. This can be enforced through BCAs. Goods from non-member countries entering the coalition's market will pay a charge equal to the difference between the coalition's floor price and the carbon price already embedded in the goods. Goods traded within the coalition will circulate freely. This arrangement maintains competitiveness for member producers, reduces emissions leakage, and creates incentives for other countries to adopt comparable pricing and join the coalition.

Credibility requires rigorous measurement, reporting, and verification.

Together, these principles establish a framework that provides immediate economic value to participants, sends a technological and financial signal for decarbonisation, and offers a mechanism for gradual expansion. This addresses the longstanding incentives and equity concerns that have hindered global climate co-operation.

III. Scenarios and quantitative predictions

In Global Climate Policy Project (2025), the working group uses two global trade models to analyse the economic implications of the coalition concept. This approach ensures robustness through methodological diversity. The analysis examines three distinct policy scenarios to evaluate the coalition's potential impact on emissions, revenues, production, and prices. In all scenarios, carbon pricing is limited to four emissions-intensive, trade-exposed industries: iron and steel, aluminium, cement, and fertiliser.

The *Current Policy* baseline reflects existing carbon pricing arrangements, with industrial carbon pricing limited to the European Union (EU), the United Kingdom (UK), and the EU's economically integrated neighbours. A $50 per ton of Carbon dioxide (CO_2) carbon price and BCA is assumed.

The Uniform Price scenario establishes a coalition-wide minimum carbon price of $50 per ton of CO_2. The coalition comprises a diverse group of members, including the EU, European Free Trade

Association (EFTA), the UK, Australia, Canada, Brazil, China, India, Indonesia, and nine lower-income economies from Africa.

The Graduated Price scenario maintains the same coalition membership but implements differentiated price floors calibrated to economic development levels: $75 per ton of CO_2 for high-income countries, $50 for upper-middle-income countries, and $25 for lower-income countries. Additionally, this scenario features a universal $75 per ton of CO_2 border charge applied to imports from non-participating jurisdictions. This creates stronger incentives for coalition expansion while accommodating development considerations.

The model outcomes show that the climate coalition has transformative potential for industrial decarbonisation. Both the Uniform Price and Graduated Price scenarios achieve emissions reductions approximately seven times greater than the Current Policy baseline. This indicates that co-ordinated action strongly amplifies mitigation effectiveness compared to unilateral measures.

Carbon pricing under coalition scenarios also generates substantial fiscal resources, with annual revenues approaching $200 billion under both pricing structures. These revenues accrue across the full spectrum of participating economies, from high-income to developing countries, creating opportunities for climate finance and just transition investments.

On the other hand, coalition members experience only moderate price increases in targeted industries, with impacts varying by sector and modelling assumptions. Price effects are modest, although price increases are higher (5-23 percent) in models that incorporate trade frictions. The price signals incentivise emissions reductions while remaining within bounds that allow for manageable adjustment.

Also, despite carbon pricing, industrial output remains stable within coalition countries. Modelled production declines for aluminium, cement, fertilisers, iron, and steel remain below 2 percent for coalition participants. This suggests that, when implemented multilaterally, co-ordinated carbon pricing need not trigger industrial decline.

Finally, the Graduated Price scenario shows promise in supporting continued economic development in lower-income countries. In models that incorporate trade frictions, industrial output increases for low- and lower-middle-income coalition members under graduated pricing relative to the current policy scenario. These countries are often characterised by less emissions-intensive production processes and capture competitive advantages through the BCA.

Overall, the quantitative analysis in Global Climate Policy Project (2025) shows that a broad climate coalition based on carbon pricing for emissions-intensive industries can provide significant environmental benefits while maintaining economic viability. Additionally, generating nearly $200 billion in annual revenues, distributed across diverse economies, creates fiscal space for climate adaptation, just transition programs, and sustainable development investments.[15] The moderate impacts on production and prices, coupled with the potential for

[15] Nearly all revenues stem from the domestic carbon price; border adjustment revenues are comparatively quite small.

lower-income countries to gain competitive advantages under graduated pricing, suggest that carefully designed coalition arrangements can reconcile climate ambition with economic and political imperatives.

IV. Political Feasibility of a Climate Coalition

The political feasibility of a climate coalition is subject to legitimate scrutiny, especially in light of the controversial reception of existing unilateral BCAs. Low- and middle-income countries have expressed significant concerns about the EU's Carbon Border Adjustment Mechanism (CBAM), citing insufficient consultation and the imposition of standards set outside of their control. These concerns could readily extend to coalition-based carbon pricing, where uniform price requirements might perpetuate the perception of inequitable burden-sharing, despite the favourable modelling projections in the last section.

While the graduated pricing structure is aligned with the United Nations Framework Convention on Climate Change (UNFCCC) principle of common but differentiated responsibilities and capabilities and acknowledges the varying marginal abatement costs of different economies at various stages of development, it creates other potential friction points. High-income producers may resist competitive disadvantages compared to lower-priced jurisdictions, and negotiating price tiers could lead to disputes over classification criteria and transition timelines. Considering these and other challenges, Global Climate Policy Project (2025) propose design choices to ease such tensions, grounded in evidence, designed to be practical and financially sustainable, and expanding upon earlier frameworks by Cramton et al. (2017) and others.

The carbon price agreement could incorporate sunset clauses that automatically increase lower-tier carbon prices as countries' per capita incomes rise. Additionally, exports from lower-tier countries could be subject to the importing country's higher carbon price, maintaining competitive neutrality while preserving domestic policy space for gradual industrial transformation.

In addition, revenue recycling and transfers within an integrated carbon market could address distributional concerns more elegantly than price differentiation alone. Free allowance allocations or direct revenue transfers between coalition members could compensate for disparate economic impacts while maintaining uniform price signals. While potentially more difficult practically, this could simplify administration and reduce opportunities for carbon leakage through price arbitrage.

Also, current international climate finance mechanisms—including the Green Climate Fund, the Adaptation Fund, and bilateral initiatives—operate largely independently of recipient countries' mitigation commitments (UNFCCC 2021; Weikmans and Roberts 2019). This disconnect represents a missed opportunity to leverage finance to incentivise participation in co-ordinated climate action: linking financial transfers to coalition membership could create mutually reinforcing benefits (Kornek & Edenhofer 2020). Developing countries would receive compensation for implementing ambitious climate policies, which would reduce free-riding incentives. Meanwhile, donor countries would gain assurance that their contributions would directly enhance global emissions reductions rather than merely substitute for domestic efforts.

The coalition's revenue potential provides a robust foundation for such conditional transfers. The modelling by Global Climate Policy Project (2025) projects approximately $170 billion in annual carbon pricing receipts from high-income members and China alone. Allocating even a modest fraction of these revenues to international support, mirroring the EU's practice of earmarking ETS revenues for innovation and just transition funds, could finance substantial technology deployment and social protection programs in developing member countries.

Similarly, while maintaining policy credibility demands stringent safeguards, a carefully designed offset mechanism could serve multiple coalition objectives, such as broadening membership appeal, mobilising private capital, and monetising natural climate solutions in countries with abundant, low-cost mitigation potential. Allowing producers or importers to meet a limited portion of their carbon pricing obligations through high-integrity credits from projects in other member countries, particularly forest-rich nations like Brazil or Indonesia, could reduce compliance costs while generating conservation finance.

Incorporating low- and middle-income countries is critical to the coalition's long-term effectiveness and legitimacy. Broad-based participation enhances market power for setting global industrial standards, amplifies network effects that make membership more attractive than non-participation, and accelerates the pace of global decarbonisation through expanded coverage. Achieving broader membership requires policy frameworks that extend beyond BCAs. For example, the climate coalition could eliminate tariffs and non-tariff barriers on agreed-upon lists of clean technologies and environmental goods, reducing capital costs for industrial transformation. Technology co-operation and transfer mechanisms could include co-ordinated research agendas that address the priorities of developing countries, the harmonisation of technical standards to facilitate market access, and the allocation of pooled carbon revenues to joint demonstration projects that prove commercial viability in diverse contexts. Intellectual property frameworks, including voluntary licensing arrangements, patent pools, and standardised joint venture templates, could reduce legal uncertainties and transaction costs. Domestic policy support through coalition-funded technical assistance could help members design and implement complementary policies, such as feebates, tax credits, and green public procurement programs. The Climate Club's efforts discussed in Chapter 1, among other efforts, exemplify such collaborative approaches.

We caution, however, that it is important to recognise that co-operation and enforcement mechanisms evolve incrementally. Although the ultimate objective is expansive membership at ambitious price levels, initiating co-operation among three or four major emitters, such as China, India, Brazil, and the EU, at relatively moderate carbon prices would be a significant achievement in global climate governance. This foundation could then expand through demonstration effects and increasing returns to participation.

More generally, the value of a multilateral agreement should be judged not on its immediate impact but on its potential to dynamically change the landscape of co-operation in an area of inadequate, fragmented and asymmetric climate policies. A global, ambitious carbon price may take time to become feasible, but striving to improve co-operation and mitigate free-riding is beneficial, imperative – and possible.

V. The path forward

The contemporary international landscape is characterised by escalating geopolitical tensions and resurgent economic nationalism. These forces create substantial uncertainty for multilateral co-operation at a time when climate change necessitates unprecedented co-ordination. Despite—and indeed because of—these centrifugal forces, the imperative for collective climate action and preventing free-riding persists. Rather than allowing divergent national interests to impede climate progress, policymakers must identify institutional mechanisms that can accommodate diverse national circumstances while maintaining environmental integrity.

The climate coalition framework outlined in this chapter provides a pragmatic approach to overcoming the impasses that have historically hindered international climate negotiations. By reframing co-operation around mutual benefits and reciprocal commitments rather than national burden-sharing, this approach creates positive-sum dynamics that can attract diverse participants. The quantitative analysis in Global Climate Policy Project (2025), combined with contemporary developments, suggests that coalition-based approaches could transition from theoretical possibility to political feasibility.

Several trends reinforce this assessment. For example, the explicit endorsement of coalition mechanisms by Brazil, the host of 30th Conference of Parties (COP30), signals high-level diplomatic support. The Climate Club's establishment demonstrates that major economies recognise the value of co-ordinated action beyond traditional UNFCCC frameworks. The proliferation of carbon pricing across national and subnational jurisdictions has created a distributed infrastructure of policy experimentation. Together, these developments collectively constitute essential building blocks for broader coalitions, providing institutional opportunities for policy co-ordination that can facilitate participation from economies across the development spectrum.

This chapter summarises the analysis in Global Climate Policy Project (2025), which proposes a flexible, evidence-based framework for international climate co-operation that balances effectiveness, self-enforcement and equity. The framework explicitly addresses the economic incentives necessary to encourage the adoption of ambitious climate policies across countries with varying levels of development and economic structures. It shows how properly designed policy co-ordination and transfer mechanisms can overcome free-riding incentives while respecting sovereignty constraints.

Translating this framework from concept to reality requires co-ordinated action across multiple governance levels and diverse stakeholder communities. Finance and trade ministries in potential coalition countries must expand their roles to include climate leadership, recognising that effective climate policy requires deep integration with core economic policy instruments. This shift acknowledges the centrality of climate to economic strategy and international competitiveness. Indeed, international financial institutions, particularly the IMF, World Bank, and regional development banks, possess unique comparative advantages in facilitating coalition formation. Their technical expertise in policy design, established relationships with finance ministries, and capacity to mobilise financial resources position them as natural co-ordinators for policy dialogue and harmonisation efforts.

The timeline for coalition formation is approaching a critical point as the EU CBAM will be implemented in 2026. While this unilateral measure could promote broader climate action, it risks triggering retaliatory responses and accelerating fragmentation if it is not embedded within a co-operative framework. A multitude of incompatible border adjustment mechanisms, each reflecting national industrial priorities, would risk substantial compliance costs on firms as well as trade disputes, and ultimately deliver environmental outcomes far inferior to those that could be achieved through co-ordinated action.

Thus, as COP30 approaches in Brazil, geopolitical fragmentation and climate urgency present challenges and opportunities alike. Although the weakening of traditional multilateral frameworks is worrisome, it creates opportunities for coalition approaches that may be more effective than universal agreements constrained by the lowest common denominator. Brazil's COP 30 presidency offers a promising opportunity, as the country is well-positioned to bridge the interests of developed and developing countries. Leadership from a major emerging economy could expand coalition membership beyond the traditional developed country core, thereby enhancing legitimacy and effectiveness.

The path forward requires balancing ambition with pragmatism. Rather than waiting for universal consensus and perfect prices, initiating co-operation among willing partners at moderate carbon prices, alongside clear pathways to expanding membership, is a more viable approach. The climate coalition framework provides such a path.

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7 Counting on carbon pricing: Determining a carbon price paid in third countries and coalitions

CAROLYN FISCHER AND MICHAEL MEHLING[16]

Abstract

Trade-related climate measures—which condition trade or market access on the basis of carbon intensity and climate performance—have recently been on the rise. For reasons of fairness, legal and political acceptability, and to incentivise climate action abroad, these measures often seek to account for a carbon price (or some other form of cost) incurred in the country of origin of traded goods. An example is the European Union's Carbon Border Adjustment Mechanism (CBAM), which allows importers to claim a reduction in the number of CBAM certificates they have to surrender in order to account for a carbon price "effectively paid" in a third country. Similar challenges arise in the work of co-operative initiatives such as the Climate Club, which seeks to align carbon pricing and trade measures among diverse members. While conceptually compelling, determining the carbon price "effectively paid" is far from straightforward in practice. This analysis systematically dissects alternative options for such a determination, identifying their respective implications and trade-offs.

I. Introduction

A. Background

Over the past decade, trade-related climate measures (TrCMs) have proliferated, seeking to reduce the greenhouse gas (GHG) intensity of traded goods and services. The European Union (EU) Carbon Border Adjustment Mechanism (CBAM), adopted in 2023, stands out as the most prominent example, but is only one among many measures adopted or under consideration at the interface of climate policy and international trade (Evenett et al. 2024; UNCTAD 2023). The

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United Kingdom has announced the introduction of its own CBAM from 2027, and Australia and Canada are actively reviewing such an instrument.

Whether in the form of explicit border carbon adjustment (BCA) tied to domestic carbon pricing schemes or of other policy interventions conditioned on GHG performance and affecting international trade, TrCMs are emerging as responses to a set of interlinked challenges. The first is the risk of "carbon leakage", where unilateral carbon constraints lead to a relocation of production and associated emissions to jurisdictions with less stringent policies. The second is the need to address the emissions related to consumption: due to how emissions are accounted for at the international level, countries could claim to be successfully decarbonising when they are only outsourcing emissive production.

B. Motivations for recognising carbon pricing in third countries

If TrCMs such as the EU CBAM seek to "level the playing field" by equalising carbon cost exposure across domestic and foreign producers, an important question arises: should these measures account for a carbon pricing instrument (CPI) applied to producers in their country of origin, and if so, how? Several reasons can justify recognising a CPI levied abroad. One is the resulting incentive effect: crediting a third country's CPI can be a powerful driver to encourage greater uptake of carbon pricing (Clausing et al. 2024; Mehling et al. 2024). Recognition of foreign carbon prices allows trade partners to retain revenues domestically, and it avoids double pricing of emissions, which could run counter to the goal of internalising the external costs of production.

A second set of reasons relates to the admissibility of the TrCM under international trade law: ignoring foreign climate efforts risks discriminatory outcomes, as emissions embedded in domestic goods would otherwise be burdened only once while those in foreign goods would potentially be covered twice. Burdening already priced imports could be considered a case of less favourable treatment—and thus discriminatory—under the national treatment provision set out in Article III of the General Agreement on Tariffs and Trade (GATT). Finally, recognition of third country carbon pricing can also be justified on grounds of fairness and political expedience: failure to account for a CPI imposed in the country of origin could intensify diplomatic backlash and retaliation.

While ample reasons thus support giving recognition to a carbon cost borne in the country of origin, leading to its recommendation as a component of good practice in implementing BCAs (Aylett et al. 2025; Cosbey et al. 2019), the "how" of doing so entails significant methodological complexities. The EU CBAM Regulation, which provides for a reduced compliance obligation if foreign producers can document a "carbon price effectively paid" on the production emissions of goods entering the EU, offers a practical example (European Union 2023, Art. 9). Despite clarifying that this provision only applies to a carbon price paid "under a carbon emissions reduction scheme, in the form of a tax, levy or fee or in the form of emission allowances under a greenhouse gas emissions trading system, calculated on greenhouse gases covered by such a measure, and released during the production of goods" (European Union 2023, Art. 3(29)), the exact conditions for its application have been widely debated.

Studies discussing operational aspects (Boute 2024; Marcu et al. 2023) or proposing alternative ways to account for foreign climate policy effort (Dominioni & Esty 2023; Weil 2021) have contributed valuable theoretical insights to our understanding of how to recognise a carbon price paid in third countries. What is still missing is a systematic evaluation of different options for designing and implementing such recognition, along with the respective merits and trade-offs. This question also gains relevance outside a purely unilateral context, when several jurisdictions seek to co-ordinate the use of TrCMs in clubs or coalitions.

Very different approaches have been proposed to recognise foreign climate action, from crediting explicit carbon prices—like the EU CBAM—to estimating the implicit shadow costs of regulatory standards or relying on notions of comparable ambition. Moving away from an explicit CPI towards implicit or qualitative measures, however, amplifies methodological complexity, legal uncertainty, and political vulnerability. Unlike explicit carbon prices, which can be expressed in transparent numerical terms, the implicit price signal created by other types of climate policies, such as performance standards or subsidies, is difficult to quantify and highly context dependent. Similarly, attempts to calculate "effective carbon rates" have proliferated in recent years, but their assumptions and coverage vary widely (Agnolucci et al. 2023; Dolphin & Xiahou 2022; OECD 2024). Effective rates may combine fuel excise taxes, emissions standards, or renewable subsidies into a single metric, yet results are sensitive to the choice of baseline, sectoral disaggregation, and treatment of exemptions.

For example, the OECD work on net effective carbon rates (Net ECR) (OECD 2023) demonstrates that while indirect taxes and fuel subsidies are the main drivers of carbon cost signals in economies as a whole (Figure 1), they play a much smaller role in the case of industrial emissions, where explicit CPIs are the overwhelming drivers of the net signal (Figure 2). Since emissions-intensive industrial products are the primary focus of leakage concerns and TrCMs, this illustration highlights the importance of calculating sector-specific (or product-specific) measures, since aggregate measures may be misleading indicators of the industrial competitiveness consequences of carbon and energy pricing policies.

Figure 1: Total Net Effective Carbon Rates and components by major countries and groupings (Data from OECD Effective Carbon Rates 2023)

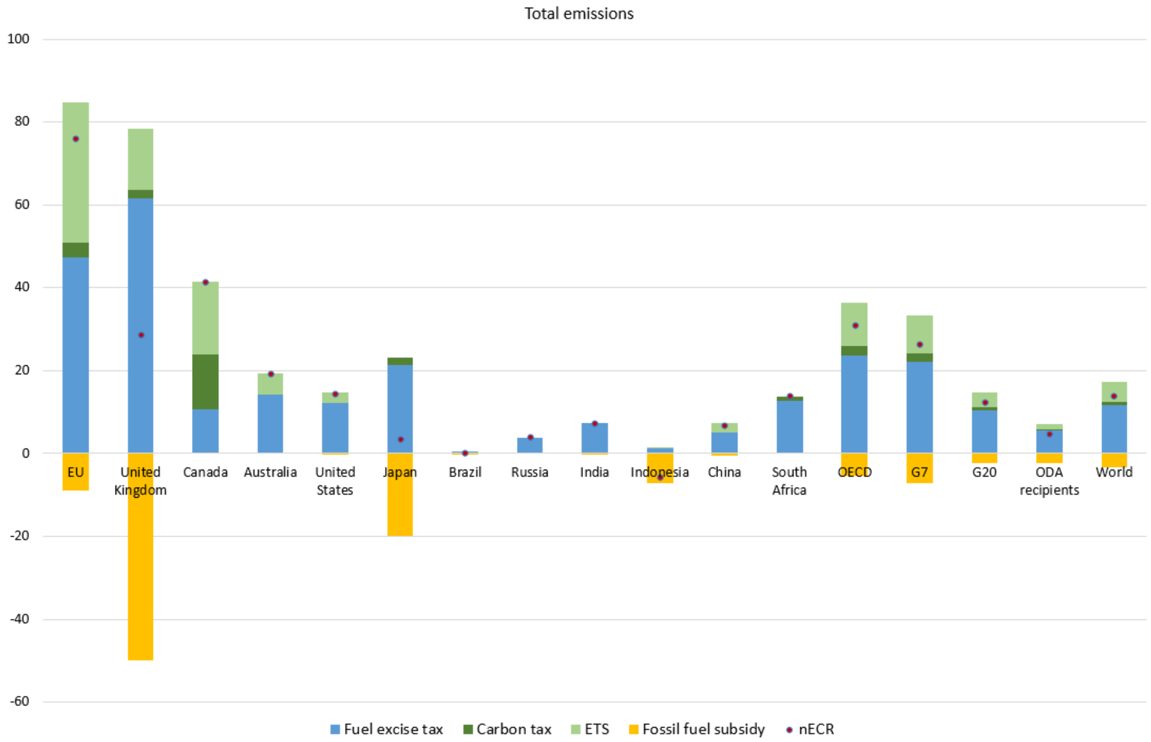
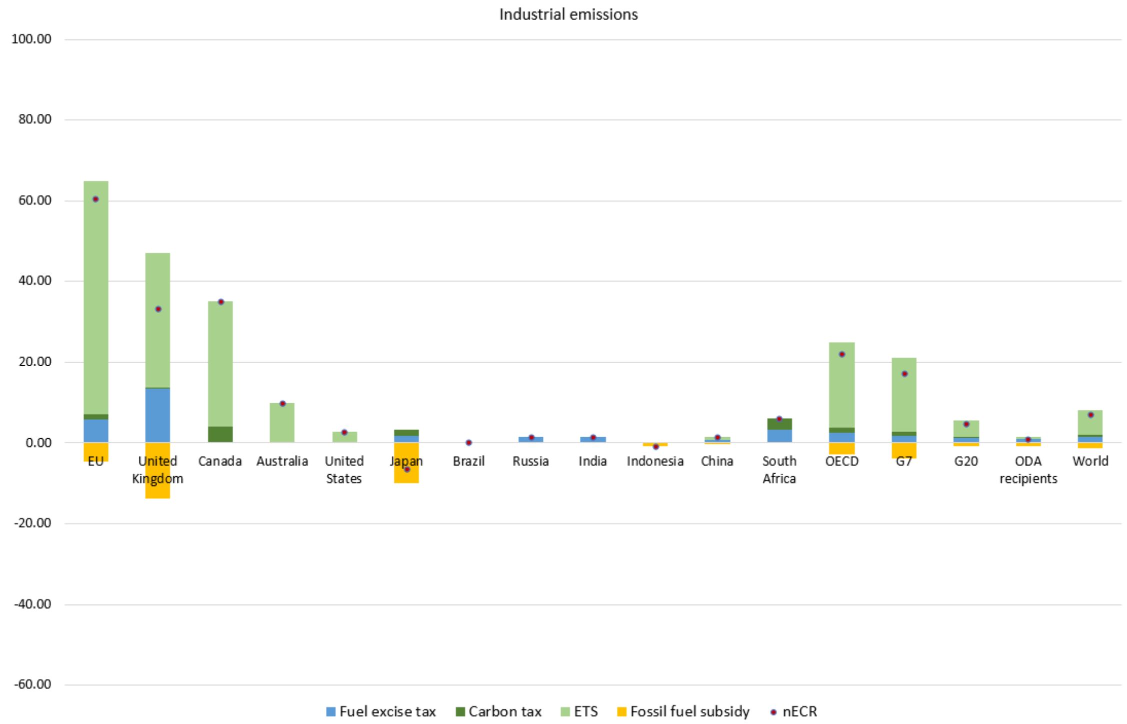


Figure 2: Industrial Net Effective Carbon Rates and components by major countries and groupings (Data from OECD Effective Carbon Rates 2023)



C. Objectives of this article

Our article deliberately narrows its focus to explicit CPIs as applied to industrial emissions, using the EU CBAM as a reference, and coalition proposals—such as the one in this volume—as case studies. While roughly 43% of global industrial emissions are now covered by a carbon price, these instruments vary widely in design and ambition (World Bank 2025), and any effort to translate these heterogeneous policies into a common denominator for purposes of a TrCM involves a degree of normative judgement.

Our article examines these challenges. Section II dissects the many decisions that need to be considered when accounting for carbon pricing in third countries, drawing on the EU CBAM as a case study. Section III explores the rationale behind, and options for, differentiation when recognising foreign carbon pricing, particularly in relation to developing countries. Section IV then discusses coalition settings where carbon pricing serves as a condition of membership. Section V concludes by distilling broader lessons for the design and implementation of TrCMs such as the EU CBAM.

II. Determining carbon prices effectively paid: A decision tree

A guiding principle for BCAs is symmetry: imports should receive treatment no less favourable than domestic products. This principle has two main aspects: 1) the measure should not accompany policies that do not impose carbon prices domestically (i.e., non-pricing policies) or carbon costs that are not effectively paid (as through free allocation), and 2) good practice would have its application account for similar carbon prices paid in the country of origin.

The first aspect relates to what carbon prices are being effectively paid in the implementing jurisdiction, to circumscribe what is being proposed for adjustment at the border. For example, the EU Emissions Trading System (EU ETS) is the primary (and only EU-wide) instrument for pricing GHG emissions from industry, so the EU CBAM proposes to apply the prevailing ETS price to the emissions embedded in imported goods associated with key ETS-covered industrial sectors that are considered vulnerable to leakage. Many Member States also have excise duties on energy products, and while minimum tax levels are set by the EU Energy Taxation Directive, these duties vary across countries, are imposed for many reasons, and are not included in the calculation of the EU CBAM. Furthermore, the EU CBAM will be phased in as free allocation in the EU ETS is phased out, in effect affording imported products similar benefits of free allocation for symmetric rates of embedded emissions.

The second aspect of symmetry is that a BCA-implementing jurisdiction should recognise the carbon prices borne by foreign producers of similar products—at least the same kinds of prices paid by domestic producers and potentially a broader category, recognising the differentiated circumstances. The reasons that justify doing so were already set out above in Section I.B.

The subsequent discussion will focus on the key implementation questions involved when accounting for similar carbon prices paid in third countries. Notably, most decision points involve multiple options with different trade-offs in terms of environmental impacts, administrative complexity, and inclusivity of different country circumstances.

D. Circumscribing the carbon prices being adjusted

What kinds of carbon prices are under scope for adjustment?

The features of the domestic CPI—its levels, coverage, and special treatments—will define the boundaries of the BCA, respecting the principles of symmetry. For this analysis, it will be presumed that the policy being adjusted is a domestic explicit CPI, either an ETS or carbon tax, borne by emission-intensive industries producing traded products as well as electricity (thereby covering direct emissions as well as indirect electricity-related emissions).

E. Defining minimum qualifications for foreign CPIs

Different countries have different institutional circumstances and capacities that lead to different choices in CPI design. For example, the EU chose an ETS over a fiscal approach for legal and political reasons. Other jurisdictions, like Chile, have deployed taxes. Both are forms of explicit CPIs, with the attendant compliance cost proportional to measured emissions. However, other forms of indirect taxes—like excise taxes on coal or other fossil fuels consumed by industry, if they are not based on carbon content—entail similar incentives for reducing CO_2 emissions from fuel combustion. (Conversely, fossil fuel subsidies can function like negative carbon prices for those fuels). Many if not most countries have these kinds of pricing interventions, and for some—particularly developing economies that need to leverage existing capacity—it might be more expedient to look to these instruments for embodying carbon price incentives. These indirect taxes can be transformed into explicit carbon prices by re-denominating them from a price per unit of fuel or energy into a price per ton of carbon content.

Given the complexity of determining carbon pricing effectively paid, it makes sense to lay some ground rules for the CPIs that should be eligible for the exercise. Options to be more expansive have benefits of fostering inclusivity but entail complications in determining the emissions covered.

Does the jurisdiction of origin have a mandatory carbon pricing instrument?

In defining what CPIs qualify for crediting, the spirit of symmetry need not be so strict as to require identical CPIs; any mandatory explicit CPI can be taken into account, whether or not it takes the same format as the CPI imposed in the jurisdiction adopting the BCA. Symmetric treatment should also be considered a minimum; if the foreign jurisdiction does not have an explicit CPI, the BCA-implementing jurisdiction could also consider whether indirect taxes on the consumption of carbon-intensive fuels qualify, in which case they must be converted to direct carbon pricing equivalents.

Voluntary carbon market mechanisms, by contrast, would not generally be eligible for credit, with some potential exceptions. Offset mechanisms could be recognised to the extent they serve compliance purposes under a mandatory CPI. Section III.B. discusses how carbon credits might feature in special provisions for developing countries.

Is that carbon price observable by statute, auction, or robust secondary markets?

Carbon taxes typically have rates determined by legislation. Emissions trading systems, however, have carbon prices that emerge through markets, with varying degrees of transparency. The BCA-implementing jurisdiction will likely require publicly available data, such as published auction results or observable trading prices on secondary markets. For systems that do not make pricing data publicly available—such as those with primarily bilateral trading, intra-firm averaging, or poor liquidity—additional evidence would be needed to establish a credible carbon price or they risk exclusion.

Is the price applied sector wide or only to exports?

If the foreign jurisdiction chooses to apply its CPI only to exports, only a subset of its overall production—namely that entering the BCA-imposing country—will be subject to a price signal on embedded carbon. While carbon export tariffs would help the jurisdiction retain revenue, they fail to create a comparable decarbonisation incentive. An export tax need not be based on actual firm emissions, nor would it level the playing field and avoid leakage in the same way as a sector-wide CPI: foreign producers would face a lower average carbon cost than that borne by producers in the BCA-imposing jurisdiction.

A decision must be made regarding the amount of emissions not destined for the BCA-imposing jurisdiction that needs to be covered for a CPI to qualify for crediting. For membership in a climate coalition, which aims to co-ordinate ambition, a CPI restricted to exports would be asymmetric and unsuitable. For a jurisdiction implementing a unilateral BCA, from an environmental and economic perspective, little is to be gained from recognising an export tax, and it represents a significant departure from symmetry expectations. Still, requiring comparable CPI coverage as a condition for recognition is likely to be considered more intrusive in sovereign policy choices and therefore could prove diplomatically more controversial.

Is the carbon price applied to facility-level emissions or upstream?

Considering the EU CBAM case, the CPI being adjusted at the border is applied downstream at the source of emissions from the targeted sectors. If that is also the case with the foreign CPI, one can proceed to the next question. If the CPI is applied upstream, however, such as with a carbon-based fuel excise tax, then it may be reasonable to evaluate the degree of carbon-cost pass-through to the emissions embedded in exported goods, allowing recognition where pass-through to embedded emissions is verifiable.

Allowing for upstream CPIs can support developing countries in implementing carbon pricing since they may have better administrative capacity to build on existing excise tax frameworks rather than setting up the regulatory and emissions monitoring, reporting and verification (MRV) frameworks needed for downstream CPIs. Choices then need to be made about the minimum requirements for upstream interventions and how to calculate the ensuing carbon prices embedded in traded goods. A challenge with upstream pricing is that it only covers combustion-related emissions, unless complemented with another instrument to capture process emissions and end-of-pipe options for capture and sequestration. Indirect pricing instruments may also not apply consistent prices across emissions sources. Accurate estimates of embedded pricing would require fuel-specific combustion information by product, leading to additional data requirements and reporting burdens.

Is the CPI mass-based or rate-based?

In a mass-based CPI, such as the EU ETS, compliance is based on the total mass of emissions from covered activities. By contrast, rate-based systems, such as tradable performance standards or feebates, set intensity benchmarks and require firms to pay for their emissions only if they exceed the benchmark, whereas those performing better than the benchmark can sell credits or obtain a rebate. While both systems create an opportunity cost to emissions on the margin—meaning additional emissions require additional payments or net costs—rate-based systems do not charge for embedded emissions on average. Since a BCA that is designed to prevent leakage and ensure symmetry will seek to adjust for differences in embedded carbon costs, rate-based systems can be problematic to recognise for crediting. However, emerging economies are increasingly turning to intensity-based ETSs for heavy industry. Excluding rate-based CPIs can be the simplest option, because it eliminates the need for further analysis. Otherwise, rate-based allocations can be dealt with in evaluating the degree of free allocation for adjusting credits for carbon pricing effectively paid.

F. Determining the credit granted for foreign carbon pricing

As just discussed, marginal carbon prices are different from average or embedded carbon prices. What is typically observed is the former—the statutory tax rate or the market price of allowances—but BCAs adjust for the latter, namely the price effectively paid on all emissions embedded in a good. As a consequence, a set of questions must be answered to determine the extent to which carbon prices are effectively paid.

What share of covered emissions are effectively paid?

Rebates, exemptions, or free allocation—both in the BCA-implementing and the trade partner jurisdiction—reduce the carbon payment liability for residual emissions and should be proportionately reflected in credited rates. Data requirements should be taken into consideration for whether facility-level allocations or sector averages can be used. One simple heuristic could be to assess revenues garnered by the foreign jurisdiction as a share of emissions covered by the CPI, yielding an average rate of embedded emissions pricing. In most systems, however, average allocations vary by sector and even firms. Sector or product benchmarks with observable rates in legislation or regulation could be used, but when benchmarks are facility-specific for identical products, the calculation becomes more difficult, especially if the information is not publicly available. In many systems using nearly full free allocation or rate-based approaches for trade-exposed producers, declaring a presumptive carbon cost of zero may be expedient. In fact, since more productive and efficient firms are more likely to export to a BCA-imposing jurisdiction, it could well be that exporting firms are also net sellers of allowances or credits issued for overperformance and thus have negative costs to pass through on embedded emissions.

What share of the sector's emissions are covered?

Few CPIs cover all emissions in a sector. Those regulating point sources frequently have a facility-level threshold for coverage to avoid excess administrative costs for small firms. As mentioned, those applied upstream will not capture all downstream emissions. Incomplete coverage implies that either the presumptive carbon price should only be applied to a portion of the embedded emissions, or the credit rate should be adjusted accordingly.

If facility thresholds are not vastly different from the BCA-implementing jurisdiction, a reasonable simplification would be to treat imports with the presumption that they are regulated, since small emitters are likely responsible for small amounts of emissions embedded in trade. Else, to be eligible for the credit, importers would need to demonstrate their products come from regulated facilities, which may add complexity to compliance.

For upstream CPIs, a determination is required as to the share of embedded emissions covered upstream (and passed through downstream), which for the purposes of a BCA requires a product-specific approach. In other words, in addition to calculating a presumed carbon price, one must also estimate to which emissions that applies. Combustion emissions can be estimated based on fuel consumption data, but a question is then whether to use firm-specific data on combustion fuels or to apply some form of default coverage benchmarks. The former would require exporting firms to document their own fuel consumption, while the latter would calculate a presumptive coverage rate based on industry averages.

Was the introduction of the foreign carbon price accompanied by reforms that lowered fossil fuel excise taxes or increased subsidies?

This question emerges from the similarities between explicit and implicit carbon prices. The implementing jurisdiction must decide whether to acknowledge only explicit CPIs or gross or net effective carbon prices or changes among them. For example, in introducing an explicit CPI, some of the effects can be offset by changes in existing fuel excise taxes as a result of a broader reform, repeal, or even a renaming of those taxes to carbon taxes. A "no backsliding" requirement could discourage such behaviour but would be politically controversial for its intrusion in domestic policy choices.

Other kinds of subsidies can also be wielded to improve the competitiveness of traded goods in ways that erode or enhance carbon pricing. Some subsidies may indirectly reduce the cost increases from carbon pricing (e.g. indirect cost compensation under the EU ETS, or electricity tax rebates enjoyed by industrial emitters in Germany); although implemented outside the direct carbon pricing mechanism, they function similarly to free allocation and merit similar treatment, since they effectively undermine the price signal on embedded emissions. Other subsidies may reward additional emissions-reducing behaviour (e.g. EU ETS revenue channelled into an Innovation Fund and awarded to installations for industrial decarbonisation projects); although they also lower costs for industry, such subsidies further environmental goals and primarily lower embedded emissions rather than the pricing thereof.

When are payments deemed to be made and how is currency converted?

For any recognised CPI, symmetry calls for using similar timeframes and rules for determining the credited price as are available for domestic producers. When crediting carbon prices paid, additional determinations must be made regarding what exchange rate to use (e.g. nominal or purchasing power parity), the relevant timeframe for the exchange rate (day of payment or of import, or weekly/monthly/yearly average), and the relevant timeframe for the carbon price paid (at the moment of payment, at the moment of import, or daily/weekly/monthly/yearly average in the case of fluctuating prices).

III. Special provisions for developing countries

A. Why might developing countries merit preferential treatment?

Accounting for a carbon price paid on embedded emissions of imported goods could also involve some form of differentiation based on the level of development of the exporting country in which the goods were produced. A principled case for such differentiation can be made on the basis of fairness. Developing and least developed countries have contributed far less to global emissions and often lack administrative capacity to implement complex CPIs, much less impose high carbon prices, which could entail excessive adjustment costs (Finon, 2019). Differentiated treatment in crediting for carbon prices can mitigate such concerns without negating the intended effects of the BCA, as a blanket country exemption might. Within co-operative initiatives such as the Climate Club, differentiation could help maintain participation of emerging and developing members while upholding collective ambition.

Differentiation can also be justified on legal grounds. While international trade law—notably the principle of Most Favoured Nation (MFN) set out in Article I of the GATT—precludes differential treatment based on the country of origin of traded goods, the so-called Enabling Clause adopted under the GATT allows preferential treatment of developing countries as long as such treatment is generalised, non-discriminatory, and aimed at development. Moreover, a foundational principle of the international climate regime, Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), expressly calls for country differentiation by mandating developed countries to take the lead in combating climate change and the adverse effects thereof.

B. How to differentiate: options to afford preferential treatment

Differentiation can be operationalised at different levels when determining a carbon price paid in developing countries.

Alternative payment options that benefit developing countries

Jurisdictions implementing a BCA could simply accept other payments in lieu of CBAM certificates for products originating in eligible developing countries. One option would be to credit the purchase of approved carbon credits—such as Article 6.4 Emission Reductions issued under the Paris Agreement and retired by exporters—counting these based on the value paid, not as a way to offset embedded emissions, to remain consistent with the crediting of other CPI compliance mechanisms. Aside from offering greater compliance flexibility, this option would also mobilise project finance to developing countries for the implementation of mitigation projects (Sandler & Schrag 2025). A second option could be payment into a development-oriented mitigation fund, again ensuring that payments benefit developing country trade partners rather than accruing to the jurisdiction imposing the BCA. As with recognition of a foreign CPI imposed only on exports, the trade-off of such approaches is that the carbon price incentive for industrial goods will not be extended beyond the exported products subject to the BCA.

Preferential carbon pricing crediting

As a second option, importing jurisdictions could afford some form of favourable valuation to carbon prices introduced in developing country trade partners. That could entail an explicit multiplier or bonus for developing country carbon prices, which would amplify incentives to apply carbon pricing. The multiplier could potentially be linked to a quantifiable metric such as purchasing power parity (PPP), an internationally recognised factor that reflects differences in price levels or determined by a formula related to development status. Such a multiplier could be sizeable, although its application would have to balance equity gains against the potential erosion of leakage protection.

A hybrid or mixed approach could involve inflating the carbon price imposed on exports provided the exporting country covers more than exported emissions only, for example by scaling the carbon price by the share of sectoral output sold to third markets, thereby rewarding sector- or economy-wide instruments over an "exports-only" carbon price. Conversely, a higher carbon price levied on exports could be fully credited as long as that export tax is imposed in conjunction with some form of minimum sectoral or economy-wide carbon price, with this minimum potentially differentiated by development level (Parry et al. 2021).

Preferential benchmarking

A third approach would be to give, in effect, a free allocation benchmark to imported goods from developing countries. This approach would differentiate the embedded carbon cost adjustment by reducing the emissions intensity to which the import adjustment is applied rather than reducing the carbon price signal. Products from developing countries would, on average, face a lower CBAM, although clean producers would still retain a competitive advantage. This option preserves the demand-pull incentives for firms to invest in low-carbon production capacity in developing countries, although it would tend to lessen country incentives to adopt carbon pricing.

Transitional preferences

Across all options, differentiation and preferential treatment could be limited to a transitional period, for instance under a sunsetting clause that affords developing countries more time to adjust and develop more robust carbon pricing policies. Guardrails would remain pivotal: clear evidence of actual payment, robust transparency and certification, and alignment with common definitions and clear criteria to avoid contentious claims.

IV. Accounting for carbon prices in a club or coalition

Recent proposals for carbon clubs or coalitions reflect the search for co-operative mechanisms that overcome the problem of free-riding in international climate policy (e.g., Nordhaus, 2015;

Wolfram et al., 2025)[17]. At the external boundary of such a club or coalition—where trade occurs with non-members—BCAs would continue to apply, although that application could still entail netting out of carbon costs by deducting a foreign carbon price from the BCA compliance obligation.

Defining a clear membership condition is essential for the credibility of any such club or coalition. Conditioning participation on a carbon price offers a quantifiable and transparent metric for membership, although it can still require a number of determinations on the type and scope of CPI as well as how to account for particular design features, such as rebates or exemptions. Earlier sections already discussed options available when making such determinations and their trade-offs. Additionally, membership can be dependent on adoption of a minimum carbon price, which could be set uniformly for all members or differentiated by income level. A graduated floor—requiring higher prices from advanced economies and lower ones from emerging and developing countries—has been advocated to balance environmental effectiveness with equity and political feasibility (Bekkers et al. 2024; Parry et al. 2021). The rationale of such an approach is twofold: it preserves incentives for ambition among high-income countries while offering a pathway for participation to countries with more limited fiscal or administrative capacity. Still, for some developing economies any carbon price might exceed available capacities, requiring a careful evaluation of membership conditions and their implications.

Another dimension concerns scope and phasing of the club or coalition. Starting with economy-wide price floors may be politically and administratively unrealistic. A more viable pathway might be to begin with trade-exposed, emissions-intensive sectors such as steel, aluminium, cement, and fertilisers. These sectors are both significant sources of emissions and highly vulnerable to carbon leakage, making them natural candidates for early alignment. A sectoral start also enables experimentation with methodologies for calculating embedded emissions and crediting foreign carbon prices, which can then inform the gradual expansion to other industries and, ultimately, to economy-wide participation.

Finally, the institutional design of such clubs or coalitions must navigate the constraints of international trade law. A common external BCA directed at non-members, or exemptions for members that meet the price floor, could be challenged under the National Treatment obligation defined in Article III of the GATT or the Most-Favoured-Nation obligation set out in Article I. Ensuring WTO-compatibility will require transparent, non-discriminatory design aligned with Article XX environmental exceptions (Espa & Holzer 2023; Mehling et al. 2022).

V. Conclusions

Determining how to account for carbon prices paid in third countries, whether under a unilateral border adjustment or as a condition of club or coalition membership, turns out to be more complex than it might appear at first glance. What seems like a straightforward question (has a foreign producer paid a carbon price, and if so, how much?) quickly leads into a thicket of methodological, legal, and political considerations. The analysis presented in this chapter shows

[17] See also the contribution by Kimberly Clausing, Axel Ockenfels and Catherine Wolfram in this report.

that there is no single "right" approach. Each option carries trade-offs that must be carefully understood. A restrictive interpretation of "carbon price effectively paid" reduces administrative complexity but risks undermining incentives for foreign climate action and may be perceived as unfair by trading partners. A more expansive approach, by contrast, enhances inclusivity and equity, but heightens methodological complexity. Differentiation for developing countries offers a way to balance fairness with effectiveness but again raises the question of where to draw the line and how to avoid eroding the environmental incentives.

The discussion of carbon clubs and coalitions reinforces these insights. Setting a carbon price as a condition of membership promises a transparent yardstick yet raises similar challenges to those encountered when looking to recognise a carbon price paid in a third country.

As jurisdictions operationalise TrCMs like the EU CBAM, they will need to remain conscious of both intended and unintended consequences. A durable and effective approach will require balancing environmental integrity, administrative feasibility, legal and political viability, and fairness across diverse country circumstances. That, in turn, calls for transparency in rulemaking, dialogue with affected partners, and openness to iterative adjustment as experience accumulates. The Climate Club could serve as a forum for such dialogue and a platform to harmonise methodologies for recognising foreign carbon prices and support members in aligning BCAs with fairness and transparency.

Ultimately, the effort to "count" foreign carbon prices is not only about avoiding double taxation or calibrating BCAs. It is about shaping the incentives for climate policy in a global economy that remains fragmented in its ambition and instruments. If designed carefully, recognition of foreign carbon prices—whether under a unilateral BCA or as a condition for membership in a club or coalition—can contribute to stronger incentives for mitigation, fairer treatment of trade partners, and greater legitimacy for the adopted measures.

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8 A global buyers club for lower-emission oil and gas to accelerate methane mitigation

MARCELO MENA

Abstract

The climate impact of natural gas depends heavily on methane leakage across its supply chain. Comparing Norwegian gas (≈0.05% leakage) with high-leakage Permian gas (≈3.7%) shows how dramatically outcomes differ: methane can more than triple total warming, erasing the perceived climate advantage of switching from coal or oil to natural gas. As global oil and gas trade expands—especially liquified natural gas—these emissions represent both a significant risk and a strategic opportunity. This analysis finds that a co-ordinated "buyers club" starting in 2027 and setting near-zero methane intensity standards (<0.2%) by 2030 could drive major improvements. Using temperature-based marginal abatement cost curves and current liquified natural gas trade patterns, the study demonstrates that leading importers controlling roughly two-thirds of global liquified natural gas demand could catalyse deep supply-chain mitigation, transforming markets and ensuring natural gas use aligns with climate goals.

I. Introduction

A. Natural gas as a transition fuel

As countries increase the deployment of renewables and shut down coal-fired power plants, they are deciding how to replace existing baseload and increase the reliability of electricity production. A decade ago, natural gas was presented as a "bridge fuel," capable of supporting variable output from renewable sources. But that depends entirely on maintaining low methane leakage rates throughout the supply chain. When lifecycle emissions are properly calculated using methane's 20-year global warming potential (which is 84 times more powerful than CO_2), high-leakage gas can deliver worse climate outcomes than coal—the very fuel it purports to replace (Gordon et al. 2023).

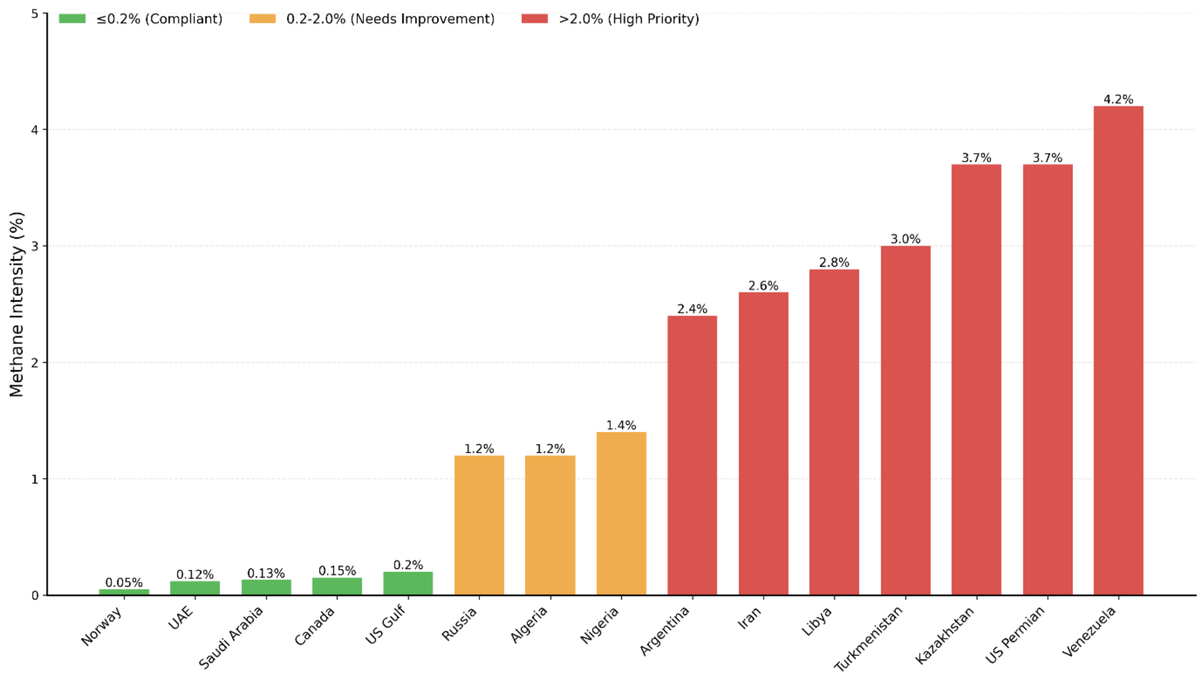
The climate impact of natural gas, and liquified natural gas (LNG) in particular, extends far beyond combustion emissions, encompassing the entire supply chain from wellhead to regasification terminal. Current methane leakage rates vary dramatically by region and technology, creating both enormous climate risks and unprecedented mitigation opportunities.

At the production level, best-performing countries like Norway achieve methane intensities of just 0.05% of production (IEA 2024), demonstrating that 0.2% targets are not only achievable but conservative. The Netherlands maintains an intensity of 0.08% (IEA 2024), Canadian operations average 0.15% (MacKay et al. 2021), and the US Gulf Coast achieves approximately 0.20%

(Gorchov Negron et al. 2023). However, production from major US unconventional basins, such as the Permian, shows intensities of 3.7% (Zhang et al. 2020)—185 times higher than those in Norway. Major exporters to China (Kazakhstan, Turkmenistan, Venezuela, and Russia) also have notoriously high leakage rates (IEA 2024), as shown in Figure 1.

Figure 1: Global Methane Intensity by Production Region (% leakage rate)

Methane leakage rates from oil and gas production across 15 countries, categorised as compliant (≤0.2%, green), needs improvement (0.2-2.0%, orange), or high priority (>2.0%, red). Data from IEA Global Methane Tracker (2024-2025), TROPOMI satellite observations, and peer-reviewed studies (Zhang et al. 2020; Irakulis-Loitxate et al. 2021; Sherwin et al. 2024)

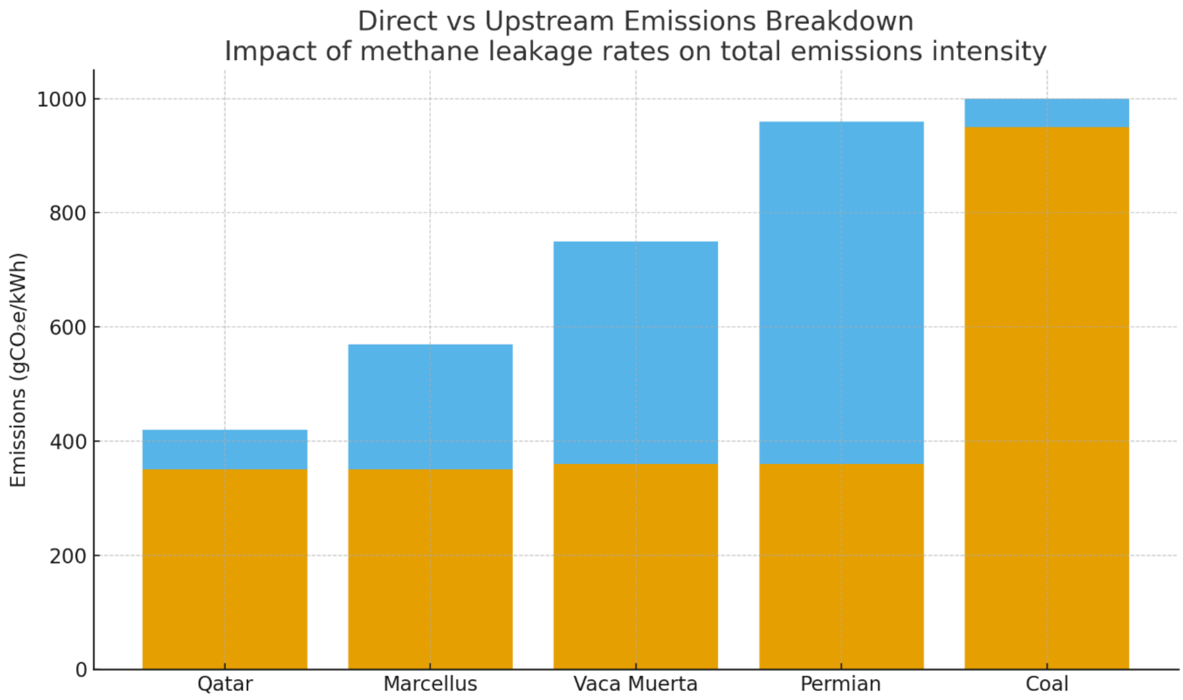


LNG transportation adds additional emissions through multiple pathways. Terminal operations contribute approximately 0.1% of total leakage during liquefaction and regasification processes. More significantly, LNG-fuelled vessels emit substantial methane through engine slip, with rates varying dramatically by technology: low-pressure dual-fuel four-stroke engines (86% of the LNG shipping fleet) slip 6.4% of fuel consumed, while more efficient high-pressure systems achieve slip rates below 1.5% (ICCT 2024). This can double the full footprint of transportation emissions per ton-km when accounting for this slippage leakage.

B. Chile coal phase-out and natural gas as a transition fuel

When Chile decided to phase out coal use in power generation in 2018, it was expected that natural gas would replace it. But since then, there has been increasing awareness of the role of methane leakage in determining emission trajectories. Analysis of major gas supply sources reveals dramatic variations in power generation emissions intensity. In Figure 2, we can see the total emissions from power generation using the standard lifecycle assessment methodology for gas-fired power plants. Higher leakage sources yield only a 5% reduction in emissions compared to coal, while cleaner sources (such as Qatar) can achieve a 58% reduction in emissions. This significant difference indicates that unless a country secures lower leakage of natural gas, it undermines emission reduction trajectories that are aligned with the 1.5 °C target. As more countries continue to phase out coal, this question will come up frequently.

Figure 2: Lifecycle Emissions from Power Generation (g CO_2 eq/km) using GWP20, for selected export regions to Chile from Qatar, United States, and Argentina compared to coal.



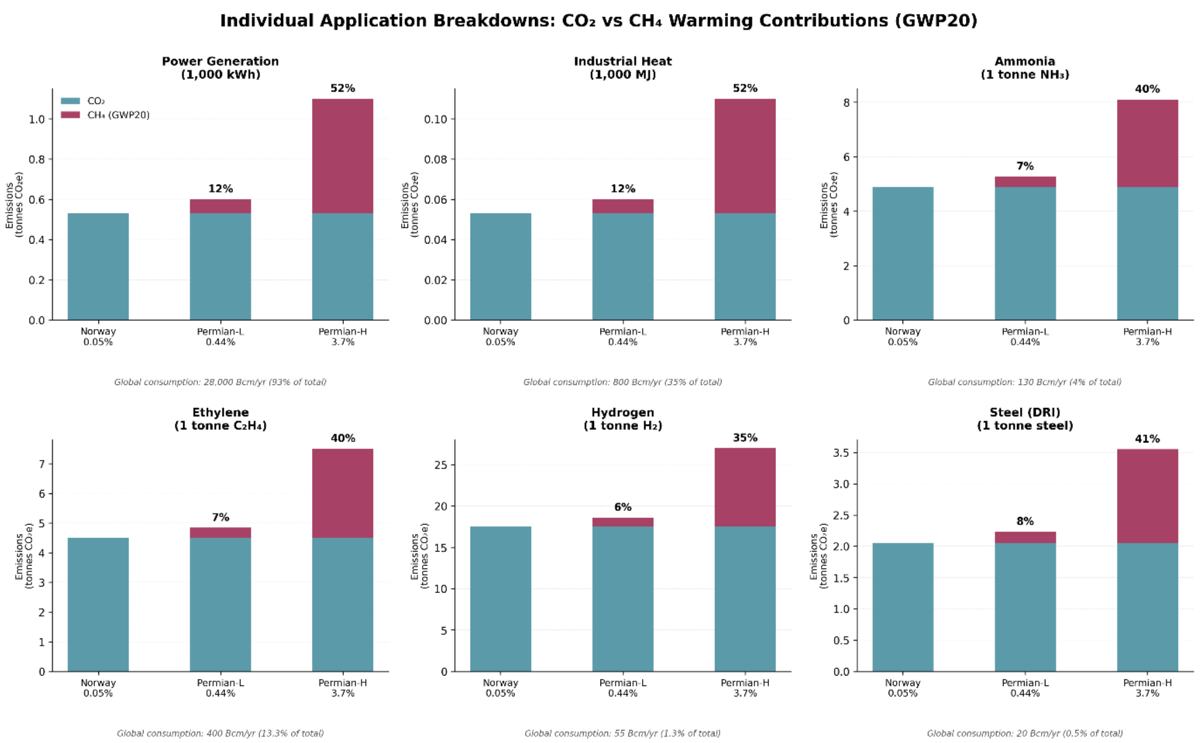
This analysis demonstrates why methane mitigation represents the most urgent climate priority for the gas sector. Without aggressive leakage control, the industry's climate narrative weakens, and continued gas expansion risks undermining near-term warming goals. The buyers club framework addresses this challenge by creating market incentives and capacity-building funding to drive all suppliers toward environmentally sound and economically efficient practices. Importantly, rapid methane mitigation complements broader decarbonisation pathways, as cutting methane emissions alongside CO_2 reductions is essential to meeting the Paris Agreement targets (IEA 2025).

C. Implications for other commodities

When natural gas is extracted and transported, methane leaks into the atmosphere—and these "upstream" emissions are being dramatically undercounted across global supply chains. This problem goes far beyond natural gas power plants and affects the production of everyday industrial materials. Satellite measurements from the Permian Basin revealed methane leakage rates of 3.7% of extracted gas, representing the highest rate ever measured from a US oil and gas producing region (Zhang et al. 2020). In comparison, best-practice production regions like Norway's operations achieve leakage rates near 0.05%, while intermediate operations reach approximately 0.44%. Using the IPCC AR6's 20-year global warming potential for methane (GWP20 = 83), which reflects methane's powerful short-term climate impact (IPCC 2021), these differences in leakage rates dramatically alter the total warming contribution of natural gas-based production. Figure 3 shows how methane leakage increases total climate impact across six different applications, comparing three leakage scenarios.

Figure 3: Methane Leakage Impact on Climate Warming Contributions Across Natural Gas Applications

CO_2 and CH_4 (GWP20) warming contributions per unit output for six natural gas applications under three upstream leakage scenarios: Norway (0.05%), Permian Basin-Low (0.44%), and Permian Basin-High (3.7%). Percentages show warming increase relative to lowest leakage scenario. Global consumption (bcm/yr) shown below each panel.

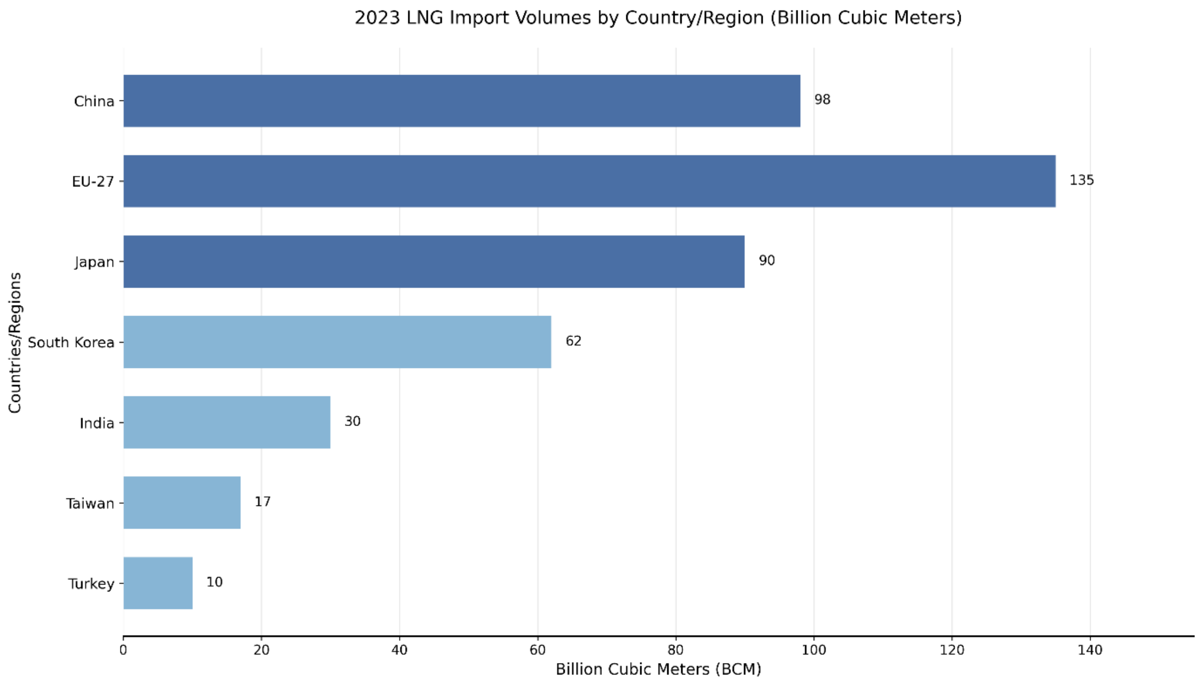


Under high-leakage conditions (3.7%), the warming contributions increase by 12% to 52% for both power generation and industrial heating, 7% to 40% for ammonia and ethylene production, 6% to 35% for hydrogen, and 8% to 41% for steel made with direct reduced iron. When methane emissions are considered, the emission reduction claim from switching to natural gas-based steel production may be cut in half (Mandova et al. 2023), effectively negating the climate benefits of switching from coal or oil to natural gas in many applications. This matters because cleaning up methane emissions from natural gas production is not just about electricity generation. It is also critical for producing fertilisers (ammonia), plastics (ethylene), clean fuels (hydrogen), and steel—materials that underpin modern life. Globally, ammonia production alone accounts for 170 billion cubic metres (bcm) of natural gas demand, representing 20% of industrial natural gas consumption (IEA 2021). The power and industrial sectors together account for approximately 75% of global natural gas demand growth, with chemicals and heavy industries being particularly gas-intensive (IEA 2025). As Figure 3 illustrates, the global consumption of natural gas for these applications is substantial, ranging from power generation as the largest consumer to steel production via direct reduced iron among the smaller applications. The problem is that current carbon accounting systems ignore these upstream methane leaks, which means we are systematically underestimating the true climate impact of products traded around the world.

D. Market structure and leverage points

The global LNG market's concentrated structure creates unique opportunities for implementing environmental standards. With 567.5 bcm in 2024 across 22 exporting and 48 importing markets, a relatively small number of major buyers control market access (IGU 2025). Globally, imports are led by the European Union (EU) at 140 bcm annually, China at 98 bcm, Japan at 74 bcm, and South Korea (62 bcm) (Figure 4). These four importers alone represent approximately 85% of major market trade, providing substantial market power to drive supply chain transformation. These proportions are likely to change in the future, and LNG will increasingly replace piped gas. Consequently, influencing this market will have a greater impact on the natural gas market and, ultimately, the oil market. This article assumes that the effect of LNG methane requirements will gradually extend to the global oil and gas market over time.

Figure 4: Global LNG Import Volumes (billion cubic meters).



Global LNG supply is projected to significantly exceed demand through 2040, creating a unique opportunity for buyers to drive environmental standards without risking supply security. According to the Institute for Energy Economics and Financial Analysis (IEEFA), global LNG export capacity is expected to reach approximately 666.5 million tonnes per year (MTPA) by 2028—roughly 900 bcm per year—which could be sufficient to meet all global demand requirements through 2040, even under optimistic industry forecasts (IEEFA 2024). For context, Shell's bullish 2040 demand projections range from 630 to 718 MTPA, while the IEA's stated policies scenario projects only 482 MTPA by 2050, both well below the 2028 supply capacity (Shell 2025; IEEFA 2024). This buyer's market gives major importers unprecedented leverage to require stronger methane standards without supply security concerns. The stakes are high: LNG-importing countries are effectively outsourcing methane emissions from oil and gas production in supplier countries. Collectively, for China, the EU, Japan, and Korea, these imports are associated with an estimated 15.3 million tonnes (Mt) of methane emissions each year (IEA 2025), making these imported emissions a critical part of their climate accountability, as they represent a significant number of unaccounted emissions.

This buyers market also presents a clear opportunity to ensure that those who want to participate in either selling or buying contribute to an energy transition that serves as a bridge, not a roadblock, to temperature reduction.

II. Methodology

We likely exceeded the 1.5 °C threshold in 2024 (Copernicus 2025). There is an increased awareness that we need to address overshoot and focus on short-term mitigation measures that can help reduce temperatures more quickly (Shleussner et al. 2024). Other authors have shown that similar CO_2 eq trajectories can yield very different mid-century temperature outcomes (Allen et al. 2022; Duffy et al. 2024; Buma et al. 2025), so targets, expressed in nationally determined contributions (NDCs), should distinguish short-lived and long-lived species, to be able to keep 1.5 °C alive. To highlight the role of potent, short-lived species in warming, some have proposed shifting from determining equivalencies based on long-term warming potential (GWP100) to shorter-term warming potential (GWP20), but this approach has not yet achieved consensus. More importantly, it has not allowed for comparing measures in terms of their contribution to temperature reduction in different time horizons, nor the cost-effectiveness of reducing temperature in those horizons. We have developed a new metric that focuses on the cost-effectiveness of temperature reduction to help prioritise measures that will bring down warming more quickly and affordably. The Temperature-based Marginal Abatement Cost Curve (T-MACC) framework provides a direct linkage between mitigation investments and temperature benefits, revealing methane's unique value proposition for near-term climate action.

(1) **T-MACC = MAC / ΔT_avoided**.

This framework utilises the Absolute Global Temperature Potential (AGTP) metric to transform emission reductions into temperature reduction. This article will use the same methodology to focus strictly on the proposed buyers club.

A. Economic returns from methane mitigation

The IEA Global Methane Tracker 2025 estimates that $260 billion in investment through 2030 could achieve a 75% reduction in methane emissions from fossil fuels. Achieving 0.2% methane intensity in this proposal would capture approximately 85% of this potential. Notably, approximately 45% of the required reductions could be eliminated at a negative cost when accounting for the value of captured gas, with most measures offering returns exceeding 25%—well above the typical investment thresholds for oil and gas.

B. Quantitative assessment using Temperature-Based Marginal Abatement Cost Curves

To provide precise estimates of the buyers club's climate impact, we apply the T-MACC methodology described above.

Our analysis has some limitations due to data availability, particularly regarding the future proportion of LNG versus total traded gas, and how this approach can ultimately impact the whole oil and gas production. There are also significant uncertainties projected for the increase in natural gas demand to replace coal, as well as the number of countries that will transition directly from coal to clean energy, particularly with the rapid expansion of battery storage. Here, we assume that the purchasing capacity of LNG will influence the global oil and gas market in a similar proportion to the reduction in emissions. The ultimate emissions reduction will depend on that, hence our estimation will likely be on the high end of mitigation potential.

Baseline Methane Emissions: According to the IEA Global Methane Tracker 2025 data, global oil and gas operations emit approximately 80 Mt CH_4 per Year, accounting for 67% of the 120 Mt annual emissions from the fossil fuel sector.

Market Coverage Calculation: Four major importers control substantial market leverage:

- EU: 140 bcm (24.7% of global trade)
- China: 97.8 bcm (17.2% of global trade)
- Japan: 74 bcm (13.0% of global trade)
- South Korea: 62 bcm (10.9% of global trade)
- **Combined coverage**: 373.8 bcm of 567.5 bcm total = **65.9% market share**

Implementation timeline:

The implementation ramps up progressively, starting with 20% adoption in 2027 as the foundation year, increasing to 50% by 2028 as markets develop, and reaching 75% in 2029 with expanded enforcement. By 2030, the system achieves full implementation at 100% effectiveness, which is then sustained through 2045 to ensure long-term impact. This is also due to the independent implementation of similar targets by oil and gas companies within their existing commitments. The IEA (2025) estimates that current pledges and policies can reduce emissions by 55%.

Implementation Assumptions:

Under conservative implementation assumptions, the model starts with an initial weighted methane intensity of 2.8% across major exporters and targets a reduction to 0.2%, representing a 93% improvement from the baseline. It assumes 75% full enforcement effectiveness supported by enhanced monitoring to meet this ambitious goal, alongside a 90% market response rate driven by strong economic incentives for compliance. Overall, the framework covers 90% of emissions from LNG operations within scope, ensuring a broad and meaningful impact. The emissions reductions are calculated annually based on the following formula.

(1) ΔE(t) = Baseline_Emissions(t) × Coverage_Factor × Intensity_Improvement × Enforcement_Rate × Market_Response

III. Buyers Club Implementation Framework

A. Existing frameworks

The concentrated nature of LNG import markets creates an unprecedented opportunity for buyer co-ordination. Unlike traditional climate commitments, which require complex international negotiations and consensus, a buyers club leverages the collective purchasing power of major importers to set common methane performance standards and incentivise compliance across global supply chains. This approach respects national sovereignty while using market mechanisms to drive global environmental improvements. This vision builds on existing efforts.

European Union: Setting the Global Standard

The EU Methane Regulation establishes the world's first import-based methane standard, requiring equivalent measurement, reporting, and verification (MRV) in all new LNG and gas contracts from 2027. It introduces importer reporting obligations from 2028 and enforces maximum methane-intensity thresholds from 2030 through delegated acts. The regulation aligns closely with the Oil and Gas Methane Partnership 2.0 (OGMP 2.0), the UN-backed gold standard for methane reporting, effectively incentivising suppliers to adopt OGMP-compliant practices to maintain access to EU markets. Together, these measures establish a robust compliance baseline for global LNG trade, encouraging suppliers to implement high-integrity MRV systems progressively.

Asian Market Leadership: The CLEAN Initiative

Similarly, Japan's JERA and Korea's KOGAS have co-founded the voluntary Coalition for LNG Emission Abatement toward Net Zero (CLEAN Initiative), now joined by over 20 major Asian LNG buyers—including utilities, trading houses, and energy firms. CLEAN creates a buyer-led platform leveraging collective procurement power to demand lower methane emissions across LNG supply chains. While voluntary, it sets shared transparency expectations, including supplier emissions disclosure aligned with OGMP 2.0 reporting tiers. By anchoring a methane data ecosystem in Asia, CLEAN complements the EU's regulatory push with a market-driven pathway to accelerate methane reductions globally. This approach is voluntary, but Japan has considered border taxes on carbon emissions from imported goods, which could include this commodity.

International Co-ordination Efforts

Between 2022 and 2024, the US, Australia, the EU, Japan, Korea, and Canada co-led the international Measurement, Monitoring, Reporting and Verification (MMRV) Working Group, which measured and verified methane emissions from oil and gas production. This approach was supported in a broader group during the APEC Joint Statement on Accelerating Methane Mitigation from the LNG Value Chain (joined by the same group plus Chile, Indonesia, New Zealand, and Peru), showing the broad collective interest to leverage collective procurement power to drive methane reduction standards.

New regional approaches: Latin America and California

The Latin American Energy Organization (OLADE) has established a Methane Emissions Observatory, building on a 2021 ministerial declaration that committed to advancing methane mitigation in the region's oil and gas sector. Since then, OLADE has published analyses identifying gaps in national emissions reporting and supported countries in strengthening their frameworks.

Latin America stands out globally, with a higher proportion of countries adopting oil and gas emission standards compared to other regions—including Peru, Argentina, Colombia, and Ecuador, which have already approved regulations. Additionally, the membership of national oil companies (NOCs) in OGMP 2.0 is relatively high, with only a few NOCs yet to join.

The region has also hosted two Methane Emissions Summits and is exploring pathways to harmonise regional emission requirements, aiming to enhance transparency, consistency, and impact across countries. There are incentives for this to materialise, as many countries are both importers and exporters of oil and gas.

California's leadership adds further momentum. Through its Low Carbon Fuel Standard (LCFS) and the anticipated passage of SB 613, California is poised to establish the world's first methane-intensity requirements for imported oil and gas products. Given that several Latin American countries are key suppliers to California's energy markets, alignment with these standards could unlock preferential market access while accelerating the adoption of high-integrity MRV practices. This emerging regulatory signal strengthens the case for regional co-ordination, to position Latin America as a frontrunner in delivering low-methane oil and gas to global markets.

Industry Framework Integration

The OGMP 2.0 framework—adopted by more than 110 oil and gas companies, which cover 40% of global production—requires measurement-based methane reporting and company-specific targets, enabling comparability across suppliers. In parallel, the Oil and Gas Decarbonization Charter (OGDC) sets a collective goal of near-zero methane emissions (<0.2% intensity) by 2030, now signed by over 60 producers representing a significant share of global oil and gas production. The proposed buyers club aligns procurement eligibility with OGDC-aligned performance and utilises OGMP 2.0 reporting to monitor compliance.

B. Implementation roadmap

The buyers club must move rapidly through co-ordinated phases to capture first-mover advantages and establish market standards before competing frameworks emerge. Success requires balancing environmental ambition, just transition principles, and commercial viability while maintaining broad political support. Key elements requiring resolution include the group composition, compliance dates, reporting requirements, and support mechanisms for lower-income countries in mitigation, potentially through a methane fee for non-compliance collected by importing countries. These elements would be decided in working groups supported by analytics, following models similar to International Maritime Organization (IMO) negotiations. Implementation begins with the 2025-2026 Pre-Launch Preparation phase, during which major importers conduct feasibility studies, establish technical working groups, develop comprehensive MMRV protocols and certification systems, and engage with leading suppliers on pilot projects. The 2027 *Foundation Year* marks the formal launch of the buyers club secretariat at 20% effectiveness of reaching the near zero methane target, with the secretariat including sufficient technical capacity to review industry compliance with MMRV protocols and certification. In 2028, the *Market Development* phase reaches 50% effectiveness by expanding emissions verification requirements to 0.2% compliance tracking, implementing a methane fee system for non-compliance with revenues generated and recycled to support mitigation efforts, and adding new member countries with capacity-building support. The 2029 *Enhanced Enforcement* phase achieves 75% effectiveness by strengthening compliance mechanisms, expanding market coverage, establishing robust border adjustment mechanisms, and preparing for full enforcement. From 2030-2045, *Full Implementation* reaches 100% effectiveness by enforcing a 0.2% methane intensity requirement across the complete supply chain and generating significant annual resources for climate finance through the methane fee scheme for non-compliance

IV. Economic Benefits

A. Economic estimation methodology and returns

The economic assessment employs established methodologies from climate economics literature to quantify implementation costs, co-benefits, and avoided damages. Unlike traditional environmental regulations that impose net costs, the buyers club generates positive economic returns through multiple quantifiable channels.

A.1. Implementation cost estimation

Technology upgrade and deployment support ($3.2 billion annually) is drawn from the IEA's estimate that $260 billion through 2030 could achieve a 75% reduction in fossil fuel methane emissions, with our initiative capturing approximately 85% of the oil and gas sector's potential, resulting in proportional annual investment requirements (IEA 2025). Enhanced administrative and enforcement costs ($0.9 billion annually) are based on scaling existing regulatory frameworks, such as the EU Methane Regulation implementation costs and OGMP 2.0 verification expenses (European Commission 2023). Developing country capacity building ($0.8 billion annually) follows Green Climate Fund methodologies for technology transfer and institutional strengthening in emerging economies (GCF 2024).

A.2. Co-benefits quantification

Health co-benefits ($6.2 billion annually) employ the social cost of air pollution methodology, applying World Health Organization damage functions for PM2.5 and NOx reductions from decreased methane emissions, using value-of-statistical-life estimates adjusted for purchasing power parity across affected regions (WHO 2021; EPA 2023). The value of recovered methane gas ($4.5 billion annually) is calculated using Henry Hub natural gas prices, adjusted for transportation costs and processing expenses, assuming 60% of the avoided methane can be captured and commercialised based on industry best practices (EIA 2024). Energy security benefits ($0.5 billion annually) encompass portfolio diversification premiums and supply disruption insurance values from the energy security literature, reflecting reduced dependence on high-volatility suppliers (Cherp et al. 2022). Avoided stranded asset risk ($1.3 billion annually) is estimated through net present value calculations for LNG infrastructure investments that would become uneconomic under tightening climate policies, following International Renewable Energy Agency (IRENA) asset transition methodologies (IRENA 2023).

A.3. Climate damage avoidance

Avoiding climate damages ($625 billion by 2045) employs the Kotz et al. empirical damage function integrated with NGFS Phase V scenario frameworks. This methodology uses an empirically derived relationship between temperature changes and gross domestic product (GDP) impacts based on historical data across countries, demonstrating nonlinear economic damages from warming. The approach integrates this damage function with NGFS temperature pathways and transition scenarios to provide consistent climate-economic projections. Temperature calculations rely on Absolute Global Temperature Potential (AGTP) metrics to translate emission reductions into quantifiable temperature decreases over policy-relevant timeframes. The methodology accounts for regional damage differentiation, recognising that economic impacts vary across countries based on baseline temperatures and development levels. It incorporates multi-pollutant accounting to capture combined temperature effects from methane, CO_2, and other climate forcers. The framework applies NGFS-consistent discount rates to calculate present values of future avoided damages across different timeframes.

A.4. Revenue generation and market mechanisms

Revenue generation ($35-50 billion annually) derives from differentiated pricing mechanisms that create economic incentives for compliance. This includes methane intensity fees applied to high-emission LNG based on carbon pricing literature, with revenues calculated using the covered trade volume (373.8 bcm) and emission intensity differentials between current practices and the 0.2% standard (Stern 2022). Price premiums for certified low-emission LNG follow voluntary carbon market methodologies, with premiums estimated at $15-25 per metric ton CO_2-eq based on methane credit pricing in compliance markets (IETA 2024).

A.5. Overall economic assessment

The benefit-cost analysis follows standard environmental economics methodology, discounting future costs and benefits at a 3% real discount rate, consistent with climate policy evaluation guidelines (Nordhaus 2021). The 87:1 benefit-cost ratio, including climate damages, reflects the exceptional cost-effectiveness of methane mitigation relative to CO_2 abatement, driven by methane's high near-term warming potential and the significant co-benefits from utilising captured gas. Direct benefit-cost ratios (1.5:1) exclude climate damages to provide conservative estimates for decision-makers preferring narrower economic assessments.

B. Trade-compatible implementation

The buyers club approach respects international trade principles while achieving environmental objectives:

- **Non-discriminatory:** Standards apply equally to all suppliers regardless of origin
- **Science-based:** Requirements based on measurable environmental performance
- **Proportionate:** Penalties reflect actual environmental harm caused
- **Transparent:** Clear rules and appeal mechanisms ensure fair treatment

V. Results: Temperature and Emission Impacts

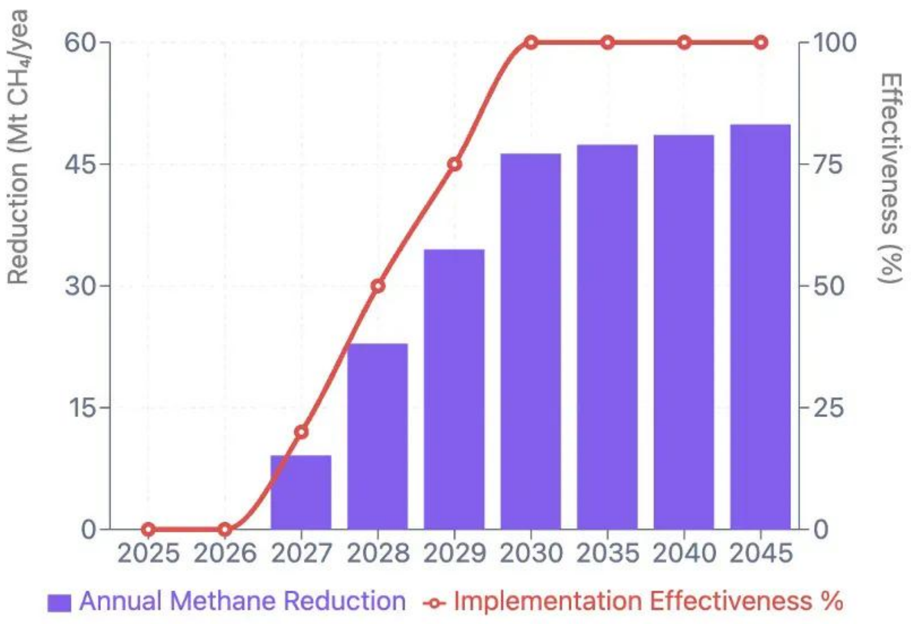
A. Temperature benefits

The temperature benefits from methane reductions accumulate steadily over time. By 2030, these actions are estimated to deliver a 0.0086 °C reduction in warming, increasing to 0.031 °C by 2035, 0.056 °C by 2040, and reaching 0.073 °C by 2045. This impact is substantial: achieving a 0.073 °C reduction by 2045 is equivalent to eliminating 26% of global coal power CO_2 emissions, removing 3.9 billion tons of CO_2 annually (based on GWP_{20}), or shutting down approximately 1,200 large coal-fired power plants worldwide.

B. Global methane impact

Figure 5 summarises the results of emissions reductions. The analysis demonstrates that a co-ordinated LNG buyers club represents a highly effective market-based solution for methane reduction, achieving impressive emission cuts that scale from 9Mt CH_4/year in 2027 to 45.1Mt CH_4/year by 2045 (57.9% reduction of oil and gas methane emissions by 2030). The cumulative impact over two decades totals approximately 731.4 Mt of CH_4, demonstrating sustained effectiveness that grows stronger over time as market coverage expands, and enforcement mechanisms mature. Notably, this trajectory is achieved through voluntary co-ordination among major LNG importers, making it politically feasible and economically viable compared to more complex regulatory alternatives.

Figure 5: Annual Methane Emission Reduction Trajectories and Sectoral Impact Analysis for LNG Buyers Club Implementation, 2025-2045



The buyers club approach offers a compelling proof of concept for market-driven climate action, capturing over half of the technically achievable methane reduction potential identified by the IEA while maintaining commercial competitiveness. By 2030, this initiative could single-handedly reduce global anthropogenic methane emissions by 8%—a substantial contribution given that it operates through a subset of the oil and gas sector. The 90% market coverage achieved through LNG trade linkages provides a strong foundation that could be expanded to pipeline gas and domestic production as the model proves successful. This analysis suggests that buyers clubs represent a scalable and replicable approach that could serve as a cornerstone for broader methane reduction strategies, offering immediate climate benefits while building momentum for more comprehensive sectoral transformation, especially in these challenging times for consensus-based multilateralism.

VI. Conclusion: The Hidden Climate Crisis in Global Supply Chains

When natural gas is extracted and transported, methane leaks into the atmosphere—and these upstream emissions are being systematically undercounted across global supply chains. Current carbon accounting systems ignore these leaks, leading to a fundamental underestimation of the true climate impact of products traded worldwide. This problem extends far beyond electricity generation: methane emissions from natural gas production affect every industrial material that depends on natural gas as feedstock or fuel—fertilisers (ammonia), plastics (ethylene), clean fuels (hydrogen), and steel. The magnitude of this underestimation is staggering. Satellite measurements reveal methane leakage rates ranging from Norway's best-practice operations at 0.05% to the Permian Basin's 3.7%—a seventy-fold difference (Zhang et al. 2020). Using methane's 20-year global warming potential (GWP_{20} = 83), these leakage variations dramatically alter the total warming contribution of natural gas across applications. Under high-leakage conditions, warming impacts increase by 12-52% for power generation and industrial heating, 7-40% for ammonia and ethylene production, 6-35% for hydrogen, and 8-41% for steel production via direct reduced iron—effectively negating the climate benefits of fuel switching from coal in many cases (Mandova et al. 2023; IPCC 2021).

This matters because the affected sectors consume enormous volumes of natural gas. Ammonia production alone accounts for 170 bcm annually (20% of industrial natural gas demand), while the power and industrial sectors together drive 75% of global gas demand growth (IEA 2021 2025). The materials produced—fertilisers, plastics, hydrogen, steel—underpin modern civilisation, making upstream methane emissions in natural gas supply chains a critical but overlooked dimension of global climate policy.

The Buyers Club Solution: Transformational Action Through Market Co-ordination

The global oil and gas buyers club, launching in the near term and achieving 0.2% methane intensity standards by 2030, directly addresses this systemic undercounting of methane emissions. With major importers controlling 66% of the global LNG market, this co-ordination mechanism provides sufficient leverage to drive comprehensive supply chain transformation to best-practice standards within three years. By establishing measurable, enforceable methane intensity requirements across traded LNG, the buyers club ensures that the climate benefits promised by natural gas fuel switching—across power generation, industrial heating, and materials production—are actually realised.

The climate case is compelling: a 0.073°C temperature reduction by 2045, equivalent to eliminating over one-quarter of global coal power. The economic case is overwhelming, with benefit-cost ratios exceeding 85:1 and net annual direct benefits of $4.1 billion. This initiative alone would reduce global anthropogenic methane emissions by 8.1%, making it the single most effective climate policy available today.

Global LNG supply is projected to significantly exceed demand through 2040, creating a unique opportunity for buyers to drive environmental standards without risking supply security. This buyer's market gives major importers unprecedented leverage to require stronger methane standards.

Expanding the Framework: The Climate Club's Role in Industrial Decarbonisation

The buyers club model offers a proven template for the Climate Club to expand co-ordinated climate action across industrial supply chains. While the LNG buyers club addresses upstream methane emissions in natural gas trade, the Climate Club can promote this framework to tackle embodied emissions across the full spectrum of traded industrial commodities—particularly those heavily dependent on natural gas as feedstock.

The Climate Club should prioritise three strategic actions to leverage the buyers club model for industrial decarbonisation:

First, establish methane intensity standards for industrial feedstocks. The Climate Club can extend the 0.2% methane intensity framework beyond LNG to natural gas used as feedstock in ammonia (fertiliser), ethylene (plastics), hydrogen (clean fuels), and direct reduced iron (steel) production. By co-ordinating among major importing nations, the Climate Club would create common standards that prevent competitive disadvantages while ensuring that fuel-switching climate benefits are realised. Given that ammonia alone accounts for 170 bcm of natural gas demand, and these four sectors represent substantial portions of global industrial emissions, methane intensity requirements for industrial feedstocks would deliver climate benefits comparable to the LNG buyers club itself.

Second, integrate methane accounting into industrial product standards. The Climate Club's work on establishing common carbon accounting methodologies for trade should explicitly incorporate upstream methane emissions using temperature-based metrics (GWP_{20}) rather than conventional 100-year metrics that understate methane's near-term climate impact. This is particularly critical for carbon border adjustment mechanisms and green industrial procurement policies, where current accounting frameworks systematically undervalue low-methane supply chains. By adopting methane-inclusive accounting, the Climate Club would correct the fundamental flaw in existing carbon pricing systems that allows high-leakage operations to masquerade as climate solutions.

Third, co-ordinate buyer coalitions for hard-to-abate sectors. The Climate Club provides the ideal forum for organising co-ordinated procurement requirements across steel, cement, chemicals, and other industrial commodities. Following the LNG buyers club model, Climate Club members representing major import markets could establish minimum methane and carbon intensity standards, creating economies of scale for clean industrial production while protecting first-movers from competitive disadvantages. Germany's leadership position, combined with EU market power and partnerships with major Asian economies, gives the Climate Club unique convening authority to replicate the buyers club success across multiple industrial value chains.

The alignment is natural: the Climate Club's mandate to prevent carbon leakage and support industrial decarbonisation complements the buyers club's market-co-ordination approach. Both mechanisms recognise that unilateral action creates competitive risks, while co-ordinated standards among major buyers create level playing fields that enable transformation. By promoting the buyers club framework as a replicable model, the Climate Club can extend its reach beyond member countries to reshape global industrial supply chains through strategic market co-ordination.

The Window for Action Is Now

Acting in 2027 captures the current window of LNG supply surplus and regulatory alignment. Delaying action risks locking in high-emission infrastructure for decades as the current construction boom consolidates. The 0.2% buyers club model provides a template for ambitious climate action through trade mechanisms, demonstrating that transformational environmental outcomes and economic prosperity are not only compatible but mutually reinforcing when proper incentives align market forces with climate necessity.

The stakes are high: LNG-importing countries are effectively outsourcing methane emissions from oil and gas production in supplier countries. Collectively, for China, the EU, Japan, and Korea, these imports are associated with an estimated 15.3 Mt of methane emissions each year (IEA 2025), making these imported emissions a critical part of their climate accountability. The Climate Club can expand this accountability framework across all industrial commodities, ensuring that imported products reflect their true climate impact.

The choice is clear: act now to correct the systematic underestimation of methane's climate impact across global commodity chains or watch as high-leakage natural gas infrastructure undermines the climate benefits of fuel switching for decades to come. The buyers club represents the most significant climate opportunity in the energy sector, and the Climate Club offers the institutional architecture to scale this model across the entire industrial economy. Together, these co-ordinated approaches can deliver the transformational decarbonisation that fragmented national policies cannot achieve alone.

Marcelo Mena

Marcelo Mena, MS, Ph.D. is the founding CEO of the Global Methane Hub, the world's first globally co-ordinated philanthropic effort dedicated to reducing methane emissions, which has advanced policies and projects in over 150 countries and leveraged over $10 billion in climate finance. Also a professor at the School of Biochemical Engineering at Pontificia Universidad Católica de Valparaíso and a TED speaker, Mena served as Minister and Vice Minister of the Environment for Chile, where he helped create over 1.3 million square kilometers of protected land and ocean and orchestrated a pioneering coal power emissions phase-out agreement. Mena previously co-chaired the Climate and Clean Air Coalition and served as Practice Manager at the

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Part III: Effective and inclusive industrial decarbonisation policies

CLIMATE CLUB

9 New roles, new rules. Industrial decarbonisation through policy and partnership

PATRICIA ESPINOSA CANTELLANO

Abstract

This article argues that to meet global climate goals, decarbonisation in industry needs to be accelerated through proactive public policies that promote sustainability while creating the conditions for robust economic growth. To this end, countries need to establish an ecosystem of catalysts that reduce risk, foster scale, and lend credibility. Five such catalysts are essential: 1) Public policy frameworks that integrate industrial decarbonisation into national economic planning; 2) Budgetary credibility, to provide the necessary public finance anchoring; 3) Private finance mobilisation through financial instruments that facilitate divesting from carbon intensive activities and investing in lower intensity industrial processes; 4) Alignment of fiscal policy with climate goals, avoiding carbon-intensive subsidies, tax breaks, or unpriced externalities; and 5) Capacity and institutional strengthening to ensure effective implementation. Governments' response to this challenge will determine not only the pace of emissions reduction but also the distribution of industrial competitiveness in the twenty-first century.

I. Introduction

Industrial processes account for roughly a quarter of energy-related carbon dioxide (CO_2) emissions, mostly due to their continued dependence on fossil fuels (Ritchie 2020). If emissions from direct industrial processes are considered, the proportion rises to nearly 30% (Ritchie 2020). Given that energy emissions represent almost three quarters of all greenhouse gas (GHG) emissions, the industrial sector has a critical role to play in the transition towards sustainable economic practices that serve the needs of consumers, promote jobs and prosperity, and protect the planet. A decisive shift towards net-zero pathways is urgent to reconcile sustainability and profitability in economies across the world.

This shift is already happening, even if the pace of change does not reflect the urgency needed to address the mounting climate crisis and limit its impacts. In the last 18 months, major economies have advanced in the codification of market rules and investment signals. The EU's Net-Zero Industry Act entered into force in 2024, setting a 40% domestic manufacturing capacity goal by 2030 for strategic net-zero technologies and establishing a Union-level target of ≥50 million tonnes (Mt) of annual CO_2 storage capacity by 2030—intended to de-risk private capital and anchor long-term supply chains. At the same time, the European Union Carbon Border Adjustment Mechanism (EU CBAM) is phasing in and becomes fully operational in 2026, aligning trade incentives with low-carbon production and gradually replacing free Emission Trading

System (ETS) allowances, a clear price-based demand signal to induce change in carbon-intensive value chains. Across the Atlantic, the United States moved from broad subsidies to detailed rules that determine which projects get paid for real decarbonisation. But subsequent political debates have introduced a high degree of uncertainty, underscoring a central lesson for all jurisdictions: policy certainty on national climate goals and enhanced private sector commitment is gradually becoming a necessary condition to expand industrial investment in a sustainable way that is aligned to the overarching goals of the international climate regime. Finance flows are more likely to go where rules are legible and durable.

Recent analysis by the International Energy Agency (IEA) in the World Economic Forum's Net Zero Industry Tracker 2024, shows that effective national strategies combine multiple instruments—from product standards and public procurement to carbon pricing, offtake contracts, and infrastructure planning—and that international co-ordination multiplies the impact by reducing fragmentation. Updated sectoral diagnostics show that around 40% of direct industrial CO_2 emissions come from the eight hardest-to-decarbonise sectors. Given their outsized share, decarbonising these sectors unlocks most of the potential emissions reductions. Coupled with credible and long-term public signals, this co-ordinated approach is especially powerful in mobilising private capital and scaling technology diffusion (World Economic Forum 2024).

The window of opportunity is both urgent and unusually constructive. On the one hand, global energy-related CO_2 emissions hit a new high in 2024, even as industrial process emissions dipped modestly—proof that incremental progress will not self-propel to net zero. On the other hand, foundational elements that were missing five years ago are coming into view: product standards for green steel and low-carbon cement are moving from pilots to procurement policy; border measures are aligning carbon cost signals across jurisdictions; and multi-country infrastructure (CO_2 transport and storage, hydrogen corridors) is becoming politically thinkable.

This article takes that sense of urgency seriously and advances a pragmatic thesis: industrial decarbonisation will succeed only where policy and markets are deliberately coupled. Getting that coupling right requires moving beyond single-instrument debates (carbon pricing versus subsidies, standards versus trade measures) toward a system design that aligns five catalysts—strategic policy frameworks, budget credibility, finance mobilisation, climate-aligned fiscal policy, as well as capacity and institutional strength.

II. The missing link: policy-enabled market transformation

The industrial transition illustrates a paradox at the heart of climate economics: technological progress has never been faster, yet investment in heavy industry decarbonisation remains extremely slow. The explanation lies not in the absence of innovation, but in the lack of credible, durable, and internationally consistent policy signals. In other sectors—renewables, batteries, and increasingly electric mobility—cost declines combined with supportive frameworks have allowed markets to drive diffusion (Bauer 2024; Bauer 2025). In heavy industry, by contrast, markets alone will fail. Asset lifetimes extend over several decades, capital intensity is extreme, and value chains are deeply embedded in global trade. These features mean that firms will not risk billions on first-of-a-kind technologies without the assurance that the regulatory and market environment will remain stable long after electoral cycles shift.

Recent evidence underscores the scale of the challenge. Industry directly emitted 2.7 giga tonnes (Gt) of CO_2 in 2022 from industrial processes, accounting for a significant portion of global energy-related emissions. Most of these emissions were concentrated in steel, cement, and chemicals production (IEA 2025). The IEA's Net Zero Roadmap calculates that by 2030, about 35% of necessary emission reductions in industry must come from technologies still at prototype or demonstration stage, such as hydrogen-based steel, Carbon Capture Utilisation and Storage (CCUS) -integrated cement, or low-carbon chemicals (IEA 2023). These technologies will not go from pilot to commercial maturity without deliberate public policy intervention, because the business case remains negative under current carbon prices and market structures.

EU CBAM demonstrates the risks of fragmented or transitional frameworks. While CBAM is a pioneering attempt to equalise carbon costs on imports, its phased implementation and the simultaneous free allocation of EU-ETS allowances until 2034 create ambiguity for investors. Producers are uncertain whether carbon costs will truly bite in the short term, which weakens incentives to commit to high-risk decarbonisation investments (Das and Bandyopadhyay 2025). Similarly, several emerging markets and developing economies (EMDEs) have announced long-term climate neutrality pledges but have not embedded them into fiscal budgets or industrial roadmaps. Nationally Determined Contributions (NDCs) articulate national ambition in percentage terms but often fail to specify the role that different subsectors will bear in the transformation burden, how infrastructure (hydrogen pipelines, CO_2 transport and storage) will be financed, or what competitiveness measures will mitigate transitional risks. The result is a credibility deficit: investors discount the promises heavily, knowing that the link between abstract targets and operational policy is tenuous (Pauw et al. 2019).

This disconnection between climate ambition and industrial policy implementation produces stop-go dynamics. Governments announce new pledges, firms initiate pilots, but once financing cycles reveal that the enabling conditions are not in place, investments stall. A second, subtler issue is that many policies are designed without sufficient integration of business perspectives. Industrial firms understand cost curves, infrastructure bottlenecks, and global competition in ways governments often cannot. Where policies have been co-designed with industry, they have rapidly created bankable instruments. Germany's H_2Global (H2 Global Foundation 2025) mechanism is illustrative: through iterative engagement with producers and buyers, policymakers designed two-sided contracts that stabilise revenues and hedge against market volatility, creating an investable instrument at scale.

The conclusion is that the failure of market-led industrial decarbonisation is not primarily a problem of technology cost curves, but of institutional economics. Long-lived, capital-intensive assets require a level of policy insurance that markets cannot self-generate. By pooling political will, standardising definitions, and facilitating convergence across borders, policy risks can be converted into policy certainty—the missing link without which markets cannot mobilise at scale (Coveri et al. 2020).

III. The five catalysts for accelerated industrial decarbonisation

The transformation of industrial systems is not a linear process. It cannot be reduced to the diffusion of a single technology or the enactment of one “silver bullet” instrument. Instead, successful transitions emerge when multiple elements—policy frameworks, fiscal anchors, financial mobilisation, market signals, and institutional capacity—operate together in a reinforcing cycle (De Propis et al. 2021; Nilsson et al. 2021). History shows this clearly: renewable energy only became globally competitive once governments combined long-term policy targets, feed-in tariffs or auctions, concessional finance, and Research and Development (R&D) support into an integrated system. The same will be true for industry. A single carbon price, a one-off subsidy, or a procurement standard cannot by itself mobilise the volume of finance required to decarbonise the industrial sector. What is needed is an ecosystem of catalysts that accelerate change by reducing risk, creating scale, and embedding credibility, goals that are in line with the work done under Pillar II of the Climate Club’s overarching strategy.

These catalysts are interdependent. Each one loses potency in isolation but becomes transformative when combined with the others. For example, a green steel project will not proceed if fiscal incentives are strong, but standards are absent; nor will it succeed if standards exist, but finance cannot be mobilised at scale. The missing link in most countries is precisely this systemic approach: policies are introduced piecemeal, with little regard for coherence or sequencing. By conceptualising industrial decarbonisation through five interlocking catalysts: strategic policy frameworks, budgetary credibility, finance mobilisation, climate-aligned fiscal policy, and institutional capacity, we can begin to design transitions that are both faster and more resilient.

The first catalyst is the establishment of strategic public policy frameworks. These frameworks must integrate industrial decarbonisation into national economic planning, not treat it as a marginal climate add-on. This means that NDCs and long-term climate strategies must be explicitly translated into sectoral roadmaps, setting out clear milestones for heavy industry, energy-intensive processes, and infrastructure development. The IEA’s Policy Toolbox for Industrial Decarbonisation produced for the Climate Club (IEA 2024) emphasises the need for policy certainty to create the demand pull necessary for firms to invest. The European Union’s Net-Zero Industry Act exemplifies this approach by embedding industrial decarbonisation into the Union’s broader competitiveness agenda, with measurable targets for manufacturing capacity and CO_2 storage.

The second catalyst is budgetary credibility. Commitments without budgetary anchoring are hollow. Too often, governments announce climate-neutrality targets that are not reflected in national budgets, leading to underinvestment and eroded trust. Budgeting is where ambition meets reality. Climate budgeting practices—such as those pioneered in the United Kingdom and increasingly adopted in OECD countries—demonstrate how explicit links between emissions targets and expenditure lines improve transparency and accountability. For industry, this matters because large-scale decarbonisation requires infrastructure (hydrogen pipelines, CO_2 transport and storage, grid expansion) that only public budgets can de-risk in the early stages (Nurdiawati and Urban 2021). Without visible fiscal allocations, private actors assume that commitments are rhetorical.

The third catalyst is private finance mobilisation. Industrial decarbonisation will require unprecedented investment: the IEA estimates over $3 trillion annually in clean energy and industrial systems by 2030, a large share of it in EMDEs (IEA 2025). Private capital will not flow at the required scale unless public finance is deployed strategically to reduce risks through budgetary commitments, as mentioned previously. Instruments such as blended finance, concessional loans, and guarantees are critical. But the private sector needs to respond to those signals, seizing the opportunities generated by forward-looking policy frameworks and budgetary signals by steadily scaling up channelling finance investments in ways that support industrial decarbonisation. This means proactively divesting from carbon intensive activities and investing in lower intensity industrial processes. Investment mobilisation in the private sector should not be merely reactive but actively support innovation and invest in new solutions and ventures.

The Climate Club's call for research in support of private capital mobilisation for industry is consistent with this aim. The Just Energy Transition Partnerships (JETPs) in South Africa and Indonesia illustrate how multi-country platforms can leverage public finance to crowd in private capital for large-scale infrastructure. Yet these arrangements remain *ad hoc* and fragmented.

The fourth catalyst is the alignment of fiscal policy with climate goals. Industrial decarbonisation will not succeed if fiscal regimes continue to favour carbon-intensive production through subsidies, tax breaks, or unpriced externalities. Reforming subsidies and introducing climate-aligned taxation is politically difficult but indispensable. For example, the gradual introduction of the EU's CBAM reflects an effort to level the playing field by internalising carbon costs into traded goods. Similarly, Japan's Green Transformation strategy is using fiscal tools—GX transition bonds, preferential tax credits—to incentivise decarbonisation while maintaining competitiveness.

The fifth and final catalyst is capacity and institutional strengthening. Even the best-designed policies fail without robust institutions to implement them. Many EMDEs lack technical capacity in Measurement, Reporting, Verification (MRV) systems, regulatory design, or project structuring. Without these capabilities, commitments remain aspirational, and industrial sectors risk premature deindustrialisation (Tyler and Hochstetler 2021). Industrial value chains are increasingly global, and a failure to build low-carbon capacity in developing countries would fragment supply chains, destabilise markets, and increase geopolitical tensions. The Climate Club's focus on capacity development, policy consultation, and advice, another element of Pillar III of its Terms of Reference, lucidly addresses this challenge.

Taken together, these five catalysts form a systemic architecture for accelerated industrial decarbonisation. Strategic frameworks provide direction, budgets signal credibility, adequate financial instruments allow for capital mobilisation, fiscal policy reshapes incentives, and institutions ensure implementation. None of these levers is sufficient on its own; all are necessary together. The originality of this framework lies not in the identification of each element, but in their integration into a coherent system. Industrial decarbonisation must go from a fragmented set of national experiments into a co-ordinated global transition.

IV. Tailoring solutions: avoiding a one-size-fits-all approach

Industrial decarbonisation is often portrayed as a global project with universal solutions. In practice, however, pathways diverge dramatically depending on national starting points, resource endowments, institutional capacity, and integration into global value chains. Treating this heterogeneity as an inconvenience to be smoothed away is a strategic error. Instead, recognising diversity and designing differentiated strategies is central to preventing both economic disruption and political backlash.

The risks of ignoring these differences are particularly acute in EMDEs. Many of these countries face the double challenge of growing industrial demand and limited fiscal and technological capacity. Industrial sectors are not only sources of emissions but also pillars of employment, export earnings, and urbanisation. Policies that impose uniform carbon costs or product standards without transitional support can inadvertently trigger premature deindustrialisation: the erosion of industrial capacity before economies have diversified or moved up the value chain (Özçelik and Özmen 2023; Ravindran and Babu 2023; Islami and Hastiadi 2020). This is not an abstract risk; development economists have already documented premature deindustrialisation in parts of Africa and Latin America, where manufacturing declined as a share of gross domestic product at levels of income far lower than those of advanced economies. Climate-aligned trade measures could accelerate this dynamic if implemented without attention to fairness.

The solution is not to abandon ambitious measures but to tailor them. This requires building a Just Industrial Transition Framework: a conceptual architecture that links decarbonisation directly to industrial modernisation and economic upgrading. Such a framework would include three interlocking components. First, differentiated timelines that allow EMDEs industries longer adjustment periods while providing credible trajectories toward convergence (Krawchenko and Gordon 2021; Upham et al. 2022). Second, targeted transitional finance, blending concessional public capital with private investment to reduce cost-of-capital barriers (Weller et al. 2024). Third, structured technology partnerships that facilitate access not only to equipment but also to know-how, standards, and managerial capacity. Together, these elements would ensure that decarbonisation does not penalise late-industrialising economies but rather accelerates their integration into the markets of the future.

V. Conclusion

Industrial decarbonisation is no longer a matter of technological feasibility; it is a question of speed, scale, and credibility. The technologies to abate the bulk of industrial emissions already exist or are close to commercial readiness. The global policy environment is gradually shifting. Governments are increasingly supporting low-carbon manufacturing, reforming fiscal regimes, and experimenting with standards and border adjustments. What remains uncertain is whether these disparate efforts will converge into a coherent global transformation or fragment into competing and inefficient regimes. The difference between these outcomes will determine not only the pace of emissions reduction but also the distribution of industrial competitiveness in the twenty-first century.

NDCs and the corresponding policy and regulatory frameworks needed to turn aspirations into implementation can help avoid fragmentation, inconsistency, and inefficiencies both nationally and internationally. Those instruments are at the heart of climate action and can be the basis for a more systemic approach that addresses the heterogeneity of national circumstances and contribute to the success of decarbonisation strategies in both the public and private sectors. The Climate Club is ideally placed to support this integrated approach and promote a more comprehensive and coherent approach to industrial decarbonisation across the globe.

The next decade is decisive. Industrial investments made before 2035 will lock in emissions trajectories well beyond 2050. If decarbonisation is not embedded into these investment decisions now, the window to meet the 1.5 °C target will close irreversibly. Yet, the same decade also offers a unique opportunity: climate policy is no longer peripheral; it has become industrial policy. Major economies are competing to attract clean manufacturing, and firms are beginning to integrate low-carbon strategies into their core business models. This urgency-opportunity nexus creates the conditions for an accelerated transformation—if, and only if, policy and markets can be aligned at scale.

The stakes extend beyond emissions. Industrial decarbonisation will shape the competitiveness of economies, the structure of global trade, and the resilience of supply chains. Done well, it can drive innovation, create quality jobs, and open new markets. Done poorly, it risks creating new fault lines in the global economy: between those able to finance transitions and those left behind, between regions with convergent standards and those excluded, between ambition and implementation. The question is not whether industrial decarbonisation will happen, but whether it will happen as a co-operative and inclusive process or as a fragmented and destabilising one.

Patricia Espinosa Cantellano

For over 40 years, Ambassador Patricia Espinosa Cantellano has worked successfully in the fields of diplomacy, international relations, and sustainable development. Her experience in national and international forums has enabled her to contribute to numerous projects with regional or global impact, particularly in areas related to sustainability, green growth, multilateralism, environmental protection, gender equity, and human rights. She is a Founding Partner and CEO onepoint5. Previously, she has acted as Executive Secretary of the United Nations Framework Convention on Climate Change (Undersecretary General) for 6 years, Ambassador of Mexico to Germany for 4 years, Mexico's Secretary of Foreign Affairs for 6 years, Ambassador of Mexico to Austria, Slovakia, Slovenia and the UN Organizations in Vienna for 4 years. Patricia has also received multiple international awards and decorations, speaks four languages and loves spending time with her family.

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10 Whole-system frameworks for advancing industrial decarbonisation

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Abstract

Industrial decarbonisation is crucial in our global efforts to mitigate climate change, prompting countries to adopt a mix of policy instruments to cut industrial emissions. Approaches vary widely due to differences in economic development, geopolitical priorities, and technological options. Identifying "what works" and ensuring policies are both effective and inclusive is critical for the long-term success of industrial transitions. Whole-systems strategies that integrate technological, economic, and social factors have proven effective in closing the implementation gap for industrial decarbonisation, especially for clusters (i.e. hubs of high-emitting facilities). The UK's Industrial Decarbonisation Research and Innovation Centre (IDRIC) pioneers a whole-systems approach to decarbonising industrial clusters, integrating multidisciplinary research and innovation. Inclusive whole-systems governance frameworks help ensure policy stability, integrate community voices, and support a just transition. At the global level, the Climate Club intergovernmental forum could advance these whole-systems approaches by harmonising standards, sharing best practices, and co-ordinating investment approaches.

I. Introduction

Industrial decarbonisation is a multifaceted challenge in the pursuit of a global net-zero economy. The industrial sector encompasses a wide variety of energy- and emissions-intensive processes, including high-temperature operations in the manufacturing of cement, ceramics, glass, paper, steel and refining. Each process presents specific technical requirements, fuel use patterns, and product value chains, resulting in varied approaches to decarbonisation. Tackling these emissions (16 gigatonnes of carbon dioxide per year (Gt CO_2/year), 43 % of total emissions) requires more than isolated technological solutions or marginal improvements in efficiency. It demands a comprehensive and co-ordinated strategy that considers the complex interdependencies among energy supply, industrial operations, infrastructure, markets, and policy frameworks. Adopting a whole-systems approach allows stakeholders to fully understand these relationships and to design effective interventions that achieve emissions reductions,

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while supporting economic competitiveness, resource optimisation, and social equity (Government Office for Science 2020).

Central to this approach is the use of advanced analytical and modelling tools that support evidence-based decision-making. These tools can simulate industrial energy flows, assess technology readiness and costs, and evaluate scenarios for scaling low-carbon solutions such as hydrogen, carbon capture, electrification, and circular material use. Moreover, they help identify cross-sector synergies; for example, shared CO_2 transport infrastructure or industrial symbiosis between neighbouring facilities. By integrating such analysis into industrial strategy and policy, governments and industries can design coherent, cost-effective, and resilient pathways to decarbonisation. In other words, they move beyond isolated interventions toward systemic transformation, where technological innovation, infrastructure planning, market creation, and workforce development are aligned to deliver lasting progress toward a net-zero industrial economy.

II. Whole-Systems Approach to Industrial Decarbonisation

A. Why a whole-systems approach is needed

The industrial sector encompasses a wide range of manufacturing operations that are closely interconnected sharing energy infrastructure and material supply chains. Consequently, potential solutions, including energy and resource efficiency, electrification, hydrogen, carbon capture, utilisation and storage (CCUS), compete for similarly limited resources. Comprehensive whole-systems analysis identifies systemic bottlenecks, e.g. grid congestion, limitations in hydrogen pipeline infrastructure, and the pace of CCUS storage deployment. This approach also highlights sequencing and lock-in risks. Whole-systems insights can inform policy design by evaluating the timing of incentives, strategies for industrial clusters, carbon pricing mechanisms, and border adjustments through an assessment of economy-wide impacts and trade-offs, including spillovers from mitigation policies (OECD 2024).

Moreover, bridging the implementation gap in industrial decarbonisation is a complex challenge, involving addressing multiple and interconnected challenges that are briefly described below. Given the complexities and interconnectivity of these challenges, a whole-systems approach is essential.

Technology: Many decarbonisation technologies, such as green hydrogen, CCUS, and direct electrification of high-heat processes, are not yet deployed at an industrial scale. Early deployments may face operational inefficiencies, downtime, or safety concerns. Investing in transitional solutions like blue hydrogen may delay the adoption of more sustainable long-term options.

Environment: Large-scale biomass use, land-intensive renewables, or water-intensive hydrogen production could create new sustainability challenges. Overreliance on carbon capture may perpetuate fossil fuel use and lock in high-carbon infrastructure. Industrial electrification could overwhelm grids if renewable deployment and energy storage do not keep pace.

Society and workforce: The shift to green technologies may disrupt traditional industrial roles, necessitating large-scale retraining. Industrial regions dependent on fossil-based industries risk economic decline without just transition measures. Rising costs from decarbonisation could be passed to consumers, disproportionately affecting low-income households.

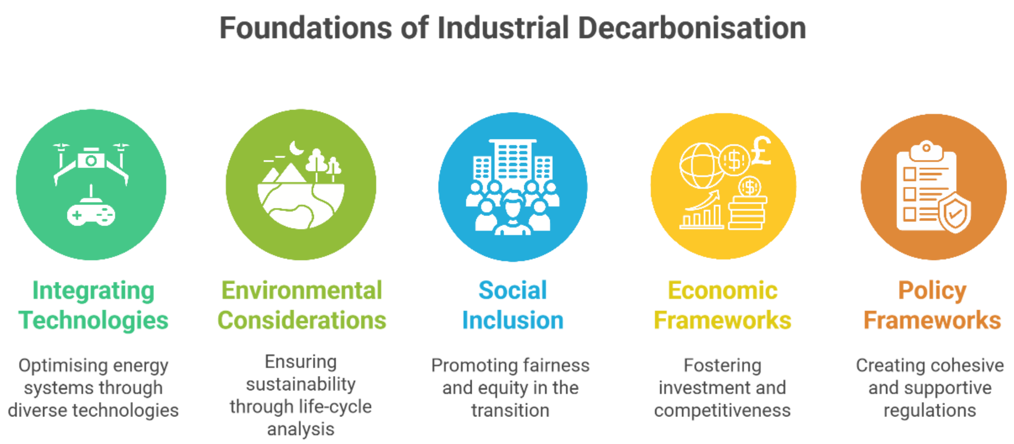
Finance: Transitioning to hydrogen, CCUS, electrification, or new processes requires substantial capital investment, with many projects having uncertain payback timelines. Existing fossil fuel-based plants, pipelines, and equipment may become stranded assets, losing value before the end of their design life. Industries in regions with slower decarbonisation may enjoy cost advantages, leading to carbon leakage, where production shifts abroad to avoid stricter standards. Additionally, dependence on renewable power or green hydrogen could expose industries to fluctuating energy costs if supply chains are immature.

Policy: Decarbonisation technologies depend on critical minerals like rare earths, lithium, cobalt, and nickel, which are often concentrated in politically sensitive regions. Countries may weaponise access to green technologies or resources, similar to historical oil and natural gas dynamics. Carbon border adjustment mechanisms (CBAMs) or subsidies could trigger trade tensions between partners.

B. Whole-systems thinking

The whole-systems approach to industrial decarbonisation represents a comprehensive framework that integrates technological, environmental, social, economic and policy dimensions. This approach recognises that achieving net-zero emissions requires co-ordinated transformation across interconnected technologies, systems and stakeholder networks, building upon effective sectoral actions, while leveraging interdependencies, promoting co-benefits and ultimately preventing unintended consequences. The key principles of whole systems-approach to industrial decarbonisation are presented in Figure 1 and described below.

Figure 1: Key principles of whole-systems approach to industrial decarbonisation.



Integrating technologies: The technological dimension of a whole-systems approach to industrial decarbonisation involves integrating various energy sources, technologies, and demand-response systems to optimise the energy system and reduce waste (Roberto and Jamison, 2021). This includes for example co-ordinated deployment of renewable generation, hydrogen production, carbon capture and storage (CCS), and smart digital monitoring systems. Recognising the interconnected nature of these technologies enables cumulative emissions reductions that exceed the sum of individual contributions. Digital technologies enhance energy efficiency and create intelligent management systems for real-time monitoring and adjustment of industrial processes.

Environmental considerations: Integrating environmental considerations into a whole-systems approach for industrial decarbonisation ensures emission reductions support overall sustainability. This approach embeds Life Cycle Assessment (LCA) to minimise impacts and applies circular economy principles to reduce emissions and maintain ecosystem integrity. Moreover, integration of nature-based solutions and appropriate monitoring, reporting and verification (MRV) methodologies foster resilient, low-impact industries that further climate and ecological goals.

Social inclusion and just transition: Whole-system approaches integrate the social dimension of decarbonisation to ensure transitions are inclusive and do not worsen social inequalities. A just transition recognises that the impacts and influence over climate policies are unevenly distributed across societies and time (Sovacool et al. 2025a). This approach also addresses job creation by considering job quality, security, access, and required skills, supported by retraining, redeployment, and compensation schemes for those negatively affected by the transition.

Economic frameworks: A whole-systems approach addresses the high upfront costs for decarbonisation infrastructure and enables plant-level investment by fostering economic co-ordination and recognising that no single organisation controls all emissions sources. Integrated strategies can cut operational emissions by up to 50%, improve energy resilience, optimise investments, and lower technology risk. The framework includes shared commercial structures to fairly allocate risks, assign innovation rights, and distribute benefits, encouraging business models that aid decarbonisation whilst promoting competitiveness (OECD 2025b).

Cohesive policy and regulatory frameworks: The coherent integration of cross-sector policy and regulatory dimensions as part of a whole-systems approach is critical to ensure that they complement industrial decarbonisation goals and to avoid fragmented or conflicting incentives (IEA 2025a). Moreover, long-term certainty and predictable policy signals are essential to promote investment in low-carbon technologies and encourage adoption of innovative solutions such as electrification, hydrogen, and CCUS. Policies must also ensure a just transition for workers and communities. Flexible regulation, standards, and collaboration are key to decarbonising industries.

Moreover, the whole-systems approach to industrial decarbonisation offers multiple interconnected co-benefits at local, national, and global scales (Sovacool et al. 2024). In addition to reducing emissions, these initiatives generate employment opportunities, strengthen community resilience, improve public health outcomes, enhance trade competitiveness, promote innovation, and contribute to geopolitical advantages. Whole-systems thinking enhances coherence by identifying leverage points, demonstrating the scale of transition challenges, and revealing synergies and trade-offs between decarbonisation strategies. This leads to co-ordinated services, multidisciplinary teams, and shared vision, reducing inefficiencies, enabling rapid innovation, facilitating collaboration, and reducing delays and regulatory obstacles. Finally, whole-systems approaches promote inclusivity, ensuring community engagement, local benefits, and preventing social backlash through transparent communication and just transition provisions.

III. Whole-systems analytical and modelling tools

A comprehensive systems approach to industrial decarbonisation requires the use of tools capable of addressing the intricate interactions among technologies, resources, infrastructure, policies, and societal factors. Such tools enable decision-makers to evaluate various scenarios, assess potential trade-offs, and formulate integrated strategies aimed at accelerating progress towards net zero emissions.

Adopting a whole-systems perspective acknowledges that an industrial facility operates as a node within an extensive network of energy, material, financial, and informational flows. By incorporating energy inputs, material flows, infrastructure dependencies, and economic and policy factors, these models provide a comprehensive perspective on system interdependencies, enabling the optimisation of solutions as well as the identification of synergistic opportunities. Decarbonising a single component in isolation, without evaluating its interconnections, may inadvertently shift emissions or result in significant inefficiencies. For example, while electrifying a steel mill with renewable energy appears advantageous, it could compromise grid stability or introduce substantial embodied carbon through new equipment. A range of robust tools are available for whole-systems thinking, as outlined below, and summarised in Figure 2.

Energy Systems Models (ESM) simulate the interactions among energy supply, demand, and emissions to identify optimal decarbonisation strategies (Bendigiri and Rao, 2023). These models provide a comprehensive representation of the entire energy system, encompassing production, conversion, and end use. They enable users to assess how various technologies, fuels, and policy measures can be leveraged to achieve emissions reduction objectives in a cost-efficient manner. They offer a technology-rich, optimisation-driven framework. In industrial contexts, ESMs can analyse sector-wide energy consumption and greenhouse gas (GHG) emissions across multiple scenarios. By considering infrastructure, costs, and resource availability, these models inform policymakers and businesses on strategic investments in low-carbon energy supply and industrial processes. These tools can be used to identify optimum mix of technologies and the broader impacts of industrial decarbonisation measures, including for example how electrification or hydrogen adoption may influence grid demand, infrastructure requirements, and energy prices.

Material Flow Analysis (MFA) tools systematically track the movement of specific materials through the industrial system from extraction to disposal (Allesch and Brunner 2015). MFA helps identify opportunities for intervention and supports the development of a circular economy by enabling industries to recognise potential areas for resource recovery, recycling, and material substitution. When combined with economy-wide input–output analysis, it demonstrates interdependencies across sectors and indicates where efficiency improvements may influence supply chains. For example, when integrated with the principles of industrial symbiosis (Xin et al. 2024), MFA facilitates the mutually beneficial exchange of materials, energy, water, and by-products among industries that traditionally operate independently. Geographic Information Systems (GIS)-based platforms enable the mapping of material and energy flows within industrial parks, highlighting instances where waste heat from one facility can serve as process energy for another, or where CO_2 emissions may be captured and reused as raw material. Such practices transform waste into a valuable resource, contributing to both emission reductions and lower raw material expenditures.

Life Cycle Assessment (LCA) is an essential tool for adopting a comprehensive systems perspective and facilitating industrial decarbonisation in a sustainable manner (McManus et al. 2025). LCA is a systematic approach designed to assess the environmental impacts associated with a product, process, or service throughout its entire life cycle—from raw material extraction, manufacturing, and distribution, through use and maintenance, to end-of-life disposal or recycling. This methodology examines the "cradle to grave" (or alternatively, "cradle to cradle") environmental footprint, enabling the identification of critical impact points such as GHG, energy consumption, water usage, and pollution, thereby providing actionable insights for enhancing sustainability. Furthermore, LCA mitigates the risk of "burden shifting," wherein addressing one environmental issue inadvertently leads to another; for example, replacing fossil fuels with biomass may lower operational carbon emissions but can affect land-use patterns. However, inconsistencies in methodologies, such as inconsistent system boundaries, carbon accounting techniques, and data quality, can impede cross-sector comparisons and limit reproducibility (OECD 2025a). Achieving effective industrial decarbonisation with minimal unintended consequences requires robust LCA practices, transparency, methodological consistency, standardised data repositories, and active stakeholder engagement.

Integrated Assessment Models (IAM) incorporate data from climate, economic, and energy systems to evaluate long-term sustainable development strategies (Songhua and Liu 2025). IAM integrate knowledge from diverse fields to evaluate strategies by which industries can decrease GHG, while sustaining productivity and competitiveness. These models assist policymakers and industry leaders in analysing trade-offs among technological alternatives, capital requirements, and climate objectives across various policy frameworks. IAM inform the development of climate targets, such as carbon pricing and net-zero pathways, by connecting socioeconomic factors with technological and environmental feedback, as well as highlighting cross-sectoral interactions. The incorporation of geospatial models, such as GIS, has further developed IAM by allowing the integration of spatially explicit data, such as land use, renewable resource potential, and regional climate impacts, which facilitates more localised policy assessments. Geospatial tools can address location-specific issues, such as identifying suitable sites for green hydrogen or steel plants based on proximity to renewable resources, water availability, and transport links for export. They can also help design CO_2 transport pipeline networks that connect industrial sources with offshore storage locations.

Digital Twins (DT) are dynamic, data-driven virtual representation of a physical system, continuously updated through real-time data, simulation results, and predictive analytics (Azam et al. 2024). Within the context of industrial decarbonisation, DTs offer detailed modelling of complex industrial networks, including manufacturing facilities, supply chains, and energy infrastructures, empowering stakeholders to test and optimise emissions reduction strategies. This process encompasses evaluations of electrification, hydrogen deployment, carbon capture solutions, and circular economy initiatives across various sectors. The resulting simulations enable efficient analysis of hypothetical scenarios, supporting the identification of cost-effective and resilient pathways to achieve net-zero objectives. When augmented by machine learning and geospatial information, these platforms can adapt dynamically to evolving conditions and optimise operational performance in real time. They offer a robust platform for evidence-based and adaptive decisions in industrial decarbonisation

Figure 2: Summary of tools available for whole-systems thinking.

Whole-Systems Analytical and Modelling Tools

Tool/Model	Description	Key Features	Example Use Cases
Energy Systems Modelling (ESM)	Simulates interactions between energy supply, demand, and emissions.	Technology-rich, optimisation-focused, scenario analysis.	Identify least-cost mix of technologies.
Material Flow Analysis (MFA)	Tracks flow of materials through the industrial system.	Hotspot identification, circular economy, GIS-based mapping.	Map material and energy flows in parks.
Life Cycle Assessment (LCA)	Evaluates environmental impacts from cradle-to-grave.	Whole systems view, carbon footprint, sustainability assessment.	Assess land-use impact of biomass.
Integrated Assessment Models (IAM)	Combines insights from climate, economic, and energy systems.	Policy assessment, trade-off analysis, geospatial integration.	Locate optimal sites for green plants.
Digital Twins (DT)	Dynamic, data-driven virtual replicas of physical systems.	Scenario modelling, cross-sectoral integration, real-time optimisation.	Test and optimise emissions reduction strategies.

In summary, achieving a decarbonised industrial sector represents one of the most intricate engineering and economic undertakings to date. Addressing this challenge requires moving beyond narrow or fragmented strategies into implementing whole-system tools, such as those described here. However, the effectiveness of these tools lies not in their isolated use, but in their integration. Combining tools like LCA, MFA, ESM, IAM, geospatial models, and DTs provides better insights than using them alone. For instance, an LCA on low-carbon cement can inform an MFA for waste analysis, which then feeds into national energy models and integrated assessment frameworks. Geospatial models help site facilities efficiently, while DTs enable real-time data integration, improving assumptions and updating predictions across all frameworks as new information emerges.

Whole-system models are essential resources for comprehensive decision-making, as they enable a holistic understanding of systemic interactions, help to anticipate unintended outcomes, and facilitate synergies across technology, infrastructure, and geography. The insights derived from these models can be applied to multi-criteria decision analysis (MCDA), which facilitates the deconstruction of complex decisions while considering competing objectives such as financial costs, as well as social and environmental impacts (Jamil and Aouni 2015). By systematically assigning weights to distinct criteria, MCDA enables the evaluation of multiple alternatives and promotes transparent, participatory decision-making processes (Ahmad et al. 2021).

IV. Case study: Industrial clusters

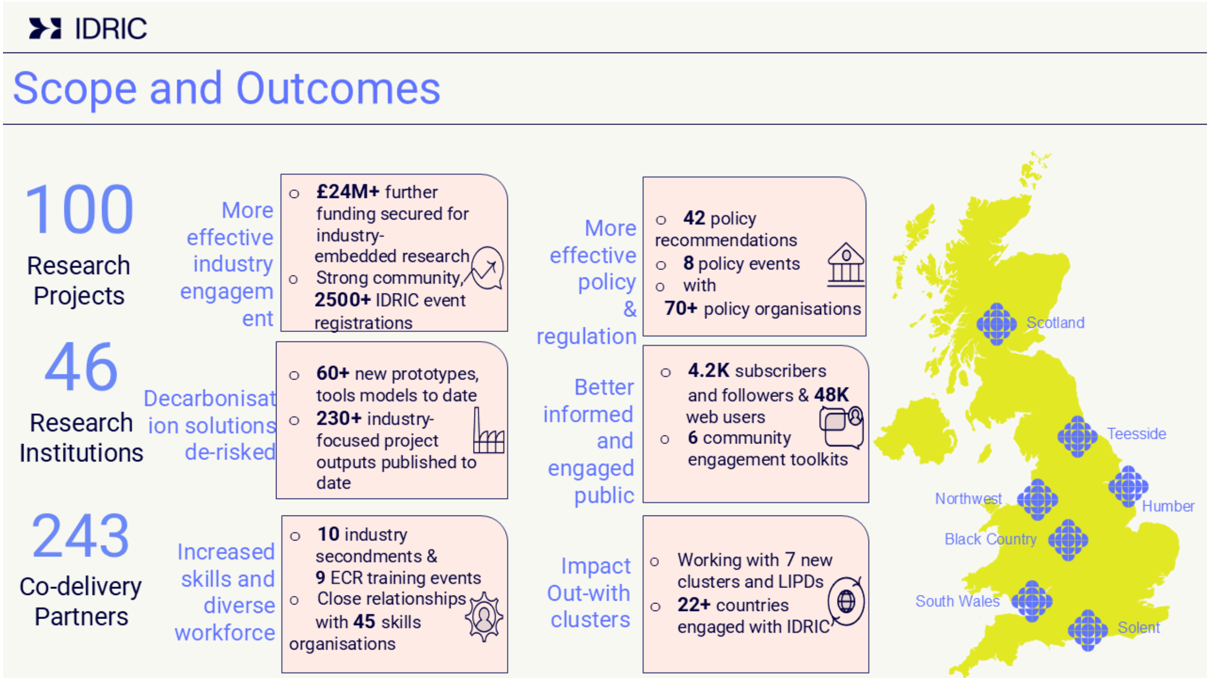
Industrial clusters are hubs of high-emitting facilities, encompassing interconnected industries, ports, and energy infrastructure, which are becoming strategic focal points for early, large-scale decarbonisation initiatives. These clusters extend beyond mere geographic proximity; they function as intricate systems, each characterised by distinct infrastructure, supply chains, workforce dynamics, governance frameworks, and social environments. Consequently, their decarbonisation requires a comprehensive whole-systems approach that integrates industrial processes, energy networks, low-carbon technologies, financial mechanisms, and community involvement across the relevant geographic region.

Industrial clusters present both significant challenges and substantial opportunities for economic growth. With more than 10,000 industrial clusters globally, transitioning just 100 clusters could result in a 5% reduction of total global CO_2 emissions and a 15% decrease in global industrial emissions, while simultaneously generating approximately 18 million jobs and contributing USD 2.5 trillion to global gross domestic product (GDP) (World Economic Forum 2022).

Industry is currently the third highest-emitting sector in the United Kingdom (UK) economy, accounting for 12% of UK emissions, 51.8 million tonnes of carbon dioxide equivalent ($MtCO_2e$) (Climate Change Committee 2025), with about half concentrated in industrial clusters such as Grangemouth, Teesside, Humber, Solent, Black Country, South Wales, and Merseyside. These areas are well suited for shared decarbonisation solutions like CCUS and hydrogen networks. The UK Industrial Decarbonisation Research and Innovation Centre (IDRIC) was established in 2021, funded by UK Research and Innovation (UKRI), initially under the Industrial Decarbonisation Challenge, to support the development of four low-carbon industrial clusters by 2030 and the world's first net-zero industrial cluster by 2040 (IDRIC 2025a; HM Government 2021).

IDRIC has emerged as the UK's leading multidisciplinary flagship for accelerating industrial decarbonisation. By using a place-based, whole-systems approach, IDRIC ensures innovations are technically, commercially, and socially viable. Rather than just pursuing new technologies, IDRIC integrates science, engineering, economics, social sciences, and policy to drive collective transformation across industrial systems, positioning the UK as a leader in industrial cluster decarbonisation research. IDRIC has established a co-ordinated, multi-disciplinary portfolio of 100 research projects with 46 research institutions and 243 co-delivery industrial partners, resulting in significant progress to derisk decarbonisation solutions (Figure 3).

Figure 3: Outputs and outcomes of IDRIC's whole systems approach and UK map of industrial clusters (2021-2024)



A. Co-creating a collaborative ecosystem

A core part of IDRIC's pioneering work has been its function as a national research and innovation integrator, establishing a whole-systems approach to co-create low-carbon solutions across the UK's industrial clusters. IDRIC's unique value is in co-creating a collaborative ecosystem of academia, industry, government, and communities to co-deliver impactful research and innovation, spanning technology, policy, economics, and regulation to accelerate the UK's path to net zero. Throughout its tenure, IDRIC has successfully engaged with more than 1000 organisations encompassing over 26 countries. Through workshops, roadshows, collaborative projects and knowledge-sharing platforms, IDRIC is breaking down sectoral silos, aligning technical, social, and policy insights for a just, effective, and resilient industrial decarbonisation. For instance, projects on carbon capture link process engineers with behavioural scientists and policy experts to address technical, financial, and social acceptance barriers in tandem.

The IDRIC Knowledge Hub provides open access to datasets, reports, and case studies from funded projects (IDRIC 2025b). Regular roundtables and policy forums, that bring together representatives from academia, government departments, regulators, and industry, are important to translate research findings into policy recommendations and align innovation, industrial strategy, climate policy, and economic development efforts.

In summary, by leveraging on IDRIC's findings and recommendations, stakeholders can develop and implement robust, data-driven decarbonisation strategies that are technically feasible, socially acceptable, and economically viable (Frontiers Report Series, IDRIC 2025c).

B. Integrating multidisciplinary research and innovation to deliver whole-systems solutions

Effective whole-system frameworks need to integrate insights from a broad spectrum of stakeholders, including researchers, industry professionals, policymakers, and members of the public. This collaborative methodology supports decarbonisation strategies that are technically sound, socially responsible, and economically sustainable. Additionally, artificial intelligence plays a critical role in improving the accuracy and efficiency of these systems, facilitating more informed predictions and superior decision-making processes (Figure 4).

Figure 4: Industrial decarbonisation assessment framework (Mehta et al. 2025).

Infrastructure development requires a regional perspective; for instance, fuel demand modelling indicates that transitioning from gas to electricity and hydrogen will likely increase demand for these energy sources in industrial areas. Early improvements to electricity networks are necessary, and hydrogen infrastructure is recommended to be developed on a national scale, starting with regionally co-ordinated hubs. The suite of simulation and modelling tools developed by IDRIC facilitates tailored analyses of emissions, energy requirements, infrastructure considerations, and cost impacts across industrial clusters, thereby supporting the creation of customised decarbonisation pathways and making informed decisions (Mehta et al., 2025).

In the UK, electrification could deliver around 57% of the emissions reductions required from industry by 2040; whilst energy and resource efficiency contribute 13%, and low-carbon technologies make the remaining reductions (CCUS, hydrogen and bioenergy contributing 17%, 7% and 5%, respectively). The mix of decarbonisation solutions differs significantly across industrial subsectors; for example, for the steel sector 96% of carbon abatement in the UK is projected to come from electrification, whilst for the cement and lime sectors, CCUS provides 62% of abatement (Climate Change Committee 2025). It should be noted that UK steel producers pay significantly more for electricity than in other countries in Europe and therefore industrial electricity pricing is a known decarbonisation bottleneck.

Comprehensive Life Cycle Assessment (LCA) is essential for directing industrial decarbonisation as it evaluates environmental impacts across entire life cycles beyond solely carbon emissions. As previously discussed, inconsistent system boundaries, gaps in data, and methodological differences impede comparability and can obscure potential adverse effects, such as toxicity or resource depletion (OECD 2025a; McManus et al. 2025). It is advised to integrate LCA methodologies early in the design process, foster circular practices, improve data sharing and transparency, and harmonise carbon accounting standards across industries. Policymakers are encouraged to promote standardised LCA frameworks, invest in early-stage assessment initiatives, and facilitate collaborative platforms to accelerate progress towards sustainable industrial transformation.

Work on socio-economic modelling has examined workforce and economic outcomes under various decarbonisation scenarios, highlighting regional differences in projected benefits (Simpson et al. 2025). Workforce planning and consideration of local economic conditions are needed to inform policy measures aimed at assessing how successfully the skills pipeline is aligning with future needs and ensuring an equitable transition. Therefore, achieving net zero requires an economic framework that encourages decarbonisation, prevents carbon leakage, fixes market failures, and promotes technology adoption and business growth.

C. Integrating policy, governance and social legitimacy in whole systems

The UK has positioned itself as a global leader in industrial decarbonisation through the adoption of comprehensive policies and regulatory frameworks. Key initiatives include the Industrial Decarbonisation Strategy (HM Government 2021)—the first of its kind worldwide—and substantial support for the advancement of CCUS alongside hydrogen technologies. Nevertheless, persistent challenges remain, including regulatory uncertainties, delays in developing effective commercial models, and the risk of excessive reliance on CCUS and hydrogen at the expense of a broader array of decarbonisation approaches. Demand-side measures are also crucial to provide certainty, considering the higher costs and risk of early deployment of technologies (IEA 2025b). These issues may pose obstacles to further progress in achieving decarbonisation objectives.

To respond to the need to address governance, regulation, and social legitimacy, whole-system governance frameworks need to be inclusive of:

- Co-ordination between energy, industry, and regional/local authorities.
- Long-term, stable policy signals to de-risk investment.
- Integration of community voices and just-transition principles.
- Cluster governance bodies empowered to co-ordinate infrastructure and stakeholder engagement.

By embedding these factors in whole-systems thinking, social and institutional realities are reflected in technical system design—a hallmark of true whole-systems analysis.

The political dynamics of industrial decarbonisation are defined by intricate relationships among industry, government, and public stakeholders (Sovacool et al. 2025b). A principal challenge is equitably distributing financial support across sectors and regions while mitigating regional imbalances and ensuring resources are allocated fairly to avoid unintended effects such as the migration of high-carbon industries. The tension between fiscal constraints and the imperative for substantial net-zero investments continues to be a significant issue for policymakers. Additionally, maintaining public confidence remains vital, as perceptions regarding employment opportunities can notably impact support for decarbonisation measures.

Securing public trust and achieving a just transition, characterised by inclusivity, equity, and local relevance, is imperative. IDRIC-supported research within the UK's industrial clusters has examined public perceptions, the concept of social licence to operate (SLO), and the importance of place-sensitive strategies that foster genuine community engagement (Lai et al. 2025). Achieving just transitions will require careful planning, inclusive decision-making, and substantial co-ordinated efforts from government, industry, and community actors. Public trust in industrial processes is influenced by transparency, perceived benefits, and fairness. IDRIC emphasises the need for locally tailored policies addressing procedural, distributive, and recognition justice (Sovacool et al. 2025b).

Industrial decarbonisation requires co-ordinated governance at all levels, considering regional industrial structures and local contexts. Policies should support smaller firms and involve affected communities, labour, and civil society to mitigate power imbalances and ensure equitable benefits. Going forward, it is recommended that authorities develop long-term strategic decarbonisation roadmaps, consider institutional innovation, ensure policy coherence, incentivise technological diversity, scale up, and encourage international learning for decarbonisation of clusters and dispersed industrial sites.

V. The role of the Climate Club in operationalising whole systems approaches on a global scale

A whole-systems approach to industrial decarbonisation, as developed by IDRIC for the UK industrial clusters (Section IV), recognises that this is not solely a technological challenge, but a multifaceted socio-techno-economic opportunity rooted in specific localities. Importantly, it necessitates moving beyond narrowly focused national policies to address the intricate global systems of trade, investment, and innovation. Nevertheless, national policy frameworks frequently remain fragmented: carbon pricing differs among jurisdictions, subsidies and border adjustments introduce trade frictions, and technology standards are inconsistent. This lack of cohesion can undermine investment certainty and contribute to carbon leakage, where industries relocate operations to areas with less stringent climate policies, resulting in offshoring and job losses. Addressing these systemic misalignments is the aim of a whole-systems perspective, integrating technology, market dynamics, governance, and societal factors into a unified and coherent framework.

Within this context, the Climate Club is emerging as a critical actor in implementing and institutionalising a comprehensive global approach to industrial decarbonisation, addressing systemic challenges that unilateral national policies alone are unable to resolve (IEA 2025a & 2025b; OECD 2024, 2025a & 2025b). The role and relevance of the Climate Club also rest on its strategic dialogues, which unite diverse members to address cross-cutting policy challenges and find shared solutions (OECD 2024). Through these exchanges, members collaborate on critical issues such as carbon leakage, just transition, community participation, value chain co-operation, and technical aspects like modelling, carbon accounting, and innovation. By fostering mutual learning and capacity building, the Climate Club can advance shared approaches that build trust and strengthen collective climate action toward a fair, effective, and sustainable low-carbon future.

Cross-border partnerships, infrastructure development, and investment are key for effective whole-system approaches that depend on fast knowledge sharing across technologies. The Climate Club can enhance collaboration by combining research and development (R&D) resources, sharing best practices, and aligning standards, which drives cost reductions and keeps industrial clusters compatible. It can also support joint infrastructure planning and finance by co-ordinating projects and lowering investment risks. From a modelling perspective, this adds shared infrastructure to system optimisation, revealing network benefits among members.

The Climate Club has the potential to accelerate cross-border projects by harmonising regulatory frameworks, technical standards, and investment schedules among its members. This collaborative approach would establish a "super-cluster" that transcends individual nations. For example, it could enable a steel facility in one country to utilise CO_2 storage infrastructure in a neighbouring state, or facilitate the import of green hydrogen by a chemical plant from a partner nation with substantial renewable energy resources. This co-operative model reflects the principles of systems mapping on an international level, systematically identifying and connecting supply, demand, and sink nodes throughout the Club's member territories to optimise resource allocation and minimise aggregate costs.

Harmonising standards and carbon pricing are key for industrial decarbonisation, which relies on accurate accounting of embodied emissions in traded materials such as steel, cement, and aluminium. This process requires product carbon standards and certification systems to be consistent across markets. These standards enable mechanisms like CBAMs and support low-carbon product markets. When integrated with MRV platforms, they offer necessary data infrastructure for calibrating and validating models of industrial value chains. The Climate Club may address these issues by aligning standards, establishing co-ordinated carbon pricing, or implementing equivalent approaches among members. Such co-ordination would change economic incentives, making it financially practical for industries to pursue decarbonisation within their jurisdictions instead of relocating operations. This approach could shift global competition towards higher universal standards and generate a broad demand for green industrial products across multiple economies.

VI. Conclusions

Industrial decarbonisation is essential for mitigating climate change and requires comprehensive whole-systems strategies that integrate technological, economic, social, and policy dimensions to address the complexities and interdependencies of industrial processes. By leveraging synergies and promoting co-benefits, whole-systems thinking can accelerate decarbonisation, enhance innovation, and ensure just transitions. IDRIC exemplifies this approach, fostering multidisciplinary collaboration and developing advanced modelling tools to support data-driven decision-making. The Climate Club through its strategic dialogues can further operationalise these frameworks on a global scale, harmonising standards, facilitating cross-border partnerships, and promoting co-ordinated investments. Ultimately, achieving net-zero emissions in industry requires aligning infrastructure, governance, data, and people, creating a blueprint for systemic industrial transformation.

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Acknowledgements

This work was supported by the UK Industrial Research and Innovation Centre (IDRIC), through awards EP/V027050/1 under the UKRI ISCF Industrial Challenge/ Industrial Decarbonisation Challenge (IDC) and also EPSRC award EP/Z53125X/1. The author is grateful to Jil S.-IDRIC, for support producing the figures and editing the manuscript

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11 Inclusive industrial decarbonisation policies to effectively integrate energy, climate, and development goals in emerging and developing economies

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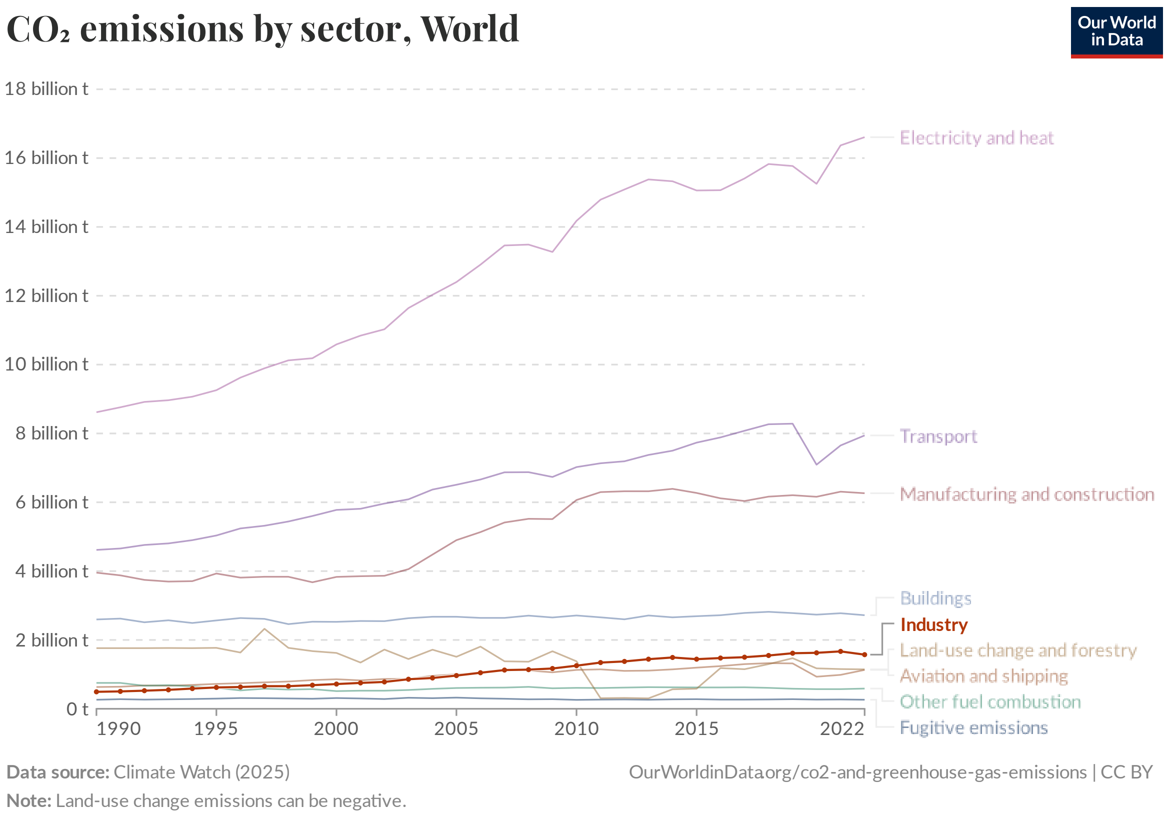
Abstract

Industrial decarbonisation is a critical pillar of the global energy transition, accounting for 37% of total final energy use and one-third of global greenhouse gas (GHG) emissions. Reframing heavy industries from "hard-to-abate" to "priority-to-abate" is essential to accelerate progress in energy efficiency, renewable energy, hydrogen, and carbon capture. For developing economies in Sub-Saharan Africa, Asia, and Small Island Developing States (SIDS), this represents an opportunity to leapfrog towards green industrialisation by adopting scalable low-carbon technologies and localising value chains. This article highlights the strategic importance of industrial decarbonisation, outlines pathways for sustainable industrial growth, and proposes a global partnership framework enabling inclusive and equitable green transformation across emerging economies.

I. Trends in industrial emissions

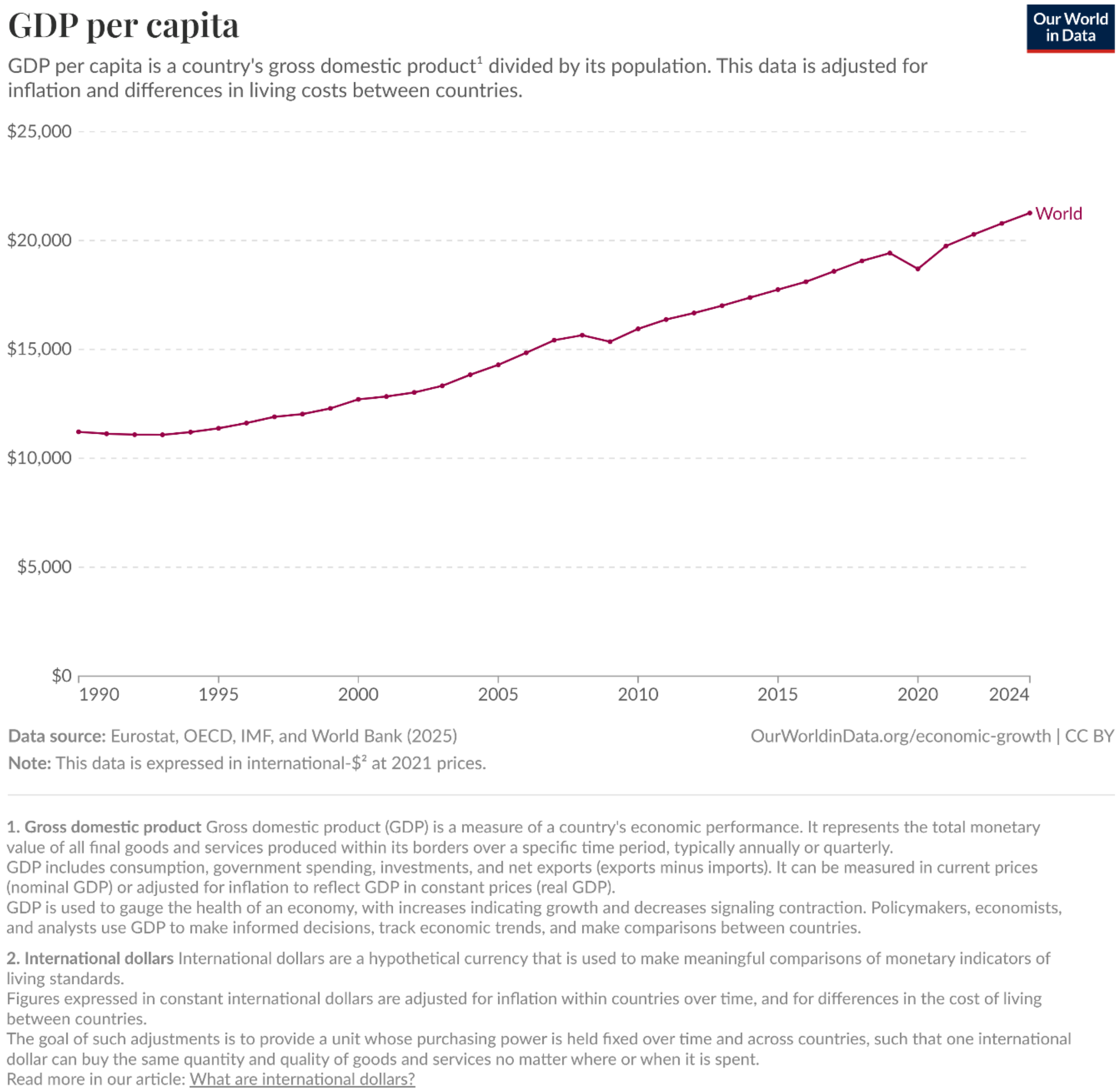
Historical trends indicate that industrial emissions have grown steadily since 1990, albeit at a slower pace than in sectors such as electricity, heat production, and transportation, as shown in Figure 1. Driven by rapid industrialisation and global economic integration, the demand for materials such as steel, cement, chemicals, textiles, food and beverages, and pulp and paper has expanded significantly, resulting in a threefold increase in industrial greenhouse gas (GHG) emissions since 1990. Industrial emissions are increasing faster than those in any other primary sector. Between 1990 and 2020, global emissions from heavy industry rose by nearly 70% (Verdolini et al. 2023).

Figure 1: CO_2 Emissions by Sector (1990-2021) (Source: Our World in Data)



Over the same period, global gross domestic product (GDP) per capita has more than doubled, rising from approximately USD 7,000 in 1990 to over USD 16,000 in 2022 (in 2011 US dollars), as shown in Figure 2. This parallel growth underscores the strong linkage between industrial output and economic development, highlighting the sector's dual role as both a driver of prosperity and a source of emissions. Advanced economies have gradually decoupled economic growth from emissions through efficiency gains and structural shifts toward value-added manufacturing and services. At the same time, emissions in emerging economies have surged as heavy industries relocated from advanced economies. Cement and steel emissions alone have multiplied two to three times since 1990, particularly in Asia and Africa, while in advanced economies, emissions have stabilised or declined.

Figure 2: GDP per Capita (1990-2022) (Source: Our World in Data)



Emerging economies, such as China (1.23 gigatonnes of carbon dioxide equivalent ($GtCO_2e$) industrial emissions in 2021), India (178.61 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 2021), and Brazil (37.35 $MtCO_2e$ in 2021) (Climate Watch 2025), are now driving the bulk of emissions growth, fuelled by rapid urbanisation and infrastructure expansion. Developing and least developed economies contribute far less to absolute terms but often exhibit higher emission intensities due to outdated technologies and limited access to low-carbon alternatives. This divergence highlights the core challenge of aligning industrial growth with decarbonisation. In Sub-Saharan Africa, energy efficiency improvements and electrification with renewables—often through captive generation—represent cost-effective pathways to power light industries, overcome unreliable grid access, and establish a competitive industrial base. The persistence of the emissions-growth link makes clear that achieving rising prosperity while lowering carbon intensity will require innovation, strong policy support, and the widespread deployment of low-carbon solutions. This trend highlights the uneven distribution of industrial emissions: relocating production does not alleviate the global environmental burden, and vulnerable populations often bear the brunt of these impacts.

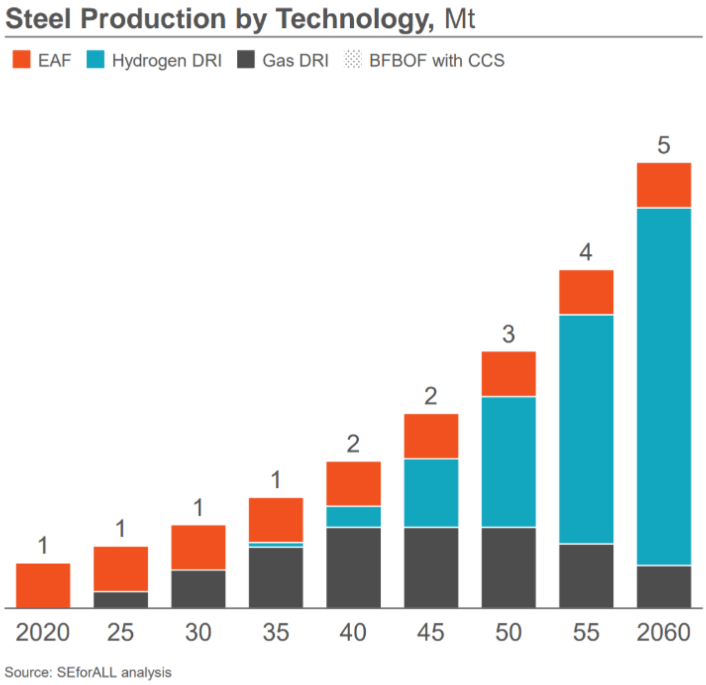
Framing a global partnership architecture for industrial decarbonisation cannot be viewed solely through an emissions lens. The interventions in energy efficiency and the electrification of industrial processes with renewable energy also serve as a fulcrum for industries to become cost-competitive in the future. In Sub-Saharan African countries, the adoption of captive generation with renewable energy is a cost-effective means of powering commerce and light industries, laying the groundwork for an industrialised economy by overcoming the lack of access to or the unreliability of grid electricity. The persistence of this link highlights the challenge of achieving rising prosperity worldwide while reducing industrial carbon intensity through innovation, policy support, and the widespread adoption of low-carbon solutions.

II. Policy and technology bottlenecks

Emission reductions in hard-to-abate industries such as cement, steel, chemicals, and aluminium will hinge on rapid technology scale-up and significant reductions in capital costs. As electricity will increasingly be generated from renewable sources, hydrogen—both as a fuel and a feedstock, especially in electric arc furnaces—and Carbon Capture, Utilisation, and Storage (CCUS) are among the technologies that need rapid scaling. At the same time, efficiency improvements in industrial motors, boilers, and drives remain indispensable. While breakthrough technologies such as hydrogen steelmaking and electric arc furnaces dominate discussions, incremental improvements in high-efficiency motors, variable-speed drives, and advanced boilers can deliver substantial near-term emission reductions. For emerging markets and developing economies (EMDEs), where industrial infrastructure is still being built or modernised, integrating the best available technologies from the outset can prevent decades of inefficiency and lock-in to high-emissions systems. Combined with clean electricity and low-carbon fuels, these measures enhance industrial resilience, reduce costs, and strengthen global competitiveness.

Nevertheless, many transformative technologies remain nascent, expensive, and concentrated in a handful of countries, leaving developing economies with limited access. The pace of technology transfer and diffusion has been insufficient, widening the gap between advanced economies, which can deploy breakthrough solutions, and emerging regions at risk of long-term dependence on carbon-intensive production. Addressing this disparity requires stronger international co-operation, open frameworks for technology sharing, and innovative financing mechanisms, such as concessional lending and blended finance, to lower adoption barriers.

Figure 3: Ghana Steel Sector Transition, Ghana Energy Transition & Investment Plan



For example, as per the Ghana Energy Transition & Investment Plan (Ghana Energy Transition & Investment Plan was supported by SEforALL), the nation's steel sector could grow significantly from its current base to about around 5 Mt per annum by 2060 with expansion into virgin steel production from current scrap steel mix. Hydrogen-based Direct Reduced Iron (DRI) and Electric Arc Furnaces would play a key role to ensure the sector's net-zero contribution to the national commitment. The capital cost to transitioning this sector alone is expected to be about 1.5 billion USD and majority of it hinges on technology transfer.

This challenge is evident even in China, where the steel sector accounts for over 15% of national CO_2 emissions. To meet its 2025 pledges, the government must reduce coal-based steel output by 90 $MtCO_2e$ (Reuters 2025). A shift from blast furnace-basic oxygen furnace (BF-BOF) to electric arc furnace (EAF) systems could reduce emissions by over 160 $MtCO_2e$; yet, the EAF share of production remains below 12%, significantly lower than the global average of 30% (LBNL 2023). In India, the industrial sector accounts for more than one-third of total emissions, with cement, steel, and fertilisers among the most significant untapped opportunities for mitigation (IEA 2025). Bridging these gaps will require scaling up finance, strengthening technology transfer, harmonising industrial standards, and aligning policy frameworks to support green industrial growth. Industrial decarbonisation, therefore, sits at the intersection of climate mitigation, energy transition, and economic development; its success will be decisive in achieving global net-zero ambitions.

III. Choices that developing economies make matter for industrial decarbonisation

The scale and speed at which EMDEs transform their existing and future industries into low-carbon emitting assets will be essential to climate-proofing and ensuring no roll-back of the gains achieved in industrial decarbonisation. Industrial demand in developing economies is projected to grow rapidly due to urbanisation, infrastructure development, and increasing domestic and export needs. Without clean-tech shifts, these countries would continue to rely on conventional, fossil-fuel-intensive pathways in heavy industry. They would carry the bulk of new industrial emissions, increasing their share in industrial emissions from today's 5-10% to 25-30% in the next 30-40 years (Vashold 2024). In such a scenario, even deep emission reductions achieved in advanced economies would not be sufficient to offset the continued carbon-intensive industrialisation in developing countries.

Industrial decarbonisation is a business opportunity for developing countries. Investing in low-carbon cement, hydrogen-based steelmaking, and circular material flows helps prevent stranded assets and reduces the long-term costs of transitioning away from fossil fuels. Leapfrogging directly into sustainable technologies and production methods can enhance competitiveness in international markets, for instance, where the Carbon Border Adjustment Mechanism (CBAM) would make carbon-intensive commodities more challenging to export to the European Union (EU). Building localised value chains around green industrial production strengthens economic resilience, creates high-quality jobs, and reduces reliance on volatile fossil fuel imports. These leapfrog opportunities are already being leveraged, demonstrating that emerging economies are reaping the benefits of such strategic choices. For example, India has 50% of its installed power capacity from renewables, five years ahead of the 2030 milestone (Govt. of India 2025). The creation of green hydrogen corridors and renewable-powered industrial parks (such as those in Tamil Nadu and Gujarat) reflects an emerging integration of energy and industrial planning (Mission Possible Partnership 2025). In another instance, Indonesia's nickel smelters in Sulawesi are increasingly powered by hydropower. In Malaysia, the Sarawak Corridor of Renewable Energy (SCORE) has combined clean electricity with industrial zoning to attract over USD 27 billion in investment and generated more than 17,000 jobs since its inception in 2010 (Sarawak Energy 2024). These examples illustrate the potential of cluster-based models, where energy supply, industrial demand, and infrastructure planning are co-ordinated both spatially and financially. This calls for developing countries to approach their energy and industrial planning in an integrated manner.

We must make access to key technologies easier for developing countries to address significant industrial decarbonisation challenges. The successful decarbonisation of industries in developing economies depends on access to a set of critical technologies, including high-temperature electric arc furnaces, low- and medium-temperature heat pumps, super-efficient industrial motors and compressors, electrolysers, short- and long-term energy storage, and advanced biofuels. These technologies remain expensive, are often demonstrated only in advanced economies, and require specialised expertise that is not always available locally. To close this gap, international co-operation on technology transfer and capacity building will be vital. Equally important are innovative financing mechanisms, including concessional lending, blended finance, and green bonds, that can lower the cost of adopting these solutions.

Supportive policy frameworks, including industrial decarbonisation roadmaps, performance standards, and targeted incentives, can further accelerate the transition and ensure the deployment of clean technologies on a large scale. The technology transfer and financing architecture must be just and inclusive. The focus must be on institutional strengthening and enabling strategic use of public finance. Less than 20% of clean energy investment reaches developing economies, according to the IEA (2021). Mechanisms such as concessional loans, blended finance, and sovereign green bonds can de-risk private capital. Recent announcements from the Climate Investment Funds (USD 12.5 billion in 2024) and Just Energy Transition Partnerships (JETPs) for South Africa and Indonesia provide instructive templates. These global developments are summarised in Table 1, which outlines major industrial decarbonisation financing mechanisms and policy instruments announced across key regions. Many of these initiatives build on frameworks highlighted in the Policy Toolbox for Industrial Decarbonisation (IEA 2024) and the Climate Club Financial Toolkit (OECD 2024), which provide detailed guidance on policy co-ordination, financing structures, and international collaboration for industrial transformation.

Table 1: Major announcements on industrial decarbonisation (non-exhaustive)

Region	Program/Initiative	Amount	Instrument
Australia	Powering the Regions Fund - Safeguard Transformation Stream (Australian Govt., 2024)	600M AUD (300M AUD Round 1)	Grants
Australia	Powering the Regions Fund - Industrial Transformation Stream (AREA, 2024)	400M AUD envelope	Grants (via ARENA)
EU	Innovation Fund 2025 awards (European Commission - Climate Action, 2025)	4.2B EUR	Grants
EU	European Hydrogen Bank (1st auction) (European Commission – Press Corner 1, 2024)	720M EUR	Contracts for Difference
EU	IPCEI Hy2Infra (European Commission – Press Corner 2, 2024)	up to 6.9B EUR	State aid for H2 infrastructure
Germany	Klimaschutzverträge (Carbon Contracts for Difference) first auction (BMWK, 2024)	maximum 2.8B EUR	CCfDs

Germany	tkH2Steel Duisburg (European Commission – Press Corner, 2024)	2B EUR	State aid grant
India	SIGHT Scheme (Tranche-I) (Govt. of India, 2025)	130B INR for H2, 130 B INR for electrolysers	Offtake support + capex incentives
Netherlands	Porthos CCS (Porthos CO_2, 2023)	1.3B EUR	Shared CCS infrastructure
Spain	PERTE Descarbonización Industrial (MIT, 2024)	3.17B EUR (public) mobilising 11.8B EUR	Grants + loans
Spain	PERTE Línea First Awards (La Moncloa, 2024)	97.5M EUR (to 14 projects)	Grants
Sweden	H2 Green Steel Boden (H2 Green Steel, 2024)	4.5B EUR debt and 300M EUR equity	Mixed private/public finance
UK	CCUS Track-2 clusters (Acorn & Viking) (UK Govt. - DESNZ, 2024)	200M GBP (Acorn + Viking)	CCUS cluster funding
UK	CCUS overall commitment (UK Govt. – HMT, 2024)	21.7B GBP for 25 years	Long-term support envelope
USA	DOE Industrial Demonstrations Program (US-OCED, 2024)	up to 6B USD	Grants
USA	48C Advanced Energy Project Credit (Round 1) (USD-DoE, 2024)	4B USD	Tax credits

IV. Strategic opportunities for green industrialisation in the Global South

Industrialisation is a key priority for developing countries to create jobs and advance economic transformation. With the growing demand for industrial products, increasing ambition to reduce commodity dependence and build local production capabilities, the industry will emerge as a key driver of energy use and emissions. In Africa, 83% of countries remain commodity-dependent, with export earnings largely reliant on primary commodities (UNCTAD 2022). This persistent reliance limits opportunities for value addition and exposes economies to price volatility in global markets. Reconciling industrialisation priorities with climate imperatives in the Global South will require strong partnerships with the Global North to enable the flow of clean technology, investments, and know-how.

Localising value chains constitutes a cornerstone of this transformation. Currently, the structure of Sub-Saharan Africa's participation in global value chains is dominated by the export of primary products rather than the import of intermediate goods for further upgrading and re-export (Abreha et al. 2021). Between 2022 and 2024, Africa imported over USD 12 billion in solar PV modules, lithium-ion batteries, and assembled electric vehicles (UN Comtrade Database), underscoring the significant economic leakage associated with limited regional manufacturing. Building domestic manufacturing capacities for renewable energy technologies, energy storage, and clean industrial equipment enables developing countries to capture more value along the supply chain, rather than remaining solely exporters of raw minerals. This is particularly relevant given that the continent holds around 30% of the world's known mineral reserves, including cobalt, lithium, and nickel, critical inputs for the global clean energy transition (UNECA 2024).

Recognising this potential, several resource-rich countries are pursuing greater local beneficiation of minerals and developing manufacturing ecosystems that enable deeper backward integration. Regional initiatives such as the United Nations Secretary-General's Panel on Critical Energy Transition Minerals and the Africa Green Minerals Strategy (AGMS) underscore the importance of using Africa's mineral wealth to drive domestic value addition, job creation, and regional industrialisation. The AGMS outlines four pillars—mineral development, human and technological capability, supply chain development, and mineral stewardship—forming a strategic blueprint to transform resource endowments into long-term industrial competitiveness (African Union 2025).

Research by the OECD (2023) and UNIDO (2022) underscores the critical importance of localised supply chains for renewable energy and clean technology components. Africa's sizeable deposits of lithium, cobalt, and rare earths present an opportunity to develop domestic battery manufacturing industries, reducing dependency on volatile global raw material markets and fostering indigenous technological capabilities. South Africa, for instance, is actively developing green hydrogen hubs, including the Boegoebaai Green Hydrogen Cluster in the Northern Cape (Mining Weekly 2024) and the Coega Green Ammonia project (Hive Energy 2025), both of which are tied to industrial parks to leverage renewable energy resources and decarbonise domestic industries, ultimately facilitating the export of low-carbon finished goods.

Similarly, Latin America's green hydrogen initiatives in Chile and Brazil are designed not only to scale production but also to create jobs and advance broader industrial strategies that diversify economies away from their traditional resource bases. These efforts exemplify how green industrialisation strategies can simultaneously address climate goals and promote inclusive economic development.

To unlock these opportunities, developing economies must prioritise the development of enabling policy frameworks. This includes aligning industrial policies, energy planning, mining strategies, and skilling, research, and development efforts to create synergies across sectors. Innovative financing mechanisms, concessional funding, and public-private partnerships play vital roles in derisking investments and accelerating the deployment of green technologies. Supply-side support could also include grants for capital equipment or preferential financing for firms meeting local content and skills development criteria. A relevant example is the Brazilian Development Bank's (BNDES) lending model for wind energy under the Programme of Incentives for Alternative Electricity Sources (PROINFA), which successfully tied financing conditions to local manufacturing and workforce development (SEforALL 2025). Complementary measures, such as technology transfer, skill development, and institutional strengthening, can ensure that gains from green industrialisation are sustainable and widely shared.

To conclude, industrial decarbonisation cannot occur in isolation in developing countries, and it must align with broader development goals such as employment, poverty reduction, and trade competitiveness. A co-ordinated global partnership, anchored in clean technology transfer, investment, and fair trade, would not only accelerate these outcomes but also advance the strategic interests of advanced economies by enhancing supply chain resilience and supporting a just and inclusive global energy transition.

V. A Global Partnership Framework for Industrial Decarbonisation

Achieving rapid and inclusive industrial decarbonisation will require co-ordinated international action that transcends the limitations of individual countries and institutions. A global partnership framework for industrial decarbonisation can serve as a unifying architecture to align stakeholders, accelerate the deployment of clean technologies, and ensure that the transition remains equitable. Such a framework must be rooted in mutual accountability, structured co-operation, and recognition of the differentiated capacities and development priorities of participating countries.

This partnership framework needs to involve a broad coalition of actors. National governments, particularly EMDEs, must be central to shaping priorities, ensuring that the framework responds to domestic industrialisation goals and development pathways. Advanced economies have a critical role in providing access to finance, technology, and markets. Multilateral agencies and regional development banks can serve as technical enablers and policy conveners. For instance, Sustainable Energy for All (SEforALL) led initiatives such as Mission Efficiency (Mission Efficiency 2025), Green Industrialization Hub (Green Industrialization Hub 2025) and Energy Transition & Investment Plans (ETIP 2025) could be leveraged to provide enabling frameworks for EMDEs to be ready to participate in this framework. It is important that the collaboration framework and its steering have an equal voice among advanced and developing economies. The private sector, including industrial technology providers, off-takers, and financial institutions, must also be engaged to scale up investments and facilitate market access for low-carbon industrial products. Finally, academic institutions and civil society organisations can support innovation, monitoring, and knowledge dissemination.

The framework could be structured around four priority pillars. The first is technology transfer and co-development, which would facilitate access to critical industrial decarbonisation technologies, such as electric arc furnaces, low-temperature heat pumps, hydrogen electrolysers, and advanced energy storage. Some of these technologies are currently deployed mainly in high-income countries, creating a global diffusion gap. Addressing intellectual property barriers, enabling policies and regulations, enhancing local manufacturing capabilities, and supporting joint research and demonstration projects will be essential.

The second pillar is finance mobilisation and de-risking. Despite significant capital needs for industrial transformation, only a small share of global climate finance reaches developing economies. The framework should enable concessional finance, sovereign guarantees, and blended capital instruments that reduce investment risks and improve the bankability of clean industrial projects. Instruments such as carbon contracts for difference (CCfDs), green public procurement, and performance-linked incentives can provide market certainty for investors and firms in low-carbon industrial sectors.

A third pillar must focus on policy alignment and regulatory co-operation. The framework should support countries in developing national industrial decarbonisation strategies that are aligned with development plans, energy access and transition targets, localisation and trade competitiveness. Harmonisation of emissions accounting standards, carbon intensity benchmarks, and environmental product declarations will be key to ensuring compatibility across markets. This is particularly relevant in light of emerging CBAMs, which must be designed to avoid penalising developing countries and instead offer pathways for participation.

The fourth pillar is capacity building and institutional development. The transition to the green industry will require significant upgrades in planning institutions, technical knowledge, and workforce skills. A co-ordinated framework can support training programmes, university-industry partnerships, and regional/national centres of excellence focused on industrial energy planning, industrial energy efficiency, clean manufacturing, and sustainable value chain design.

With the four pillars, the Climate Club can serve a catalytic role in global architecture. Launched initially by Germany during its G7 presidency, the Climate Club aims to align international efforts on industrial decarbonisation and prevent carbon leakage. Today, the Climate Club has 46 member governments across the globe representing both developed economies and EMDEs and is uniquely positioned to offer a governance platform for the global partnership framework on industrial decarbonisation. It could promote transparency by supporting common emissions accounting methodologies and providing a forum for aligning standards. Crucially, the Club could connect the implementation of CBAMs in advanced economies with financial and technical support mechanisms for developing economies, thus enabling fair participation in global green value chains.

By institutionalising co-operation across these pillars, the global partnership framework can help shift industrial decarbonisation from a fragmented effort to a co-ordinated global transformation. It would reflect the shared responsibility of all countries to meet climate goals while acknowledging the unequal capacities and resources available to them. It would also enable emerging economies to transform industrialisation into a development pathway that is not only low carbon but also resilient, inclusive, and competitive.

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Damilola Ogunbiyi is the CEO and UN Secretary-General's Special Representative for Sustainable Energy for All (SEforALL) and Co-Chair of UN-Energy. Recognised in the 2024

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Alvin Jose has almost 20 years of experience in Clean Energy technology deployment and policymaking. Alvin started his career with Bureau of Energy Efficiency, Government of India and subsequently worked and led a wide range of technical assistance programs of Governments in Asia with UNEP, UNDP, TERI and Asian Institute of Technology. Alvin is currently leading SEforALL's global work on Energy Planning and Energy Efficiency and support developing countries towards universal energy access, tripling renewable energy and doubling energy efficiency. He is currently SEforALL's Head of Energy Planning & Efficiency and leads technical assistance programs on energy transition pathways, planning, investment and subsequent policy and regulatory advisory for large scale clean energy technology adoption. Alvin holds a M.Eng in Energy Engineering and B.Eng in Electrical Engineering.

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Divyam Nagpal is a renewable energy specialist with over 14 years of experience at intergovernmental and national levels. As Principal Specialist for Renewable Energy in the UN Energy Team at Sustainable Energy for All, he leads the SEforALL Green Industrialization Hub, advancing initiatives such as the Africa Renewable Energy Manufacturing Initiative, the Council for Critical Minerals Development in the Global South, and the Southeast Asia Green Value Chains Programme. Previously, he worked with IRENA, the MIT Energy Initiative, the Global Commission to End Energy Poverty, ICIMOD, and REN21. His expertise spans renewable energy policy, off-grid systems, socio-economic impacts, and the water-energy-food nexus. Having co-authored over 15 major publications, Divyam brings deep knowledge of global market and technology trends. A mechanical engineer with an MSc in Sustainable Energy Futures from Imperial College London, he has also worked in the UK and India on techno-economic and financial assessments of renewable energy projects.

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12 Repurposing fossil fuel subsidies: Enabling decarbonisation through trade and investment law reform

ELENA CIMA

Abstract

Recent Conference of the Parties (COP) decisions have reaffirmed countries' commitment to transition away from fossil fuels in their energy systems. The phasing out fossil fuel subsidies is of course a critical element of this transition. However, current World Trade Organization (WTO) subsidy rules do not adequately reflect this shift: while they offer some policy space for green industrial support, they also permit environmentally harmful subsidies. Reforming these rules to distinguish between "good" and "bad" subsidies could help redirect support from fossil fuels toward sectors that are critical for decarbonisation. At the same time, international investment agreements often provide broad protections to fossil fuel investments, potentially constraining subsidy withdrawal or repurposing efforts. Without evolutive interpretations of existing standards or a new generation of investment agreements, these treaties may continue to obstruct climate-aligned reforms. This article explores how targeted reforms in both trade and investment law could enable a more coherent and supportive framework for global decarbonisation.

I. Introduction

Phasing out fossil fuel subsidies is one of the most effective steps governments can take to drive the decarbonisation of the economy. By lowering the cost of coal, oil and gas, these subsidies contribute to keeping carbon-intensive production in sectors like steel, cement and fertilisers locked in for decades. They also divert public funds away from clean energy and from the technologies and infrastructure needed for low-emission industrial production. Redirecting these resources can help scale up renewable energy, accelerate the deployment of net-zero emission processes, and finance innovation. While subsidy reform is decided at the national level, international rules—particularly in trade and investment agreements—can significantly influence countries' policy choices. Depending on their actual content, these rules can either undermine governments' efforts to phase out fossil fuel subsidies, by exposing them to legal or financial risks, or incentivise and facilitate those efforts. At present, because of how these rules have been traditionally formulated, trade and investment agreements largely act as obstacles to the removal of fossil fuel subsidies and, by extension, to the energy transition. This chapter looks at how these rules can be reformed so that they can actively encourage governments to remove fossil fuel subsidies and repurpose them where they are most needed for decarbonisation. In doing so, it highlights the role that the Climate Club can play in providing a platform that facilitates dialogue, fosters mutual learning, and promotes the sharing of best practices to navigate the complex challenges these reforms will necessarily present.

II. Removing fossil fuel subsidies: what role in the industrial decarbonisation process?

The impact of fossil fuel production and consumption on our climate system is staggering. According to the latest Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), "by 2019, the largest growth in absolute emissions occurred in carbon dioxide (CO_2) from fossil fuels and industry" (IPCC 2022a, 6). In addition, energy-related emissions—especially those from fossil fuels—have been increasing, reaching an all-time high of 37.8 Gt CO_2 in 2024 (IEA 2025, 31).

For decades, the IPCC has underscored the scientific evidence demonstrating the urgent need to phase out fossil fuels.[19] Several reports have noted that "the achievement of long-term temperature goals in line with the Paris Agreement requires the rapid penetration of renewable energy and a timely phasing out of fossil fuels," and that this is "technically possible and estimated to be relatively low in cost" (IPCC 2022b, 1742-43). Yet, despite this clear scientific consensus, fossil fuels remain heavily subsidised worldwide, a practice that runs counter to these findings and undermines the transition towards renewable energy.

According to a recent Report of the International Monetary Fund (IMF), globally, total fossil fuel subsidies amounted to $7 trillion in 2022, equivalent to nearly 7.1% of global gross domestic product. Explicit subsidies (undercharging for supply costs) account for 18% of the total while implicit subsidies (undercharging for environmental costs and forgone consumption taxes) account for 82% (Black et al. 2023, 3).

The Report continues explaining that "explicit subsidies have more than doubled since the previous IMF assessment, from $0.5 trillion in 2020 to $1.3 trillion in 2022" (Black et al. 2023, 3). It is clear that these subsidies play a significant role in sustaining an industry that is among the main contributors to climate change. What is more, they also indirectly support carbon-intensive industries such as steel, cement, and fertilisers. Accordingly, phasing out these subsidies—whether wholly or partially—could make an important contribution to industrial decarbonisation, particularly by reducing the competitiveness of fossil-based production routes in traditionally high-emitting sectors. In fact, as things stand, there is still a significant cost differential between fossil fuels and low-carbon alternatives, which makes clean production technologies less competitive in both domestic and international markets. Removing subsidies would therefore help level the playing field. In its latest Assessment Report, published in 2022, the IPCC addressed the issue head on when it found that "removing fossil fuel subsidies would reduce emissions, improve public revenue and macroeconomic performance, and yield other environmental and sustainable development benefits" (IPCC 2022b, 46; van Asselt et al. 2023).

III. From silence to scrutiny: fossil fuel subsidies in international (climate) law

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[19] All 6 IPCC Reports have emphasised the importance of phasing out fossil fuels – as well as fossil fuel, or more broadly energy subsidies.

For decades, climate law instruments have remained silent on fossil fuels, and even more so on fossil fuel subsidies. The 1992 United Nations Framework Convention on Climate Change (UNFCCC), for example, only referred to fossil fuels in the narrow context of recognising the special needs of economies heavily dependent on their production, use, or export.[20] The Paris Agreement, adopted in 2015, which remains the main agreement governing climate co-operation and action today, does not mention fossil fuels at all. This silence reflects a broader pattern in international climate and environmental law: setting targets or objectives and leave countries free to choose the means to meet them. The Paris Agreement is even more flexible: while it sets a global temperature target of 1.5°-2°C,[21] it leaves States free to choose their individual emissions reduction targets (so-called Nationally Determined Contributions or NDCs) as well as the specific measures and policies to adopt. No treaty to date has singled out specific climate change mitigation measures or favoured any specific policy or approach – including fossil fuel subsidy reform.

Over the years, several Conference of the Parties (COP) Decisions have recognised the need to address market imperfections, including subsidies. The *Glasgow Climate Pact*, adopted at COP27 in 2022, was the first to explicitly call for the phase-out of *inefficient* fossil fuel subsidies.[22] The subsequent *Decision on the outcome of the first global stocktake*, adopted at COP28 in Dubai in December 2023, emphasised the importance of "transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner" as well as of "phasing out inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible."[23]

An important milestone was reached on 23 July 2025, when the International Court of Justice (ICJ) delivered its Advisory Opinion on the *Obligations of States in the Context of Climate Change*.[24] In addition to resolving disputes, the ICJ—like other international court and tribunals—fulfils a critical advisory function. Though not binding, its Advisory Opinions can profoundly shape State practice and generate significant impacts across both international and domestic legal systems.

The ICJ confirmed that States have binding obligations to mitigate, adapt, and co-operate under the Paris Agreement, but also clarified that their responsibilities extend beyond treaty law to broader principles of international law. This means that all States, regardless of whether they are parties to the Paris Agreement, must take "effective" and "stringent" domestic action to reduce emissions, with their level of differentiated responsibility according to historic emissions and capacity to act.[25] The Court emphasised that States are not entirely free in choosing the measures to adopt or the ways to set their targets: they must adopt policies and measures that enable them

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[20] United Nations Framework Convention on Climate Change (1992), Preamble, Art. 4(8)(h) and 4(10).
[21] Paris Agreement (2015), Art. 2.1(a).
[22] Glasgow Climate Pact (2022), para. 20.
[23] Decision on the Outcome of the first Global Stocktake (2023), para. 28(d) and (h).
[24] This Advisory Opinions was preceded by two other Advisory Opinions on the same subject, rendered by the International Tribunal for the Law of the Sea and the Inter-American Court of Human Rights.
[25] Obligations of States in respect of Climate Change, *Advisory Opinion*, I.C.J. Reports 2025, 23 July 2025, paras. 238, 246, 250-254.

to contribute effectively to the global temperature goal of 1.5°—the target the ICJ confirms as the reference, rather than the less ambitious 2°.[26]

In other words, States can no longer act unilaterally or ignore the implications of their energy choices. For instance, they cannot simply pursue fossil fuel-based energy strategies. The ICJ is clear that "fossil fuel production, fossil fuel consumption, the granting of fossil fuel exploration licenses, or the provision of fossil fuel subsidies" may constitute internationally wrongful acts and violate international law.[27] By doing so, the Court specifically singled out the provision of fossil fuel subsidies as an action that could potentially breach international obligations.

IV. Do countries have the right incentives under international law to phase out fossil fuel subsidies?

Although an Advisory Opinion is not legally binding, it can have powerful effects in both international and domestic legal orders, including influencing domestic litigation. Since 2015, domestic climate litigation has surged, with over 2,900 cases filed against States or private companies in multiple jurisdictions (Setzer and Higham 2025, 3). As a result, we can expect a rise in litigation against fossil fuel companies and against States that are subsidising their fossil fuel industry.[28] The ICJ Advisory Opinion could significantly strengthen legal arguments in countries where climate litigation against governments and corporations is already gaining momentum and may even catalyse action in States that have so far lagged behind.

This rise in climate litigation—particularly if cases are successful—could put additional pressure on governments to rethink their fossil fuel policies, especially the provision of subsidies. The fear of domestic litigation, however, may not be enough. While it can act as a powerful incentive, there are two sets of international rules that play a critical role in this regard, and depending on how they are drafted and interpreted, they can either create obstacles or provide important incentives for countries to phase out their fossil fuel subsidies.

The first set of rules to consider is **international trade law**. Subsidies are "trade measures" and therefore fall under the scope of the Agreement on Subsidies and Countervailing Measures of the World Trade Organization (WTO) —for its 166 Member States. Currently, this agreement applies to all subsidies that may distort trade, regardless of their purpose and of any non-economic effects. In practice, this means that the same rules apply to subsidies for highly polluting, high-emission industries, such as fossil fuels, and to low-polluting, low-emission sectors, like renewable energy.

As a result, while countries are allowed to support sectors critical for the decarbonisation of the economy, they are equally allowed to continue subsidising fossil fuels as well as high-emitting industries. Over the years, some experts have proposed adding an "environmental" exception

[26] Obligations of States in respect of Climate Change, paras. 238, 246, 250-254
[27] Obligations of States in respect of Climate Change, para. 427.
[28] As of September 2024, 86 climate cases had been filed against some of the largest oil, gas, and coal producing corporations. See 'Big Oil in Court – The latest trends in climate litigation against fossil fuel companies' *Zero Carbon Analytics* (2024).

clause to the Subsidies Agreement to make it easier for countries to subsidise low-emitting sectors. Yet, this approach may not offer the most effective solution for the following reasons: (i) it overlooks the fact that not all countries are similarly situated and able to provide such subsidies as well as the fact that some subsidies may not be designed for environmental protection but may contribute to one of the other pillars of sustainable development (social and/or economic development); (ii) it may not even be necessary as many have argued that the Subsidies Agreement already provides Members with the necessary policy space to provide green subsidies; and (iii) it would not fully address the underlying problem because countries could still subsidise fossil fuels and would have little incentive to redirect support toward lower-emitting alternatives.

A more effective alternative could involve reforming WTO subsidy rules to account for environmental externalities, promoting "green" subsidies while prohibiting "dirty" ones. In fact, if fossil fuel subsidies were explicitly prohibited under WTO rules, Member States would face stronger incentives to stop supporting this industry, freeing up public resources that could be redirected to low-carbon and sustainable sectors.

International trade rules, however, are not the whole picture. Even if trade rules could be reformed and fossil fuel subsidies were formally prohibited—and pending such reform, which, if successful, would most likely be the result of several years of negotiations—governments seeking to remove them would still face a major obstacle: the protection offered to foreign investors under **international investment agreements**. In fact, international investment agreements protect all types of foreign investments, including those in sectors that harm the climate—such as fossil fuels—which need to be phased out to support a low-carbon transition (Tienhaara 2018, 229-30). As a result, these agreements can limit policy space, making it harder for countries to adopt measures that may impact the fossil fuel industry (such as the phase-out of fossil fuel subsidies) and to prioritise low-carbon investments (Grierson et al. 2021).

For example, imagine Country A has long subsidised its fossil fuel industry and hosts foreign investors in that sector. These investors are generally protected both by contracts with the host government and by the investment agreement between their home country and the country that hosts them. If Country A decides to remove fossil fuel subsidies to reduce emissions, foreign investors in the fossil fuel industry could challenge the decision. They might argue that they were treated unfairly or discriminated against—especially if subsidies in other sectors remain—and claim that the removal of subsidies constitutes indirect expropriation. Given the formulation of many investment agreements and existing arbitration practice, investors may have a viable case (Cima 2025).

This creates what is known as "regulatory chill," where governments hesitate to act in the public interest due to fear of investment disputes. In our example, Country A may delay or avoid removing fossil fuel subsidies to sidestep potential litigation. It should also be noted that a foreign investor does not need to actually win a dispute for this "regulatory chill" to occur—the mere threat of arbitration can be sufficient.[29] In fact, the fossil fuel industry has been recognised as being the "most litigious industry" in investment arbitration by number of cases, accounting for almost 20% of the total known cases across all sectors as of 2022 (di Salvatore 2021).

V. A template for reform

Reforming international investment agreements can help ensure that countries are free to phase out fossil fuel subsidies without fear of legal challenges from foreign investors, removing a key obstacle to decarbonisation. At the same time, reforming WTO rules on subsidies could create powerful incentives for governments to remove existing fossil fuel support and avoid introducing new fossil fuel subsidies, allowing public resources to be redirected toward sectors critical for a low-carbon transition.

For policymakers, understanding this distinction is essential: while WTO reforms would provide an incentive to act, the reform of existing investment agreements (or the negotiation of a new generation) would protect governments from potential disputes, ensuring that efforts to phase out harmful subsidies and promote low-carbon investments are not undermined by potential litigation risks.

A. Allowing for differentiation

The overarching goal of any reform of existing trade and investment rules is to allow for targeted differentiation.

In the **trade law** context, current rules are based on the idea that domestic subsidies can spill over and affect other countries. However, they only address spillovers linked to trade distortion—for example, by promoting exports or blocking imports. They do not consider that many subsidies, such as those for fossil fuels, can cause significant environmental harm, in addition to distorting trade. Conversely, some subsidies may deliver clear benefits for decarbonisation. A reformed framework could place the environmental impact of a subsidy at the centre, while trade effects would remain relevant but secondary. As a result, reformed rules should distinguish between "environmentally positive" subsidies, such as support for renewable energy, and "environmentally harmful" subsidies, like those for fossil fuels (Cima and Esty 2024). This distinction would allow for the application of different rules to each group of subsidies.

In the **investment law** context, current agreements provide protection to all types of foreign investments, including those in sectors like fossil fuels, that undermine climate goals. Reform could introduce differentiation here as well, limiting the scope of protection to investments that do not significantly harm the environment or the climate system. In practice, being a foreign investor would remain necessary to benefit from the protection of an investment agreement, but

[29] Elizabeth Meager, 'COP26 Targets Pushed Back Under Threat of Being Sued' *Capital Monitor,* January 2022 https://www.capitalmonitor.ai/analysis/cop26-ambitions-at-risk-from-energy-charter-treaty-lawsuits/

it would no longer be sufficient: investments that contribute to environmental harm could be excluded from such protections.

This dual approach—distinguishing between "good" and "bad" subsidies in trade law, and between environmentally responsible and harmful investments in investment law—would create both incentives and safeguards for governments to phase out fossil fuel subsidies and accelerate the transition to a low-carbon economy.

B. Building on existing practice

Reform of both trade and investment rules would not happen in a vacuum, nor should it require reinventing the wheel. Instead, it could rely on existing practice in both fields, which already offer a toolbox of options and drafting techniques.

In the context of **trade law**, a useful example is provided by Chapter 4 of the Agreement on Climate Change, Trade and Sustainability (ACCTS), adopted on 15 November 2024 by a group of like-minded countries (Costa Rica, Iceland, New Zealand and Switzerland). This is the first international agreement to explicitly define harmful fossil fuel subsidies and prohibit subsidies for coal and the production of oil and gas. The Agreement defines "fossil fuels," provides a list of what are "fossil fuel subsidies," and contains a general prohibition to introduce or maintain such subsidies. It also introduces innovative provisions on transparency, exceptions, and flexibilities for specific circumstances or vulnerable communities. These features make the ACCTS a valuable reference point for governments considering how to design new subsidies rules that address fossil fuels directly.

That said, the ACCTS reflects the ambition of four "like-minded" countries. Achieving a similar outcome at the multilateral level, particularly at the WTO, is likely to be more challenging, since WTO decisions are adopted by consensus and some Members may strongly resist a reform that singles out fossil fuel subsidies.[30]

Another option could be to situate fossil fuel subsidy reform within a broader framework for distinguishing "environmentally harmful" subsidies from other forms of support. Although this approach has not yet been fully tested, WTO practice offers inspiration. For instance, the WTO *Agreement on Agriculture* divides agricultural support into different "boxes" based on their trade effects. A similar approach could be used for industrial subsidies, but with a critical shift: the first criterion should be their environmental impact, followed by their effect on trade. Under such a system, subsidies that support environmental or sustainable development goals could be presumed permissible, with rules tailored to their trade impacts, while subsidies that are environmentally harmful, such as fossil fuel subsidies, would be presumed prohibited, except in narrowly defined cases where their trade impact is minimal (Cima and Esty 2024).

[30] A decision is considered to be taken by consensus if no Member present at the meeting when the decision is taken formally objects, which means that each WTO Member has veto power over every decision.

In the context of **investment law**, several avenues can be explored to achieve such differentiation.

A first approach is to state clearly in the preamble of an Investment Agreement that its purpose is to promote and protect only those investments that contribute positively to sustainable development. An example can be found in the 2012 *South African Development Community (SADC) Model Bilateral Investment Treaty*, which emphasises that the Parties seek to "promote, encourage and increase investment opportunities that enhance sustainable development within the territories of the State Parties." Although preambles are not binding, they influence how treaties are interpreted. Introducing this clarification in the preamble could help ensure that arbitral tribunals interpret the Agreement in line with sustainable development objectives. In practice, this means that investments that promote long-term economic, social and environmental goals could benefit from a greater protection than investments—such as those in fossil fuels—that may run counter to these objectives.

A second option is to make investment protection provisions more granular, by providing detailed definitions of the standards of treatment and protection for foreign investments. The *non-discrimination standard*, for instance, requires the host State not to treat investors differently if they are in "like circumstances" without, however, defining what qualify as "like circumstances." If the Agreement explains in more detail what "like circumstances" mean—such as considering the level of greenhouse gas emissions or the overall environmental impact of an investment—then fossil fuel investments and investments in clean energy would not be considered in "like circumstances."[31] In practice, such an approach would give governments greater flexibility to design policies that distinguish between types of investments. For instance, they could remove fossil fuel subsidies without being obliged to also remove those provided to other "greener" sectors.

A third option is to narrow the definition of what counts as an "investment" under the Agreement. By doing so, certain categories of projects can be excluded from protection altogether. Some treaties already take this approach by requiring that investments contribute to sustainable development (i.e. Bilateral Investment Treaty between Morocco and Nigeria).[32] Another example is the *Investment Agreement between Australia and the UAE*, which explicitly excludes concessions, licenses, authorisations or permits "for the exploration and exploitation of 'Natural Resources'" including "all hydrocarbons such as oil, gas, and condensates, derivates and primary by-products thereof [but not] renewable energy resources" from the definition of "investment," with the result that those activities are not protected by the Agreement.[33]

A final option is to exclude certain economic sectors or types of investments from the scope of application of the agreement, rather than through the definition of "investment". This is the case of the "modernised" text of the Energy Charter Treaty, which provides for a so-called "fossil fuel carve-out": an *optional* carve-out which allows the Contracting Parties to choose to exclude

[31] See e.g. ECOWAS Common Investment Code (2018), Art. 6(3); Investment Protocol to the Agreement Establishing the African Continental Free Trade Area (2023), Art. 12(2); Brazil-India BIT, Art. 5(2).
[32] Morocco-Nigeria BIT, Art. 1(3).
[33] Agreement between Australia and the United Arab Emirates on the Promotion and Protection of Investments, Art.1 - "Investment" (j).

fossil fuel investments made after August 2023 from treaty protection, while limiting protection for existing fossil fuel investments to a maximum of ten years from the date the modernised treaty enters into force. The effect is comparable to a narrowing down of the definition of investment: it excludes fossil fuel projects from the treaty's protection, while maintaining such protection for investments that support sustainable development.

VI. Challenges of reform: a reality check

We can identify at least three main challenges to the proposed reforms—challenges that governments and stakeholders should be mindful of, but which also present opportunities for pragmatic solutions.

The first set of challenges relates to the **scope of possible prohibitions or exclusions.** In the trade law context, options range from very narrow prohibitions that explicitly target fossil fuel subsidies (as in the case of the ACCTS) to broader formulations that propose a wider prohibition of environmentally harmful or unsustainable subsidies. Similarly, in investment law, new or amended agreements could either exclude fossil fuel investments (as in the case of the modernised Energy Charter Treaty or the Agreement between Australia and the UAE) or deny protection to a broader range of environmentally harmful or unsustainable investments. Broader formulations may be more politically acceptable especially at the WTO where decisions require consensus. Terms such as "sustainable development" could help accommodate the priorities of developing countries that may lack the capacity to subsidise green sectors but may prioritise channelling public resources toward industries that are essential for their social and economic development. However, broader formulations (e.g. an emphasis on subsidies that "contribute to sustainable development") come with their own practical challenges: a specific subsidy may advance one pillar of sustainable development (e.g., environmental protection) while undermining another (e.g., economic development)—or vice versa—and countries assign different priorities to each pillar. On the other hand, narrower rules—focusing specifically on fossil fuel subsidies or investments—can provide more clarity, but may attract less political support, in particular in the context of multilateral negotiations.

A second set of challenges, building on the first, refers to **how key terms are defined** and understood – for instance, what counts as an "environmentally harmful subsidy", a subsidy that is "harmful for sustainable development", or an investment that is considered "sustainable" or "unsustainable." While such terms could help distinguish between subsidies that should or should not be allowed and between investments that should or should not be protected—and could ultimately discourage countries from subsidising their fossil fuel industry—there is no shared definition, and this lack of clarity creates uncertainty in negotiations and implementation. While existing studies and taxonomies, including those developed to identify "sustainable investments,"[34] can offer guidance, their differences make it difficult to establish uniform

[34] See e.g. CBI, *Buildings Criteria: The Buildings Eligibility Criteria of the Climate Bonds Standard & Certification Scheme* (Dec. 7, 2023);
Regulation (EU) 2020/852 of 18 June 2020 on the Establishment of a Framework to Facilitate Sustainable Investment.

standards. This ambiguity would inevitably complicate negotiations, even where consensus exists on the need to curb fossil fuel support.

A third set of challenges concerns, in particular, the reform of international trade rules, given the persistent **difficulties in concluding new multilateral agreements**. Decarbonising the economy is not only a matter of national policy but also a collective responsibility tied to the protection of the global commons. Negotiating at the WTO would be preferable, as such "multilateral" negotiations would prevent free-riding and ensure broad participation. In practice, however, because all 166 WTO Members must agree by consensus, reaching multilateral agreement has been extremely difficult. And the "consensus rule", which effectively allows any Member to block all agreement, has undoubtedly contributed to this deadlock (Bacchus 2023, 2-3). Similar gridlock has appeared in other global negotiations, such as those launched in 2022 for the adoption of a Global Plastics Treaty (where the issue of fossil fuel subsidies was one of the most controversial). The latest session was concluded unsuccessfully in Geneva in August 2025, without the adoption of an agreement, and where industry influence and country divisions blocked progress. Given this situation, countries may need to pursue alternative pathways. One option within the WTO is the negotiation of plurilateral agreements by a subset of Members (and binding only on them). This option, however, is also facing some resistance, as several countries have been opposing plurilateral agreements at the WTO, therefore preventing their conclusion at the latest Ministerial Conferences. The result has been a shift toward negotiating and concluding trade agreements (known as free or regional trade agreements) outside the legal framework of the WTO. A realistic perspective is essential: while a multilateral solution remains the preferred pathway and the long-term goal, a practical way forward is to build "coalitions of the willing"—groups of like-minded countries, like those that got together to conclude the ACCTS—which together would form a network of open plurilateral arrangements, smaller and more flexible than the multilateral trading system, but designed so that additional countries could always join over time.

VII. Conclusions: three guiding principles

While these challenges should not be overlooked, they are not insurmountable, and reform can and should be pursued. As governments consider how to reform trade and investment rules in a way that takes into account climate and energy goals, including the overarching objective of decarbonising the economy, three principles should guide the reforms.

The first principle that should guide any new negotiation or amendment of existing rules is **co-operation**. The Opinion of the ICJ is clear in reminding countries that all governments have a "duty to co-operate" in implementing international climate commitments such as the 2015 Paris Agreement and, more broadly, in protecting the environment and the climate system. A co-operative approach is also essential to reduce the risk of free riding, since the decarbonisation of the economy is intrinsically linked to protecting the global commons. Co-operation can, of course, take many forms. As it was mentioned earlier, at least with respect to trade rules, multilateral solutions remain the preferred option. However, current political realities make them difficult to achieve. Governments should therefore pursue co-operation in multiple forms—

bilateral, regional, and plurilateral—while ensuring that such agreements remain open for others to join. But co-operation should also guide all the steps that precede actual negotiations, and Section VI has shown that many important questions must be answered to prepare for reform. The Climate Club is especially well positioned to provide an important platform to help foster dialogue and mutual learning, help countries develop best practices, and gradually build bridges toward multilateral solutions. The same applies to investment law reform. While investment law has always been bilateral in nature, the same provisions are often reproduced in newer treaties. Reform undertaken across a series of treaties or within a region can thus generate positive spillovers in other negotiations. In the context of investment rules reform as well, the Climate Club can provide a platform to foster dialogue, ensuring that countries can learn from each other and co-ordinate the way forward to avoid "fragmented" outcomes.

The second principle is **differentiation**: differentiation between countries with different levels of economic and social development, of capacity, and of dependence on fossil fuels. This principle has long been reflected in international environmental and climate agreements. The ICJ has reaffirmed that while the provision of fossil fuel subsidies may constitute an internationally wrongful act and a violation of international law, the duty that States have is a duty of due diligence – namely to adopt all the means at their disposal. And these "means" will differ from country to country. Concretely, this means that new rules on fossil fuel subsidies or investments should not just be blanket prohibitions or exclusions but should rather provide all the necessary flexibilities to ensure that they are tailored to the needs of all countries. The ACCTS provides a useful model, with exceptions that consider, among others, the need to protect low-income, remote or vulnerable communities or population groups, or the need to supply energy for the provision of essential public services.[35] In this context, the Climate Club can play a critical role, offering its developing economy members the opportunity to have access to the already existing best practices. By facilitating such exchanges, the Climate Club could help bridge the gap between countries with advanced institutional and technological capacities and those still in the process of developing them, thereby fostering more inclusive and effective global climate action.

Finally, reforms must be **comprehensive**. Because both trade and investment rules influence countries' incentives, reform should proceed along two parallel tracks—trade and investment. These tracks should remain open to dialogue and mutual learning, with the shared objective of creating a coherent set of incentives. The ultimate goal is to encourage countries to remove fossil fuel subsidies, prevent the introduction of new ones, and redirect public spending toward sectors critical for the energy transition and decarbonisation.

Industrial decarbonisation is where these principles—co-operation, differentiation, and comprehensiveness—can have the greatest impact. They ensure that any reform that is undertaken accelerates the spread of low-carbon technologies and investment across borders, while ensuring that developing and fossil fuel–dependent economies can transition at a realistic pace.

[35] ACCTS, Art. 4.6(2)(c) and (2)(f).

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