ENTiCE

ENhancing our understanding of Trade Impacts on Climate, industries, and the Environment

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D1.2- TCI Framework and Synthesis of Co-creation Results

WP1– Framing – Theoretical Underpinnings, Public Perceptions, and Policy Needs

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EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

While not confidential, the primary target audience for this deliverable is the ENTICE consortium as well as its stakeholders. It is supposed to provide the conceptual foundations for subsequent qualitative and quantitative research within the project. It shall serve as the foundation of a common language that enables deep interdisciplinary collaboration among a diverse group of researchers. Besides the framework shall facilitate engagement with stakeholders and experts in the fields of trade, climate and industrial policy. To facilitate dissemination and uptake a concise summary of the key elements of the TCI framework has been prepared as a policy paper (D1.7).

3. Short summary of results (<250 words)

This deliverable comprises a technical report describing the research process and summarizing the insights from two main outputs which are included as annexes. The first represents the TCI research framework which is intended to structure qualitative and quantitative research as well as stakeholder engagement of the ENTICE project. Its key elements include a succinct discussion of definitions of trade-, climate-, and industrial policy respectively and their interactions. It provides a concise summary of the economic foundations of trade-environment interactions and proposes a unified taxonomy of TCI policy instruments. A perspective on commodities and associated emissions across the value chain completes the framework. The second output is a manuscript for an academic perspective-type article which places the same economic foundations entailed in the TCI framework in the light of recent geopolitical and geoeconomic shifts and derives key research challenges on that basis: (1) we need to better understand complex and non-linear trade-climate links and especially understand path dependency and asymmetric effects; (2) we need to strengthen enabling conditions in terms of institutional quality and regulatory frameworks; and (3) we need to understand under what conditions can trade and industrial policy deliver co-benefits for both competitiveness and decarbonisation?

4. Evidence of accomplishment

This report.

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Preface

In today's interconnected global economy, understanding the trade-climate nexus is more critical than ever. Trade policies significantly influence environmental outcomes, while climate change affects trade flows. However, the complex relationship between these areas remains insufficiently explored, often due to data limitations, gaps in economic modeling and the evolving nature of global supply chains. The EN-TICE project aims to bridge these knowledge gaps by advancing our understanding of the trade-climate-industry (TCI) nexus. It examines how trade policies impact environmental sustainability and how climate policies shape global trade dynamics. By developing fact-based insights and innovative modeling tools, ENTICE supports informed decision-making at this crucial intersection of trade, climate, and sustainability.

E3M – E3-MODELLING AE	EL	
CMCC – FONDAZIONE CENTRO EURO-MEDITERRANEOSUI CAMBIAMENTI CLIMATICI	IT	
WI – WUPPERTAL INSTITUT FUR KLIMA, UMWELT, ENERGIE GGMBH	DE	
REFORM – FUNDACJA INSTYTUT REFORM	PL	
VUA – STICHTING VU	NL	
HOL – HOLISTIC IKE	EL	
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ICCS – EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	EL	
POLIMI – POLITECNICO DI MILANO	IT	
Purdue – TRUSTEES OF PURDUE UNIVERSITY	US	
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Executive Summary

This deliverable introduces the foundational Trade, Climate, and Industrial (TCI) Analytical Framework developed by the ENTICE project to systematically analyse the complex, intertwined dynamics essential for achieving the European Union's objective of climate neutrality and a globally competitive, sustainable industrial base.

The TCI Framework is a structured, interdisciplinary tool designed to move beyond fragmented policy perspectives. It provides a common vocabulary, defining Trade Policy by its cross-border dimension, Industrial Policy by its targeted domestic activity, and Climate Policy by its singular outcome (mitigation and adaptation). This framework is crucial for understanding how instruments—such as tariffs, carbon adjustments, or subsidies—simultaneously influence climate outcomes (e.g., leakage), industrial competitiveness (e.g., technology adoption), and broader societal goals.

A core finding is the increasing complexity within the TCI nexus, driven by the shift towards Industrial Policy Nationalism and the geopolitisation of trade. The framework systematically classifies the economic effects through which trade impacts environmental outcomes, demonstrating how climate and industrial policies modulate these effects. A unified policy taxonomy is presented to facilitate systematic, multi-domain analysis. A perspective on commodities and associated emissions across the value chain completes the framework

The accompanying Perspective Article investigates how the new policy landscape – marked by growing protectionism and competitiveness-oriented interventions – interacts with global climate goals. It expands the conceptual framework by identifying multiple channels through which trade influences greenhouse gas emissions, noting that the climate impact is non-uniform and highly sensitive to regulatory and institutional contexts. The article stresses the urgent need to strengthen analytical capacity by better integrating data, evolving macroeconomic modelling frameworks to incorporate firm heterogeneity and innovation incentives, and proposing an expanded scenario space that explicitly accounts for trade openness and climate ambition to accurately assess the overall climate impact of these evolving regimes.

The TCI Framework and its accompanying perspective article (contained in the Annexes) establish the essential conceptual foundation for all subsequent research within ENTICE, including the development of the TCI Policy Database and the quantitative modelling efforts in subsequent work packages. Initial validation from the Scientific Advisory Board and stakeholders confirmed the framework's relevance as a common analytical language. The true merits of the framework will be proven through its rigorous application in the upcoming phases, ensuring that ENTICE generates the evidence-based, actionable insights necessary to inform policymakers regarding the complex design of sustainable and competitive TCI strategies.

A more extensive summary of this deliverable has been prepared for communicating effectively with stakeholders. This policy paper version of the TCI framework has been submitted as Deliverable 1.7.

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1 Introduction

This report outlines the foundational analytical and policy framework developed under the ENTICE project to address the complex and intertwined dynamics of Trade, Climate, and Industrial (TCI) policies. These three policy areas are central to the European Union's objective of achieving climate neutrality and promoting a globally competitive, sustainable industrial base, in line with the European Green Deal and the EU's Net Zero Industrial Act. The primary purpose of this report is threefold: first, to present the comprehensive TCI Framework (provided in Annex I) that serves as a structured methodology for our ongoing research; second, to synthesise the initial findings and research capacity needs identified during the project's stakeholder engagement phase; and third, to outline key research challenges and capacity needs in an emerging new global geopolitical and geoeconomic paradigm (detailed in Annex II).

The TCI Framework itself is a structured tool designed to systematically analyse the interactions between various TCI policy instruments. It is supposed to serve as a foundation for analysing implications for broader societal goals, such as resource efficiency, economic growth, job creation, and a just transition with the quantitative tools developed and refined within ENTICE. The framework moves beyond a fragmented policy perspective, aiming to provide a unified and harmonized structure for examining how trade policies (e.g., preferential trade agreements, border adjustments, import tariffs) influence climate outcomes (e.g., emissions, leakage) and industrial competitiveness (e.g., green technology adoption, industrial relocation, subsidization). Its development was informed by a rigorous analysis of existing knowledge, including the systematic literature reviews on the economic and political science literature conducted as part of Deliverable 1.3.

The insights and analytical methods presented here directly inform subsequent work streams within the ENTICE project. The framework will be immediately applied to analyse policy narratives that coin public perception on interactions between international trade and climate change. It will also serve as conceptual foundation for the establishment of a dedicated TCI Policy Database and the qualitative model-based analysis culminating in Deliverable 5.1. The outputs of this report will facilitate the steering of our data and model development efforts (in Work Package 2 and 3 respectively), feeding specifically into the quantitative modelling and scenario analyses planned under Work Packages 4 and 5. Ultimately, the findings presented herein have been synthesized into a concise, high-level policy brief (Deliverable 1.7) to enable efficient dissemination and communication of our core findings to industrial stakeholders and policymakers at the EU and national levels.

The remainder of this report is structured into four main sections and two annexes. Section 2 reports on the research process and the methodological steps taken to establish the project's analytical foundation, the TCI framework, and the accompanying perspective article manuscript on geopolitical and geoeconomic challenges. Section 3 provides a concise summary of the key conceptual elements and outcomes derived from both the TCI Framework and the perspective article. In Section 4 we reflect the key insights and areas of interest identified during the initial phase of the transdisciplinary stakeholder process of ENTICE, detailing how these helped corroborate and refine the TCI framework and identified research challenges and capacity needs. Section 5 concludes. The report is completed by two essential annexes: Annex I contains the full TCI Framework, and Annex II outlines the perspective article "Trade and Climate in a Changing Policy Landscape".

2 Process and Methodology

Establishing a common understanding on key concepts is a critical first step in any interdisciplinary research project. Terms that appear straightforward – such as 'industrial policy,' or 'leakage' – often carry vastly different operational meanings across distinct disciplinary lenses like economics, political science, and climate science. Achieving this conceptual alignment requires broad engagement and dialogue among all researchers involved. Consequently, we decided from the outset to deliberately give space for diverse disciplinary perspectives hoping that this process would allow the team to rigorously confront inherent differences in terms, definitions and methodologies, which is necessary to eventually synthesize a robust, common understanding and a shared analytical vocabulary essential for integrated, coherent, and impactful research outcomes.

To achieve this, we implemented an interactive session with the entire consortium at the project kick-off meeting in Athens in late January 2025. To prepare the session, a first draft of a causal loop diagram was developed by Lukas Hermwille (WI) with inputs from Paola Rocchi (CMCC), Alexandros Nikas (ICCS), Oscar Widerberg (VUA) and Carsten Elsner (WI). The diagram outlines the relationship and feedback loops between international trade and environmental impacts. At the project kick-off meeting, the members of the consortium were asked to 1) review the causal loop diagram and identify missing elements and linkages and 2) to think about a selected policy field and discuss how policy interventions would affect the nodes and linkages of the causal loop diagram. The exercise was conducted in three separate breakout groups. Each group was equipped with a poster print of the initial causal loop diagram as well as markers and sticky notes to complement the print and record key insights from the group discussion.

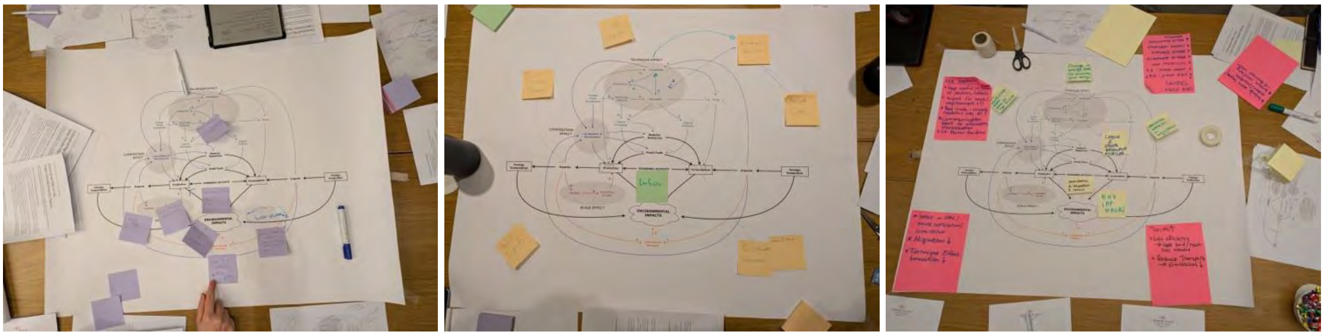

Figure 1. Photo documentation of breakout group discussions during the project kick-off meeting in Athens, January 2025.

The result of the session was not only additional input for the core authors of the TCI framework but also confirmed that the visual approach employing causal loop diagrams served well to enhance mutual understanding. Consequently, it was decided to go ahead with a TCI framework building on and elaborating causal loop diagrams.

Building on the results of the workshop, the main author of the TCI framework developed an improved iteration of the causal loop diagram which was then discussed in the context of regular online WP1 meetings. In June an additional online workshop with the entire consortium was held to discuss additional elements for the TCI framework and provide feedback to the emerging concepts shared. On that basis, Lukas Hermwille prepared a first full draft of the TCI framework (submitted as MS6 in June 2025) which was shared with the entire consortium to inform the starting work on enhanced data (WP2) and modelling (WP3) developments as well as with the Scientific Advisory Board (see section 4).

The ENTICE kick-off meeting in Athens also served as a platform to discuss recent geopolitical and geoeconomic trends influencing trade and climate interactions. During the proposal preparation the election of Donald Trump and his vigorous policy dismantling the global trade regime where not yet foreseeable. In extensive discussions, including representatives of the European Commission, the implications for the ENTICE project and its research agenda were discussed, and a decision was made to develop an academic manuscript outlining the new challenges for studying global trade and climate relationships in a new geopolitical paradigm. Given the high political and academic relevance, it was decided to use the resources originally reserved for an inward-looking analysis of key research questions and capacity needs to produce and develop a perspective type of scientific article outlining the broader research challenges emerging from the geopolitical shift for a wider academic audience.

The drafting process was led by Paola Rocchi with inputs from a wide range of co-authors (see Annex II). The team of authors regularly met online to provide feedback, take key decisions e.g. regarding the target journal, and discuss next steps. The manuscript, contained in Annex II, was since submitted for publication at the academic journal *Nature Climate Change*.

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3 Summary of Results

Note that the two outputs – Annex I and Annex II – are partially overlapping, they both contain a brief synthesis of the economic foundations of the relationship between international trade and climate and environmental impacts. However, they are not identical. The description has been tuned for addressing different audiences: the TCI Framework (Annex I summarized in section 3.1) targeting interdisciplinary researchers mostly for project-internal purposes and the perspective article (Annex II summarized in section 3.2) targeting the community of environmental economists.

3.1 TCI Framework: Navigating the Nexus of Trade, Climate and Industrial Policy

Annex I comprises the TCI Research Framework to provide the theoretical underpinnings and common language necessary for subsequent qualitative and quantitative research of the ENTICE project. The framework systematically addresses the complex and increasingly interconnected nexus between trade, climate, and industrial policy. This integration is critical in the current geopolitical environment, characterized by the 'geopolitisation' of trade and a rise in industrial policy nationalism, where achieving climate goals is increasingly tied to economic competitiveness and resilience(Hauge et al., 2025; Herranz-Surralles, 2024; Meckling, 2025). Specifically, the framework builds on four key pillars:

- A discussion on core definitions of trade, climate and industrial policy and their interdependencies;
- A succinct overview of the economics foundations of the interactions between international trade and climate and environmental impacts including a discussion on how the three policy domains influence the main economic effects;
- A unified policy taxonomy integrating perspectives from trade policy, climate policy and industrial policy research communities;
- And a classification of key commodities that may be affected by trade policies and how their production and/or consumption produce environmental impacts.

Defining Trade, Climate, and Industrial Policy

The three policy domains – Trade, Climate, and Industrial Policy – originate from distinct traditions but are fundamentally non-exclusive in practice, as policy instruments often affect all three domains simultaneously.

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Table 1. Working definitions for trade, climate and industrial policy.

Policy Domain	Definition	Primary Defining Characteristic
Trade Policy	The set of laws, regulations, strategies, and actions adopted by governments, which affect a country's (or a group of countries') foreign trade.	The "cross-border" dimension, regulating the movement of goods, services, knowledge, and capital across national borders.
Industrial Policy	The set of laws, regulations, strategies, and actions adopted by governments that explicitly guide, oppose, or control the transformation of the structure of economic activity in pursuit of some public goal.	A targeted approach to specific economic actors or productive activities within a domestic economy. Goals now include economic resilience, competitiveness and environmental concerns.
Climate Policy	The laws, regulations, strategies and actions taken by governments, organizations, and other entities to minimize anthropogenic greenhouse gas emissions (mitigation), and prepare natural ecosystems and human systems – populations, economic activities, and infrastructure – for the impacts of unavoidable climate change (adaptation).	Defined by its desired outcome: addressing and mitigating the impacts of global climate change, agnostic about the specific actors involved.

The interaction of these perspectives is crucial; for instance, a domestically targeted industrial policy to foster a "green" industry (climate/industry focus) may employ subsidies or local content requirements, which inherently impact cross-border commerce and are perceived as distorting international trade.

Economic Foundations: Trade-Induced Effects on Climate Outcomes

Beyond the direct impact of emissions from international transport (maritime shipping and aviation), trade indirectly affects the environment by reshaping the economic system and production patterns. The TCI framework utilizes decomposition analysis to classify these indirect impacts into four channels driven by trade-induced efficiency gains:

- **Scale Effect (and Income Effect):** Trade liberalization drives economic expansion, increasing production and consumption (Scale Effect), which typically raises GHG emissions unless strong decoupling measures are in place. The resultant higher incomes (Income Effect) may eventually drive consumer and policy preferences and enable investments in cleaner technologies or more efficient infrastructure to support more stringent environmental protection, though empirical support for this mechanism (Environmental Kuznets Curve) is still inconclusive.
- **Specialisation Effect (Inter-Industry Composition):** Trade encourages countries to specialize on the production of specific goods/services based on their comparative advantage, thus altering the composition of production. This may lead to environmental benefits if production shifts to regions with cleaner technologies, or detrimentally, if carbon-intensive production shifts to areas with weaker environmental standards, known as the Pollution Haven Effect (PHE).
- **Productivity Effect (Intra-Industry Composition):** Increased international competition forces less productive firms to exit the market, reallocating market shares toward more productive, and typically cleaner/less polluting, firms within the same sector. This process, termed Pollution Reduction by Rationalisation (PRR), improves the aggregate efficiency of firms (and the overall economy) and potentially lowers emissions per unit of output.
- **Technique Effect:** International trade facilitates the global diffusion of technology and knowledge spillovers. This allows for the faster adoption of low-carbon technologies, cleaner production methods and environmental innovations, improving the long-term environmental performance of economic activities.

Climate policies primarily interact with the Technique and Productivity effects by internalizing negative externalities (e.g., via carbon pricing), ensuring that the most profitable firms are also the cleanest. Industrial policies modulate the Specialisation and Productivity effects by strategically guiding or opposing the transformation of a country's economic structure.

A Unified TCI Policy Taxonomy

Given the complementarity and lack of a universally agreed taxonomy, the framework proposes a pragmatic classification system tailored for the ENTICE project to enable systematic analysis of TCI policy interactions. The unified taxonomy integrates existing classifications (including those for trade, industry, and climate policy) into 10 main categories:

- **Overarching Policies:** Framework legislation, strategic plans, and specific targets (e.g., climate laws, roadmaps).
- **Economic Instruments:** Measures creating financial incentives, ranging from carbon pricing (ETS, carbon tax) and subsidies (OPEX, CAPEX) including through preferential taxation to public procurement and disaster risk insurance.
- **Regulatory Instruments:** "Command and control" policies, including product standards, pollution standards, energy or CO2 standards, quotas, licensing, and local content requirements.
- **Competition Instruments:** Measures affecting the number of market actors, such as anti-trust actions, strategic mergers, or monopolistic state trading.
- **Trade Policies:** Tariffs, Non-Tariff Measures (NTMs)[1], export/import bans, quotas, subsidies, trade defence remedies, and rules affecting Foreign Direct Investments (FDI).
- **Monetary Policies:** Interest rate adjustments, quantitative easing, or foreign exchange market intervention.
- **Innovation Policies:** Support for research, innovation systems, and regulatory sandboxes.
- **Information Policies:** Mandatory/voluntary disclosure, labelling, and early warning systems.
- **Education & Capacity Instruments:** Measures focused on labour training and enhancing administrative capacity.
- **Infrastructure Measures:** Government investment or support for physical infrastructure, such as power grids, EV charging or hydrogen infrastructure, or flood protection and other climate-resilient assets.

Value Chain Perspective and the Role of Commodities

The impact of TCI policies is highly dependent on the type of commodity being traded. The framework adopts a full life cycle perspective, differentiating environmental and economic consequences based on whether emissions hotspots are upstream (before a company's operations, e.g., extraction, processing) or downstream (after products leave the company's control, e.g., use phase, disposal). Key commodity categories, their value chain impacts, and corresponding policy relevance are summarized in

[1] Note that non-tariff measures may overlap with regulatory instruments above. We reserve this category for regulatory instruments that directly and predominantly affect im- or exported goods.

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Table 2.

Table 2. Key commodities and their environmental impacts across the value chain and policy relevance.

Commodity Category	Primary Emission Hotspots	Policy Relevance
Energy	Upstream: Extraction/Processing (Fossil Fuels); Downstream: Combustion (Fossil Fuels).	Trade in low-carbon energy (e.g., green hydrogen) is expected to become key for industrial transformation.
Raw Materials	Upstream: mining and extraction, Initial Processing, Inbound Transport (e.g., critical minerals).	Policies must include stringent environmental safeguards to prevent shifting environmental burdens (e.g., land degradation, water contamination).
Basic Materials	Upstream: Production of Feedstocks, Energy-Intensive Manufacturing (e.g., steel, cement, chemicals).	Policies addressing fossil feedstock reliance are crucial, as trade pattern shifts (e.g., due to CBAM) could lead to significant carbon leakage if production relocates.
Food & Agriculture	Upstream: Land Use Change (Deforestation), On-farm Production (Fertilizers, Livestock).	International trade is a major driver of deforestation, making import regulations crucial for embedded land-use emissions.
Manufacturing Equipment & Consumer Goods	Upstream: Production (Embodied Carbon); Downstream: Use Phase (Energy Consumption).	Clean technologies (e.g., EVs, heat pumps) have upstream impacts but enable massive downstream emissions reductions; policies can facilitate or hinder their global diffusion.

Differentiating impacts by commodity type is paramount for accurately assessing the effects of TCI policies and ensuring that policy interventions are properly tailored. The ENTICE project plans to further disaggregate existing databases (e.g.,GTAP) to enhance granularity in critical areas, including power generation, metals/plastics recycling, cement/fertilisers, and critical minerals' lifecycles.

3.2 Perspective: Trade and Climate in a Changing Policy Landscape

The perspective article “Trade and Climate in a Changing Policy Landscape” (see Annex II) investigates how the recent shift in trade and industrial policy – marked by growing protectionism, industrial policy nationalism, and competitiveness-oriented interventions – interacts with global and EU climate goals. Earlier work on trade–environment linkages largely focused on liberalisation, carbon leakage, and competitiveness concerns (Copeland et al., 2021; Paroussos et al., 2015). However, emerging measures such as the United States' Inflation Reduction Act, the European Union's Carbon Border Adjustment Mechanism, and targeted tariffs on clean energy technologies illustrate a broader paradigm change (Cosbey et al., 2019; European Commission, 2023). Similar industrial mandates in China and India (Hayashi, 2020) reinforce this trend, suggesting that domestic competitiveness increasingly shapes trade policy even when climate rationales are invoked. These developments challenge multilateral cooperation, alter incentives for low-carbon transitions, and raise the question of whether protectionist dynamics yield environmental outcomes comparable to, or distinct from, those associated with trade liberalisation.

The second part of the paper develops a conceptual framework that identifies multiple channels through which trade influences greenhouse gas emissions. Beyond the direct contribution of international transport – responsible for around 3% of global fossil CO_2 emissions in 2023 (Friedlingstein et al., 2025a) – trade affects emissions through scale dynamics, inter- and intra-industry composition effects, and the role of clean energy innovation and diffusion (Cherniwchan et al., 2017; Melitz, 2003; Melitz & Redding, 2021). The climate impact of these channels is neither uniform nor linear: short-term effects, such as increased transport activity and market expansion, tend to raise emissions, while longer-term mechanisms, such as productivity gains, cleaner firm selection, and green technology innovation and spillovers, may favour decarbonisation. Interactions across these channels generate feedbacks that are highly sensitive to time horizons and to enabling conditions including regulatory frameworks, institutional quality, and political economy dynamics (Kono, 2019; Shapiro, 2025). Strong governance and coherent regulatory signals can align trade-induced innovation with ambitious climate goals, while weak institutions or lobbying by incumbents risk reinforcing carbon-intensive trajectories.

The paper further emphasises the need to strengthen analytical capacity. Better integration of firm-level, transport, and innovation data with macroeconomic accounts would improve estimates of emissions embedded in global value chains (Wiedmann & Lenzen, 2018). Modelling frameworks must also evolve: computable general equilibrium and integrated assessment models often rely on simplified assumptions, while recent trade theory emphasises firm heterogeneity, innovation incentives, and multinational behaviour (Balistreri et al., 2024); and these novel trade theories should be integrated in large-scale macroeconomic models (in ENTICE WP3). Hybrid approaches that link economy-wide models with sectoral, techno-economic, or agent-based models can better capture the systemic and dynamic nature of trade–climate interactions.

Finally, the paper proposes an expanded scenario space that explicitly accounts for trade openness and climate ambition. While the Shared Socioeconomic Pathways (O'Neill et al., 2014, 2017) consider protectionist dynamics in selected scenarios and they justify them with "concerns for food security or energy security", but they lack quantification of trade openness and protectionism. A structured framework distinguishing between cooperative green internationalism, fossil-fuelled protectionism, and fragmented decarbonisation illustrates how economic and environmental outcomes depend on interdependencies, temporal asymmetries, and institutional strength. Protectionism, therefore, cannot be assumed to mirror liberalisation in reverse; its climate impact is path-dependent and contingent.

By synthesising these insights, the paper argues that assessing the impacts of trade policies requires moving beyond competitiveness and geopolitical concerns. Attention to regulatory and institutional contexts, combined with improved data, modelling, and scenario design, is essential to determine whether evolving trade regimes hinder or enable progress towards ambitious climate goals.

4 Stakeholder Engagement and Co-Creation

Engagement with SAB members

On July 15, 2025, we held an online, dedicated session for a first meaningful interaction between the consortium and the project's Scientific Advisory Board (SAB). This exchange included (a) a short introduction to the scope, objectives, and methodology of the ENTICE project, (b) a brief introduction from the SAB members, (c) the presentation of the TCI framework, (d) a discussion on the preliminary perspective paper on the trade–climate linkages (presented in section 3.2) including channels, dynamics, and enabling conditions, and (e) the scope and aim of the first ENTICE scenario co-design workshop.

On the TCI framework, the SAB offered first reactions and some insightful comments (which, to the extent possible, have since been integrated into the TCI framework itself). The framework itself was largely seen as an ambitious but necessary shared communication basis across the project work and across the scientific and policy communities. The SAB members noted the importance of reinforcing the role of financial systems (enablers or inhibitors, e.g., linked to the EU taxonomy) and of political economy (coalitions, lobbying, etc.) in the framework, as well as integrating elements relating to justice, asymmetries, and 'majority world' perspectives.

Another important point of discussion was the challenge of, and inherent fuzziness in, drawing consistent lines between TCI policies and assigning/labeling the diversity of policy instruments across the climate, trade, and industry domains. The SAB members also pointed to a pertinent concern in the policy world, revolving around the fragmentation of similar policy instruments among different blocks of countries (e.g., in terms of CBAM format implementation), as well as to a diverging viewpoint that certain (flagship even) instruments can be considered as response measures – for instance, CBAM may be deemed as a guardrail that the global response to a country's climate policy is aligned with what its climate objectives.

There was also some discussion on the clarity and readability of the framework as a resource (glossaries, scope, limitations).

Finally, with regard to the perspective on climate-trade interlinkages, apart from suggestions to stick to clear evidence from the literature with regard to the strength and direction of specific effects (e.g., avoiding to claim confidence over the exact environmental and climate implications of protectionist measures), an overarching comment again revolved around the TCI framework and how the perspective on these interlinkages can be linked to it.

IAM COMPACT event and survey

The ENTICE project was invited to participate in a policy event held by the IAM COMPACT research project, on August 29, 2025, at the Acropolis Museum, in Athens, Greece.

The policy event, titled 'Responsive Science in Support of Climate Policy Making', was co-organised by our partner ICCS/NTUA (who is also the coordinator of the IAM COMPACT project) and Society for the Environment and Cultural Heritage (ELLET). The conference agenda (link) included five thematic sessions, some welcome notes and opening remarks by the two co-hosts, panel discussions with external moderators, as well as a policy intervention by the Mayor of Athens.

On that day, more than 150 participants attended the final conference and had the opportunity to learn about our key findings, ask their questions, and raise their concerns, allowing to collectively discuss on the future of Greece, the EU, selected major emitting and less developed countries, and the planet. The event included representatives from:

- Regional government/Municipalities in Greece
- Ministry of Environment and Energy & Ministry of Development and other Ministries
- Advising bodies to the government
- Energy industry associations
- NGOs (e.g., Climate Analytics, WWF, etc.)
- Research organisations
- Universities (national and international)
- Journalists
- Economic think tanks
- Private sector incl. Lawyers, development firms and industries

Among the five thematic sessions, one explicitly focused on the interplay between trade, industry, and Europe's competitiveness in the context of net zero transition, revolving around a guiding question: "how can Europe remain competitive towards net zero, in a world of trade tensions and geopolitical challenges?". In this session the TCI framework and its key elements was presented and participants were invited to share feedback through an online survey.

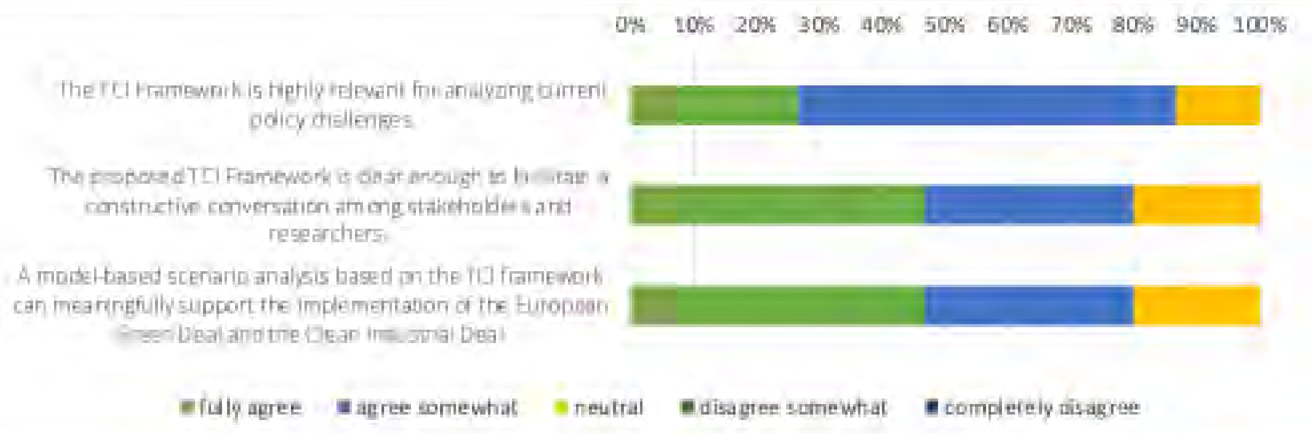

Figure 2. Overview of survey results collected from ENTICE stakeholders.

According to the survey results (see Figure 2), based on fifteen responses from policymakers, experts and other relevant stakeholders, the TCI framework was mostly received and considered as a very relevant or extremely relevant tool for analysing the current European policy challenges, and it was seen as adequate to provide a structured approach to identifying key issues and comparing approaches across different contexts and communities. The TCI framework was also evaluated (very) positively with regard to clarity to facilitate a constructive conversation among academia, policymakers and stakeholders, while the survey participants also seemed to agree that a model-based scenario analysis based on the TCI framework can meaningfully provide insights for the implementation of the European Green Deal and the Clean Industrial Deal, although a concern was raised regarding clarity on how the TCI framework can be operationalised across different policy contexts.

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5 Conclusions

The comprehensive TCI Analytical Framework and the accompanying perspective article contained in the Annexes establish the essential conceptual and methodological foundation for all subsequent research within the ENTICE project. By moving beyond fragmented disciplinary views, the framework provides a unified, harmonized structure for analyzing how trade, climate, and industrial policies interact to shape the trajectory of Europe's net-zero transition and competitive position. The initial validation from both the Scientific Advisory Board (SAB) and broader stakeholder groups underscores the framework's relevance as a necessary common language, particularly in addressing the complexities of industrial policy nationalism and the shifting geopolitical landscape. This consensus confirms that ENTICE is well-positioned to deliver integrated and politically relevant insights.

The framework's core utility lies in its immediate applicability to the project's technical work streams. It serves as the conceptual bedrock for establishing the dedicated TCI Policy Database, guiding the disaggregation of existing economic models, and structuring the qualitative and quantitative scenario analyses in subsequent work packages. Furthermore, the systematic definitions, unified taxonomy, and focused attention on key commodities ensure that ENTICE's findings will be grounded in a rigorous, shared vocabulary, significantly enhancing the project's capacity for coherent communication and stakeholder engagement. The SAB and stakeholder feedback, while supportive, also rightly highlighted the need to reinforce the framework's engagement with political economy and financial system dynamics, which will be critical areas of refinement during the project's execution phase.

Ultimately, the true merits of the TCI framework and the perspective article will be proven through their rigorous application in the upcoming phases of the ENTICE work programme. As we proceed to operationalize this framework – from analyzing policy narratives and establishing the TCI database to executing the final model-based scenario analyses – we will continually test and refine its utility against real-world policy dynamics and empirical data. This iterative application will ensure that the framework not only remains relevant but is robust enough to generate the evidence-based, actionable insights necessary to inform policymakers at the EU and national levels regarding the complex design of sustainable and competitive TCI strategies.

ANNEX I – Research Framework: Navigating the Nexus of Trade, Climate and Industrial Policy

Lukas Hermwille

A1|1 Introduction

Trade has been a cornerstone for global economic growth and welfare improvement, as it increases the accessibility to a wide range of resources, promotes economies of scale, accelerates efficiency in production and consumption of goods, facilitates the access of consumers to a variety of goods, accelerates knowledge spillovers, innovation, and technology diffusion, and enhances competition and product specialisation. Despite not being equally distributed across countries and industries, these benefits have been fuelling a continuous acceleration of trade in the global economy over the last six decades (according to WTO, data volume of trade has more than quintupled since the 1990s). At the same time, the growth of international trade has in turn increased considerably the interconnectedness and interdependencies among firms and countries worldwide. Industries and consumers depend on materials and intermediate goods, whose production and supply is scattered around the globe, creating complex global value chains. In parallel, and especially following the Paris Agreement, climate policies have been developing rapidly in both developed and developing countries, affecting the operation and decision-making processes of all economic agents. As the global economy is becoming increasingly interconnected, with the expansion of complex global value chains, climate policies are gradually becoming an important factor affecting trade flows. Trade policies also have large impacts on climate and the environment as well as implications for climate mitigation efforts. Therefore, the interactions between trade (policies) and climate (policies) have been a prime concern of decision-makers influencing policy design and formulation. For example, trade measures–both intended to address competitiveness concerns and as a means to enhance mitigation action–were included in 45% of the first versions of the Nationally Determined Contributions (NDCs) (Laurens et al., 2022).

Recently, we can observe an increasing trend towards the 'geopolitisation' of trade. Herranz-Surralles (2024) defines geopolitisation "as the framing of a social phenomenon as a matter of international power competition, inciting the adoption of policies and instruments that aim at fostering an advantage over strategic competitors" (Herranz-Surralles, 2024, p. 1886). Specifically, several major economies have started using trade and/or associated regulatory policies to protect and promote the interests of national industries against external competition. China has been pursuing industrial policy strategically since the 2010s with its Made in China 2025 strategy. The US has started to leverage trade restrictions under the first Presidency of Donald Trump. The Biden administration continued to use some of these tools and additionally adopted the US Inflation Reduction Act (IRA). This major legislation was lauded as the most ambitious climate policy the US has ever adopted (Bistline et al., 2023) but it also contained measures that were perceived as protectionist causing a strong reaction from the EU among others (Kleimann et al., 2023; Landais et al., 2023). While the EU had been pursuing its own trade related instrument – the Carbon Border Adjustment Mechanism (CBAM) (Otto, 2025a; Smith et al., 2024) – the adoption of the IRA has been perceived as a wake-up call for European policy makers which responded with the adoption of the Net Zero Industry Act and the Clean Industrial Deal, most recently (see below). This alone may pose a serious threat to global climate change mitigation efforts. Hermwille et al. (2024) find that increasing industrial policy nationalism among geopolitical rivals, implemented through protective tariffs, may double the cost of climate change mitigation for the EU with limited benefits in terms of increasing competitiveness of domestic cleantech industries.

While the above discussion demonstrates that there was already a growing trend towards more restricted trade, the recent embrace of tariffs as a "weapon of commerce" (Luttwak, 1990, p. 21) by the US administration and President Donald Trump has brought this development to a new level (see also Farrell & Newman, 2019), effectively elevating it to a 'securitisation' frame. The tariffs proposed and/or introduced have been presented "as an existential threat, requiring emergency measures and justifying actions outside the normal bounds of political procedures" (Buzan et al., 1998, pp. 23–24). Another example of this weaponization of trade is Russia's curtailment of natural gas trade with Europe in the run-up to and during the full-scale war on Ukraine. Herranz-Surralles (2024) warns that this kind of securitisation framing may help to legitimize the erosion or complete disregard of norms and international law, heralding "the unravelling of international institutions" (Herranz-Surralles, 2024, p. 1888).

However, stable international institutions have not only supported global trade, which has underpinned the rapid economic development over the past century. International cooperation is also considered essential to support climate change mitigation and achieving the well-below 2°C target set out in the Paris Agreement (IPCC, 2022b). It is therefore necessary to better understand the nexus between trade, climate, and industrial policy (TCI nexus).

This is also obvious in the Clean Industrial Deal (CID) which was recently published by the European Commission (EC, 2025). The CID provides continuity on the overarching environmental objectives of the European Green Deal, it does so in a fundamentally different policy frame which foregrounds environmental competitiveness (Hermwille et al., 2025). In its preamble, the CID states: *"This is why Europe needs a transformational business plan. The Clean Industrial Deal brings together climate action and competitiveness under one overarching growth strategy. It is a commitment to accelerate decarbonisation, reindustrialisation and innovation, all at the same time and across the entire continent, also reinforcing Europe's resilience. It must present European industry with a stronger business case for large climate neutral investments in energy intensive industries and clean tech."* (EC, 2025, p. 1). The logic behind this strategy is that having the economic means is a prerequisite to afford ambitious climate policy. Moreover, in order to implement the large-scale transformation requires access to technological means (clean tech) and corresponding resources. In short, the CID is a testament to the understanding that we can only implement highly ambitious climate policies if we remain economically competitive in an increasingly competitive and even rivalrous geopolitical environment.

Industrial policy, climate policy, and international trade policy originate from distinct disciplinary traditions and have evolved along separate historical trajectories. But it is becoming more and more evident that they are increasingly interconnected and multifaceted. Industrial policy has broadened its remit from narrow economic objectives to encompass significant social and environmental goals, with the green transition emerging as an important driver alongside other objectives including security (open strategic autonomy) and keeping up in the digital transformation. Climate policy, inherently interdisciplinary, navigates complex imperatives of mitigation and adaptation through a diverse array of market-based and regulatory instruments within a challenging multilevel global governance landscape. Since the end of the World War II, international trade policy has focused on economic efficiency and comparative advantage. It is now explicitly utilized as a strategic tool for foreign policy, national security, and domestic industrial protection, often creating tensions with established liberal trade principles. The contemporary global landscape demands their integration. This integration, however, is not seamless; it involves navigating the tensions and finding coherence between policies that operate from different fundamental perspectives.

A stated objective of the ENTICE project is to analyse the interplay between existing and emerging trade, climate, and industrial policies, and assess their economic and environmental impacts. To this end, this report sets out a research framework that enables to analyse interdependencies and interactions between the three policy fields. Its purpose is fourfold:

- to guide the qualitative analysis of TCI policies and corresponding political narratives throughout the ENTICE project;
- to provide the foundations of a common language enabling effective interdisciplinary collaboration among researchers with diverse backgrounds;
- to provide a canvas for constructive engagement with stakeholders in the project's co-creation mechanism; and
- eventually to leverage this guidance for qualitative analysis, interdisciplinary collaboration, and co-creation towards facilitating/enabling scenario modelling to quantitatively underpin climate and trade policymaking.

The framework is structured in six sections. Section 2 discusses definitions for trade, climate, and industrial policy as well as their logical relationship and the complexities that arise when they interact. Section 3 offers an overview of the economic foundations of global trade and its environmental impacts. Building on this, Section 4 adds conceptual layers for climate, trade, and industrial policy and discusses how key policy instruments from each domain interact with the economic system as presented in the previous section. Section 5 then adds granularity in terms of the commodities being traded. Differentiating between different categories of commodities is necessary because trade liberalisation or protectionism will have different environmental impacts depending on which goods are being affected. An obvious example is that enhanced trade in fossil fuels will likely increase global emissions whereas trade in clean technologies such as renewable energy equipment is likely to have the opposite effect. Finally, Section 6 summarizes the key elements of the TCI framework developed in the previous sections and concludes.

A1|2 Defining Trade, Climate, and Industrial Policy

While science typically requires unambiguous definitions to facilitate rigorous inquiry, every-day-communication is replete with concepts that retain uncontested ambiguity, concepts that are clear enough to enable effective communication but flexible enough to capture a wide range of perspectives. This is particularly relevant in the context of ENTICE, an interdisciplinary research project involving scholars from engineering, sustainability science, economics, political science, trade modelling, and related fields. Given these diverse disciplinary backgrounds, participants may rely on differing implicit or explicit definitions of key concepts. In order to develop a common language, this section traces different definitions that are being sometimes implicitly employed in the academic literature and propose our own working definition for the purpose of the TCI framework – one that is not necessarily complete and exhaustive but one that can be collectively understood and uncontestably and consistently adopted in the context of the ENTICE project.

Moreover, we will provide an overview of salient classifications of policy instruments applied in each domain. We note that a perfect taxonomy of policy instruments that is comprehensive, exhaustive, unambiguous and universally agreed does not exist for any of those fields. Different policy types are analytical categories that are employed to describe existing policies. As such they are social constructs. Their definitions will change with the purpose they are being employed for. And more importantly, real world policies are messy and rarely conform to single theoretical policy instrument. Therefore, analysts will necessarily change the definitions of their analytical categories if and when we come across a new policy that does not quite fit into one of them. As a result, generations of researchers have been coming up with different "boxes" for policy instruments that are partially overlapping. Take the differentiation of a carbon tax vs. carbon trading. The former can be categorized as a tax instrument and the latter as a market-based instrument. However, both are considered under the category of "carbon pricing". Which classification you chose is a pragmatic question and most importantly an analytical choice. In this research framework we, therefore, are not trying to exhaustively review the existing literature and attempt the perfect synthesis of policy taxonomies, but will propose our pragmatic classification that makes sense for the purposes of the ENTICE project.

A1|2.1 Trade policy

Even major textbooks on trade policy do not expressly define the term (Caliendo & Parro, 2022; Kerr et al., 2007; Klasen, 2020). Lima-Campos and Gaviria (2017) discuss two different definitions for trade policy. They first define trade policy as a field of economic research, as "the science of finding the efficient point of import and export policies in a spectrum whose extremes are total 'government intervention' and total 'free trade'" (Lima-Campos & Gaviria, 2017, p. 4). The second proposed definition approaches trade policy from a legal point of view and defines trade policy "as the set of laws and regulations that affects the foreign trade of a country. To put it another way, trade policy is the ensemble of legal rules which impact and influence a certain country's foreign trade." (Lima-Campos & Gaviria, 2017, p. 5).

This second definition appears to be much more useful for the purposes of developing an interdisciplinary qualitative research framework – even if this legislative/regulatory approach is heavily reliant on/driven by its economic counterpart. However, in our view, the definition falls short in one aspect, namely that it confines trade policy to formal laws and regulations. In practice, however, policy makers employ a wide range of different instruments to affect foreign trade and not all of them have legal character. Adapting their definition we propose the following definition of trade policy:

TRADE POLICY encompasses the set of laws, regulations, strategies, and actions adopted by gov- ***ernments, which affect a country's (or a group of countries') foreign trade.***

Historically, trade policy was typically pursued within a Ricardian paradigm, which assumed that international trade has not only an overall net benefit but is beneficial for all trading partners involved. Within the paradigm, trade liberalization almost became an objective on its own. Certainly, the goal of trade policy has been to integrate a country in the global economy by strengthening the economic links among nations so as to reap the benefits of international trade (Lima-Campos & Gaviria, 2017).

A1|2.2 Industrial Policy

Several economic rationales for industrial policies are put forward in the literature. We follow the categorization by Juhász et al., (2024), according to whom these rationales relate to (1) managing the positive or negative externalities of economic activity, (2) coordination (or agglomeration) failures and (3) public input provision. Externalities denote beneficial or adverse impacts of industrial policy, for instance on national security, social cohesion or the environment. Positive externalities may be for example the spill-over of knowledge from one actor to another that is not reflected in economic gains for the former. Policy intervention can be necessary or desirable to realize positive or avoid negative externalities.

Coordination or agglomeration failures exist where collaboration between actors would create benefits for all but does not materialize because no economic actor has an incentive to take the first step. Industrial policy can help exploit this potential by providing these incentives.

Finally, governments need to make choices when providing public goods such as infrastructure provision or education. Since these public goods benefit different economic actors in different ways, these public investment decisions shape the conditions for industrial activity and need to be perceived in this perspective as active industrial policy. Market and coordination failures are particularly pervasive under uncertainty, and different policy goals are interlinked with each other (Altenburg & Assmann, 2017).

Nevertheless, while regularly used by governments around the world, industrial policies traditionally have been controversial and unpopular among economists (Cherif & Hasanov, 2019). Critics argue that policy makers in most cases will not have sufficient information to choose and design appropriate policies (informational critique). Another key argument against industrial policy is that policy makers will be prone to regulatory capture and their policies likely to be biased. Connected to this critique is the idea that governments should not be allowed to "pick winners'' and that markets are both more effective and more efficient in finding solutions. In summary, governments are considered unable to address market failures without causing severe market distortions elsewhere (Juhász et al., 2024). Juhász et al. counter this by arguing that it is actually not necessary to pick winners. Good industrial policy should rather pursue a portfolio approach – like a venture capital investor – and make sure to identify losers quickly enough and thus avoid throwing good money after bad projects (Hallegatte et al., 2013; Juhász et al., 2024; Mazzucato, 2015).

Despite being unfashionable especially under the long-dominant neoliberal economic paradigm, industrial policy is widely used globally (Aiginger & Rodrik, 2020; Evenett et al., 2024a; Juhász et al., 2022). Many policies and initiatives falling into this category have been pursued under the banner of innovation policy, trade policy, energy policy and many other labels (Juhász et al., 2024).

Correspondingly, Juhász et al. propose a broad definition of industrial policy: Industrial policy can be defined as “those government policies that explicitly target the transformation of the structure of economic activity in pursuit of some public goal” (Juhász et al., 2024, p. 216). While we agree with the general gist of this definition, we suggest further refinement. The expression “target the transformation of the structure of economic activity” can easily be misunderstood to be synonymous with changing the economic structure. In reality, however, we observe that industrial policy is frequently employed also to conserve it, especially when previously competitive industries are exposed to increasing international competition and changing geo-economic circumstances. We therefore propose the following definition:

INDUSTRIAL POLICY comprises the set of laws, regulations, strategies, and actions adopted by governments that explicitly guide, oppose, or control the transformation of the structure of economic activity in pursuit of some public goal.

Historically, this public goal has primarily been to stimulate innovation, productivity and economic growth (Juhász et al., 2024; Meckling, 2021). Recently, economic resilience and environmental concerns are receiving increasing attention. The goal of economic resilience has been elevated through major geopolitical changes. First, the COVID pandemic demonstrated how brittle and vulnerable global value chains are. And Russia’s war on Ukraine and the associated global energy crises further elevated the issue on the political agenda.

For a long time, environmental concerns played a subordinate role. Industry actors and policymakers who were concerned about the competitiveness of their domestic industries focused on protecting industry from the costs imposed by decarbonisation policies, and especially from the risks of industrial relocation and carbon leakage to countries with no or limited environmental regulation (IPCC, 2022a; Nilsson et al., 2021a), rather than pushing for a transformation. Free allocation in the European Emissions Trading System is a case in point. Efforts to reduce emissions in industry were mostly limited to low-hanging fruits and low-cost measures like energy efficiency measures. In recent years, however, with technical solutions for industry decarbonisation emerging (Agora Energiewende & Wuppertal Institut, 2019; Doré et al., 2023), policy and industry strategies increasingly aim at transforming industrial production structures to make it climate-neutral in the future (see also Bataille et al., 2018; Gläser & Wolf, 2023; Hallegatte et al., 2013; Löfgren & Rootzén, 2021; Nilsson et al., 2021a; Praetorius & Dierker, 2022; Sovacool, Bazilian, et al., 2023; Sovacool, Iskandarova, et al., 2023; Tagliapietra & Veugelers, 2023; Van Reenen, 2023).

A1|2.3 Climate Policy

Climate policy[2] is a dynamic and evolving concept, constantly refined to capture the complexity of the climate challenge and the diverse ways societies are responding to it. The academic literature offers various nuanced approaches to defining and categorizing climate policy, often reflecting different disciplinary lenses or specific policy objectives. From an economic perspective, climate change is often framed as a global externality, and climate policy is the intervention designed to internalize these costs. A common theme is its objective-based approach focussing on climate mitigation and adaptation. This fundamental distinction shapes different policy domains and priorities. Consequently, we propose the following working definition:

CLIMATE POLICY refers to the laws, regulations, strategies and actions taken by governments, organizations, and other entities to minimize anthropogenic greenhouse gas emissions (mitiga-

[2] While this research framework specifically defines climate policy for pragmatic reasons, we recognize the extensive environmental impacts of international trade beyond climate change. It is important to note that the developed policy taxonomy (see section 0) is flexible enough to capture and categorize these broader environmental policies.

tion), and prepare natural ecosystems and human systems – populations, economic activities, and infrastructure – for the impacts of unavoidable climate change (adaptation).

Policy makers have sought to build coalitions to advance climate ambition with a wide range of actors. Consequently, climate policy has been invoked to contribute to a correspondingly wide range of objectives. However, a common consensus probably is enshrined in the United Nations Framework Condition on Climate Change. Its Article 2 states that

"The ultimate objective of this Convention (…) is to achieve (…) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (United Nations, 1992, Article 2).

We note that internationally, questions about raising and transferring funds necessary for mitigation, adaptation, or compensating for climate change-related damage that has already happened (loss & damage) has become its own pillar of climate policy. However, we deem that raising and transferring funds is a core aspect of government activities and hence implicitly included in the suggested definition.

A1|2.4 Interactions and Differences

Our discussion of the definitions of trade, climate, and industrial policy has shown that they are not mutually exclusive. Moreover, none of the definitions is completely clear cut. While some policy instruments can unequivocally be classified as trade, climate, or industrial policy, there are edge cases for all of these policy fields where the distinction is less clear (see figure).

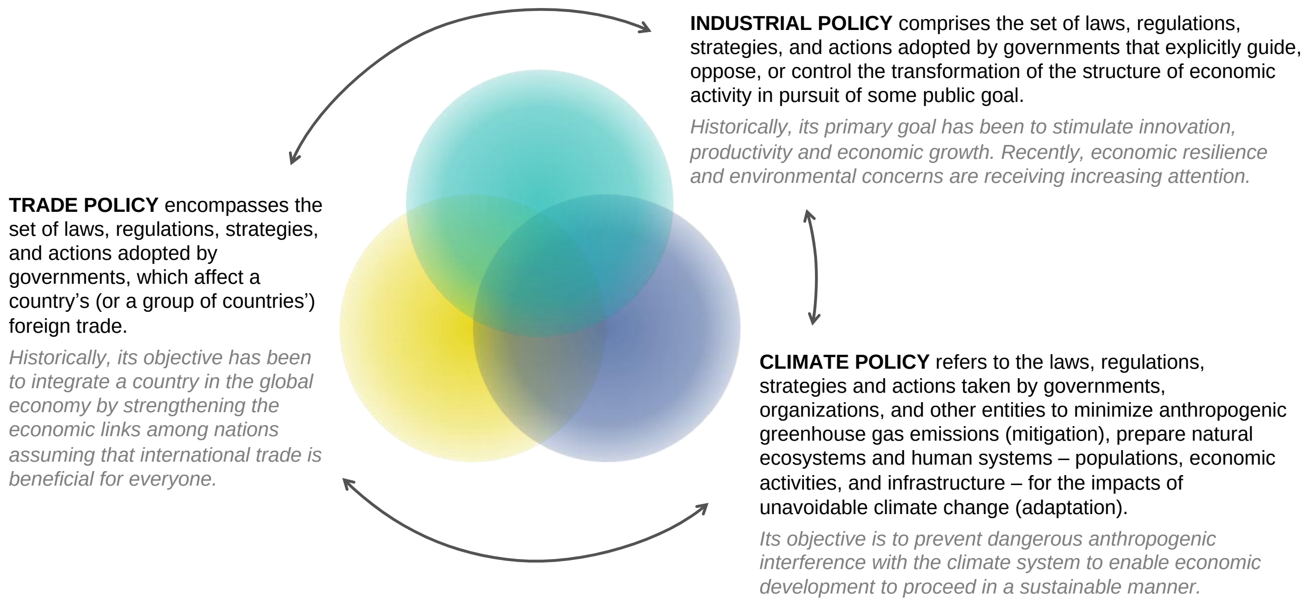

Figure 3. Definitions of and interactions between trade, climate and industrial policy. *Own illustration.*

At their core, industrial policy, climate policy, and trade policy are defined by distinct primary lenses. The defining characteristic of trade policy is the "cross-border" dimension, its direct engagement with the movement of goods, services, knowledge capacities and capital *across* national borders; its very essence is about regulating and influencing this cross-border commerce. Whether through tariffs, quotas, trade agreements, or export controls, the policy's primary domain is the interface between national economies and the global marketplace. Its objectives, such as promoting exports, limiting imports, or securing market access, are inherently tied to this international flow.

Industrial policy, in contrast, is fundamentally characterized by its targeted approach to specific economic actors or productive activities *within* a domestic economy. It's about government efforts to shape the economy by targeting specific industries, firms, or economic activities. The focus is on altering the structure of domestic economic activity and production, fostering "national champions," or improving the competitiveness of particular domestic sectors within a global market environment. While it aims for broader societal goals, its mechanism of action is through direct or indirect support and regulation of industrial businesses or specific types of economic activity.

Meanwhile, climate policy stands apart by being primarily defined by its desired outcome: addressing and mitigating the impacts of global climate change. Its core objective is to reduce greenhouse gas emissions (mitigation; objective at the *global* level), adapt to the unavoidable consequences of a changing climate (adaptation; objective at the *national* or even *subnational* level). The policy is agnostic about actors in the sense that it seeks to achieve these environmental outcomes regardless of who implements the measures – be it governments, organizations, businesses, or individuals. The choice of instruments (e.g., carbon taxes, regulations, subsidies) is driven by their effectiveness in achieving the environmental goal, rather than by a specific type of economic entity or cross-border transaction as the primary defining factor.

These differing foundational perspectives create a dynamic and often challenging interplay. When industrial policy aims to foster a domestic "green" industry (targeting specific firms/sectors), it often employs tools like subsidies or local content requirements. These measures, while domestically focused on actors, inherently impact cross-border commerce by making foreign goods less competitive or by favouring domestic production. This is where the "green protectionism" debate arises, as a policy designed to support a domestic industry (industrial policy), possibly in the context of climate action (climate policy), can be perceived as distorting international trade (trade policy).

The urgent need to achieve climate outcomes (e.g., decarbonization) increasingly compels both industrial and trade policies to align with environmental goals. Industrial policy becomes "green industrial policy" to accelerate clean technology development. Trade policy is then leveraged to promote environmental goods and services or to prevent industrial relocation and carbon leakage (e.g., CBAMs). Here, the outcome-oriented nature of climate policy dictates the direction and even the instruments used by the actor-targeted industrial policy and the cross-border focused trade policy.

While synergies exist, the distinct primary definitions also create friction. A trade policy focused on reaping the economic benefits of specialization and comparative advantages in trade might clash with an industrial policy prioritizing domestic job creation in a specific sector, or a climate policy imposing stringent standards that encourage decarbonisation but may act as trade barriers or instigate industrial reconfigurations. The "outcome" of climate policy (e.g., lower emissions) might be achieved through measures that are seen as protectionist by trade policy (e.g., subsidies for domestic green industries), or that disproportionately burden specific industrial actors ("de-industrialisation").

A practical conclusion from this discussion is that it is not useful to classify specific instruments as exclusively either trade, climate, or industrial. When discussing both theoretical policy instruments and empirical examples of policies, they will almost always have effects relating to each policy domain. They may differ, though, with respect to how impactful, far reaching, or long-lasting these effects are and whether they are synergistically contributing to the underlying objectives or undermining them.

A1|2.5 The Political Economy of the TCI Nexus: the Rise of Industrial Policy Nationalism

The interdependencies within the trade, climate, and industrial policy nexus previously discussed, are heavily influenced by political forces. This section explores how the recent return of industrial policy is a new form of economic nationalism, with significant consequences for these policy areas. The core idea of economic nationalism is that a state uses its power to advance its own economic interests (Nakano, 2004). However, this concept is more complex than it seems. Nationalism, as a powerful ideology, also works to build and maintain a shared political community at home. It does this by creating a sense of a shared economic and societal destiny and collective responsibility, which in turn justifies state intervention in the economy (Fetzer, 2022). While it has historically been associated with protectionism, this concept has evolved. Industrial policy nationalism is a specific "geoeconomic turn" where industrial policy is used as a tool for national security and international competition, especially in key technology sectors like clean energy and semiconductors (Hauge et al., 2025; Herranz-Surralles, 2024; Meckling, 2025).

Several major factors are driving this shift toward industrial policy nationalism, leading countries to prioritize developing their own industries over sticking to traditional liberal trade rules:

- **Geopolitical Competition and National Security:** As the global order becomes less unipolar, countries are putting national security, resilience, and technological leadership at the top of their policy agendas (Hauge et al., 2025; Mercurio, 2024). Industrial policy is increasingly seen as a way to gain a strategic advantage and reduce dependencies on geopolitical rivals. For example, the European Union is now linking its energy transition goals to its core geopolitical strategy (Herranz-Surralles, 2024).
- **Supply Chain Resilience:** The vulnerabilities of complex global supply chains, which were highlighted by the COVID-19 pandemic and its profound economic/trade impacts, have created a strong push for better risk management. This has led to efforts to "reshoring" or "friend-shoring" critical production capabilities (Mercurio, 2024). As a result, governments are using industrial policy to build more robust domestic supply chains (Hauge et al., 2025).
- **The Geoeconomic Turn in Decarbonization:** Climate policy has shifted from a focus on international cooperation and sharing costs to a "geoeconomic competition for the benefits of decarbonization" (Meckling, 2025, p. 869). Nations are now using industrial policy to secure the economic and technological benefits of leading the clean energy transition, seeing it as a new path for economic development, enhanced competitiveness, and export-led growth (Meckling, 2025).
- **Domestic Political and Social Objectives:** From a political economy perspective, industrial policy is often popular because it can create jobs, reduce social inequalities, and respond to public demand for government action (Juhász & Lane, 2024). The political reasoning for these policies often goes beyond economic efficiency, and includes managing the domestic political conflicts that come with big economic changes (Andreoni & Chang, 2019).

Furthermore, the drive towards renewable electrification is not solely a climate imperative but also a powerful strategy for increasing economic resilience and energy security. For major economies, climate mitigation through domestic clean energy production, such as solar and wind power, directly correlates with a reduced need for volatile fossil fuel imports. This strategic linkage is particularly evident in countries like China and India, which view rapid renewable deployment as a means to decouple their economic growth from global oil and gas market fluctuations. By securing a domestic source of energy, these nations mitigate geopolitical supply risks, stabilize domestic energy costs, and strengthen their long-term economic

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autonomy – a primary objective of the new wave of industrial policy.

The rise of industrial policy nationalism makes the interactions between trade, climate, and industrial policy much more complex. This trend is a clear move away from the "Washington Consensus" model of free trade and investment (Mercurio, 2024). It is marked by an increase in protectionist measures (like import tariffs), subsidies, and export controls, which cause trade frictions and have negative spillovers that hurt other countries' economies. Specifically, these uncoordinated, unilateral policy interventions create significant opportunity costs and can lead to international conflict by eroding trust and complicating multilateral cooperation (Hoekman & Nelson, 2025). This shift also actively shapes markets and can lead to a new form of economic division, where a focus on domestic interests and national security disadvantages other nations (Mercurio, 2024).

From a climate policy standpoint, this geoeconomic shift has a dual effect. On one hand, it has the potential to speed up global decarbonization by encouraging competition and investment, which can boost innovation and drive down the cost of technology (Meckling, 2025). On the other hand, it creates significant risks, including the potential for more trade protectionism and international disputes over access to strategic resources and markets. This increased protectionism creates two separate but linked problems: it could significantly raise the cost of climate action, making it more difficult to meet climate goals and less likely that more ambitious targets will be adopted. At the same time, it can fuel conflict that erodes trust in global institutions and prevents the international collaboration that is essential for meeting climate objectives. This complicates the cooperative effort needed for global climate action (Hoekman & Nelson, 2025; Meckling, 2025).

The interdependence of these three policy domains is also demonstrated in complex regulatory interactions and conflicts, which often require reconciling instruments that serve different ultimate goals. A prominent example is the friction between the EU's Carbon Border Adjustment Mechanism (CBAM) (a climate/trade measure) and the US's Inflation Reduction Act (IRA) (a climate/industrial measure). While the CBAM aims to prevent carbon leakage by pricing emissions on imports, the IRA uses domestic subsidies to support green manufacturing. The intense, though now obsolete, debate around whether IRA subsidies should be accounted for as a de facto carbon price substitute in the calculation of CBAM levels illustrates the profound challenge of translating different national industrial policy tools into compatible terms for international trade regulation (Lydgate, 2023; Marcu et al., 2023; OECD, 2023a; Tucker & Meyer, 2021). This type of regulatory overlap highlights how industrial and climate policy choices spill over immediately into the international trade sphere, demanding greater policy coherence.

This new approach to industrial policy also expands its scope, blurring the lines between economic, security, and climate goals. The focus shifts from simply fixing market failures to actively shaping markets and growing strategic industries for global competition. These initiatives are often pursued with the dual aim of strengthening supply chain security and achieving climate targets, showing how integrated the TCI nexus is under this new paradigm (Hauge et al., 2025; Meckling, 2025).

A major concern stemming from this trend is its potential impact on global equity and justice. The policies enacted by the world's leading economic powers (e.g., the United States, China, and the European Union) are collectively reshaping the global economic landscape in a way that may disadvantage other nations, especially in the global South (Hauge et al., 2025). This is because the new wave of protectionism could leave many countries in a precarious position, especially those that have low incomes and are vulnerable to trade changes. For example, some tariffs imposed by the US could have significant negative effects on trade and structural change in African nations (Andreoni et al., 2025). Similarly, the new protectionist era of the US and EU could severely impact the economies of East Asia, as it disrupts global value chains and the free flow of goods and services that many of these nations rely on (Park, 2024). Not only would this reinforce economic divides between that can integrate into new supply chains for critical technologies and those who don't, it may also jeopardize global climate change mitigation efforts. As Meckling notes: larger, richer economies – such as China, the EU, Japan and the USA – are pulling ahead in clean technology manufacturing and deployment, whereas poorer and smaller economies lag behind (...) 90% of trade in low-carbon technology occurs among high-income countries. Yet, it is emerging economies that will grow their energy demand most until 2050 as their populations gain access to electricity and their economies grow" (Meckling, 2025, p. 873). Consequently, the recent shift towards industrial policy nationalism could turn climate action from a cooperative global effort into a zero-sum game of national competition, which poses a significant challenge to the principles of global cooperation and climate justice.

A1|3 Economic Foundations

Trade affects the environment through multiple interconnected channels. The most immediate impact comes from international transportation, as the movement of goods across borders generates directly emissions, such as container shipping and aviation. In addition to transportation, trade indirectly affects the environment by reshaping the economic system. It redistributes economic activity, shifting production across countries and sectors based on comparative advantages, resource potential, and cost structures. At a deeper level, trade is also among the core drivers of technological progress and innovation, by shaping firm productivity, pushing innovation, and encouraging the adoption of new, commonly cleaner, production methods. This section maps out the main channels through which trade shapes climate outcomes, both directly and indirectly. Section 0 first looks at the direct impacts in the form of transport emissions. Section 0 then focuses on the indirect channels driven by trade-induced efficiency gains, further classified into scale, specialisation (inter-industry composition), productivity effects (intra-industry composition). and innovation dynamics (technique effect). Finally, Section 0 focuses on how these channels interact with one another.[3]

A1|3.1 Direct impact: international transport

One of the most direct environmental effects of international trade is the increase in emissions from transportation. The movement of goods across borders relies heavily on maritime shipping, aviation, and land transport, all of which contribute significantly to global greenhouse gas (GHG) emissions as they use petroleum products. International aviation and maritime shipping accounted for roughly 3% of global fossil CO_2 emissions in 2023, further increasing in 2024 (Friedlingstein et al., 2025a), placing them among relevant drivers of increasing climate impacts, particularly for economies with high trade dependency (International Transport Forum, 2015b).

Scientific research on international transportation and its environmental impact can be grouped into three key areas (see Felbermayr et al., 2024 for a comprehensive review). The first area of research focuses on the quantification of emissions from international transportation – particularly those from international bunker fuels – providing essential input for both empirical and modelling studies. This includes efforts to measure historical emissions and assess their climate impact, which are fundamental to evaluating the effectiveness of mitigation strategies. While a broader set of emissions datasets is discussed in Section 4 and Appendix 1, several key sources are particularly relevant to this area. These include EDGAR (Monforti Ferrario et al., 2019), the Global Carbon Project (Friedlingstein et al., 2025a), and the IEA (2024), which provide geographically comprehensive, sector level data that encompass emissions from international shipping and aviation. In addition, emerging platforms such as Carbon Monitor (Liu et al., 2020a) and Climate TRACE (2023a) enhance the spatial and temporal resolution of GHG emissions data, enabling near-real-time tracking of emissions from specific sources, including those from international bunker fuels, across regions/countries and transport modes.

The second area includes a broad set of technical and econometric applied analyses, which focus on quan-

[3] While this framework does not explicitly take into account the role of financial markets, financial dynamics represent an additional channel through which trade policy may influence emissions. For example, uncertainty linked to trade tensions – such as those observed during the Trump administration – has been shown to depress equity markets, potentially reducing consumer expenditure through wealth effects. As household exposure to financial assets grows, asset price fluctuations can amplify economic responses to trade shocks, thereby affecting consumption-driven emissions. Chodorow-Reich et al. (2019) estimate that each additional dollar of household wealth raises immediate consumer spending by 3 to 24 cents, underscoring the relevance of this mechanism.

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tifying possible future emissions trajectories and evaluating the environmental performance of different transport modes, including the role of technological advancements in mitigating emissions. Sector-specific analyses of transport modes and technological advancements have focused on single transport modes, or the interplay across different transportation modes, using engineering optimisation systems and energy system models or econometric analyses, exploring the potential of decarbonisation (e.g. Doukas et al., 2021a; Fragkos, 2022a; Jonkeren et al., 2023a; Mundaca et al., 2021a; Verschuur et al., 2024a).

The third area broadens the analysis beyond the sectoral level, examining how international transport emissions interact with the wider economy. This includes both partial equilibrium Integrated Assessment Models (IAMs), which simulate energy, land use, and transport systems in detail while treating economic feedbacks in a simplified or exogenous manner, and general equilibrium models – such as Computable General Equilibrium (CGE) or macro-econometric (post-Keynesian) input-output models – which capture the systemic interactions between trade, transportation, socioeconomic impacts and climate outcomes across the entire economy. These models typically embed transport within a broader economic framework, allowing for the analysis of feedback between emissions, trade, energy transitions, and policy. Detailed-process IAMs, such as those forming the bedrock of the Intergovernmental Panel on Climate Change (IPCC) assessment reports (e.g. IPCC, 2022c), simulate how global transport emissions evolve under alternative climate policy or socioeconomic scenarios – or optimise transport emissions to achieve certain global warming or emissions goals. General equilibrium studies (e.g. Cristea et al., 2013a) show trade-driven emissions growth, while recent IAM studies (Müller-Casseres et al., 2024b; Speizer et al., 2024a) showcase respective potential for deep decarbonisation of the global maritime sector via the uptake of alternative low and zero-carbon fuels. Still, most trade models simplify transport representation via the introduction of iceberg costs, limiting insights into climate-related measures such as carbon pricing and modal shifts (Felbermayr et al., 2024).

International transport is unambiguously emissions-intensive: international trade implies longer distances and more freight activity, which increase emissions from maritime shipping, aviation, and road transport. It constitutes the clearest, more direct channel through which trade affects the climate, with substantial empirical evidence linking trade expansion to rising transportation emissions. While there are context-specific exceptions – such as cases in which importing goods from regions with cleaner production systems results in lower overall emissions than local production (Payen et al., 2015a) – the net effect of international transport remains a significant contributor to global GHG emissions at least in case transport continues to be predominantly dependent on petroleum products. A first-order effect of protectionist measures may be reduced emissions, if resulting in overall trade contraction, although they may also create logistical inefficiencies and longer distances in case of trade diversion (Q. Wang et al., 2022a).

A1|3.2 Trade, efficiency gains, and environmental outcomes

Beyond its direct environmental impact through international transport, trade also has indirect effects, arising from trade-induced changes in the broader economic system. Trade is fundamentally intertwined with the global distribution of economic activity; it can thus reshape production across countries and sectors based on comparative advantages, cost structures, and specialisation patterns. This reallocation influences which sectors expand or decline, influencing employment and income distribution, and altering entire supply chains. These shifts not only affect consumption choices but also have significant emissions and broader environmental outcomes.

Decomposition analysis – a well-established and widely applied methodological approach that seeks to identify and quantify the distinct channels through which trade influences economic activity and, in turn, environmental pressures – highlights three main mechanisms that drive environmental change due to trade: the scale effect, the composition effect, and the technique effect (Copeland & Taylor, 1994a; G. M. Grossman & Krueger, 1991a). Correspondingly, we consider the structural changes international trade induces in the economic system through efficiency improvements – such as market expansion, economies of scale, comparative advantage and specialisation, as well as firm selection and productivity gains. These mechanisms reshape production and consumption patterns, which in turn affect the level and composition of emissions. We classify the mechanisms into scale effect (Section 0), specialisation or inter-industry composition effect (Section 0), productivity or intra-industry composition effect (Section 0), and technique effect (Section 0).

A1|3.2.1 Scale and income effects: leveraging economies of scale

The scale effect refers to the process in which – with trade liberalisation – economies of scale, increased competition, and access to larger markets drive economic expansion, leading to higher production and consumption (Backus et al., 1992a), resulting in greater final and intermediate demand for energy and natural resources. In the absence of strong environmental policies, this increase in demand leads to an overall increase in GHG emissions (Lindmark, 2004a).

However, the long-term relationship between economic growth and environmental pressure is not necessarily linear. The Environmental Kuznets Curve (EKC) hypothesis suggests that, while growth initially (in low income levels) leads to higher emissions, rising income levels may, under certain conditions, shift consumer preferences and political priorities toward environmental protection, eventually reducing pollution (Kukla-Gryz, 2009a).[4] In this view, economic growth can have a conditional effect on emissions, shaped by the demand for cleaner goods and stricter environmental regulation. The empirical evidence on this hypothesis remains highly debated and inconclusive (see Dinda, 2004a; Leal & Marques, 2022a): while some studies support the Kuznets curves pattern for specific pollutants and countries, others argue that the shape of this relationship varies significantly across environmental indicators, regions, and policy contexts. Critics highlight that factors such as trade openness, institutional quality, and technological change play a crucial role in shaping the income-environment relationship, making a universally homogeneous Kuznets trajectory unlikely.

[4] Even if the EKC does not represent a change directly induced by trade in the economic system – and could be seen as a third-order effect, whereby trade contributes to income growth, which in turn influences preferences – we include it here because it is closely linked to economic growth and is typically treated as part of the scale effect in most decomposition frameworks.

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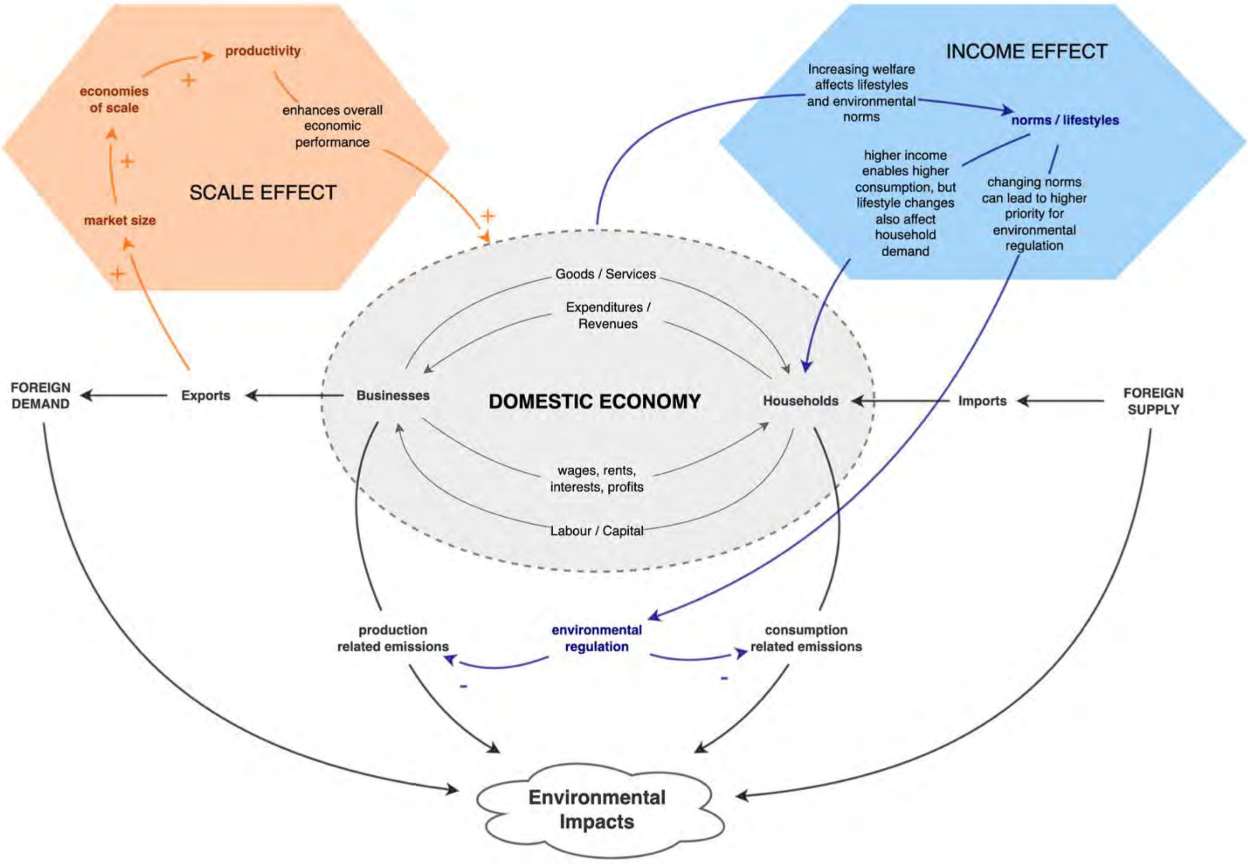

Figure 4. Schematic illustration of the scale and income effects. *Source: own illustration.*

A1|3.2.2 Specialisation effect: comparative advantages shape inter-industry composition

Beyond its impact on total economic activity, trade also reshapes the composition of production across sectors and regions, influencing the geographical distribution of emissions. This inter-industry composition effect reflects how trade alters the relative size of different sectors (often different in carbon intensity), depending on each country's comparative advantage. When countries specialise in carbon-intensive production, trade can lead to an overall increase in emissions; conversely, specialisation in cleaner sectors can yield environmental gains.

Shifts in sectoral composition are closely linked to the evolution of global supply chains as well, as some countries specialise in intermediate inputs rather than final goods. Over the past decades, advancements in shipping, trade liberalisation, and digital technologies have enabled the fragmentation of production across borders, leading to the expansion of global value chains and the widespread use of outsourcing. Today, intermediate goods trade accounts for approximately 50–60% of total global trade (Vasudevan & and Manalaya, 2023a). Firms fragment production processes across borders to optimise costs, maximise efficiency, and leverage specialised inputs, thus creating intricate global production networks. This reallocation of production across supply chains represents optimality within a single production process, where different countries contribute based on their relative cost advantages, labour skills, technological capabilities, and regulatory environments. While this structure enhances economic efficiency, it also has signifi-

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cant environmental implications, particularly concerning the distribution of emissions across production stages and regions (Peters et al., 2011a).

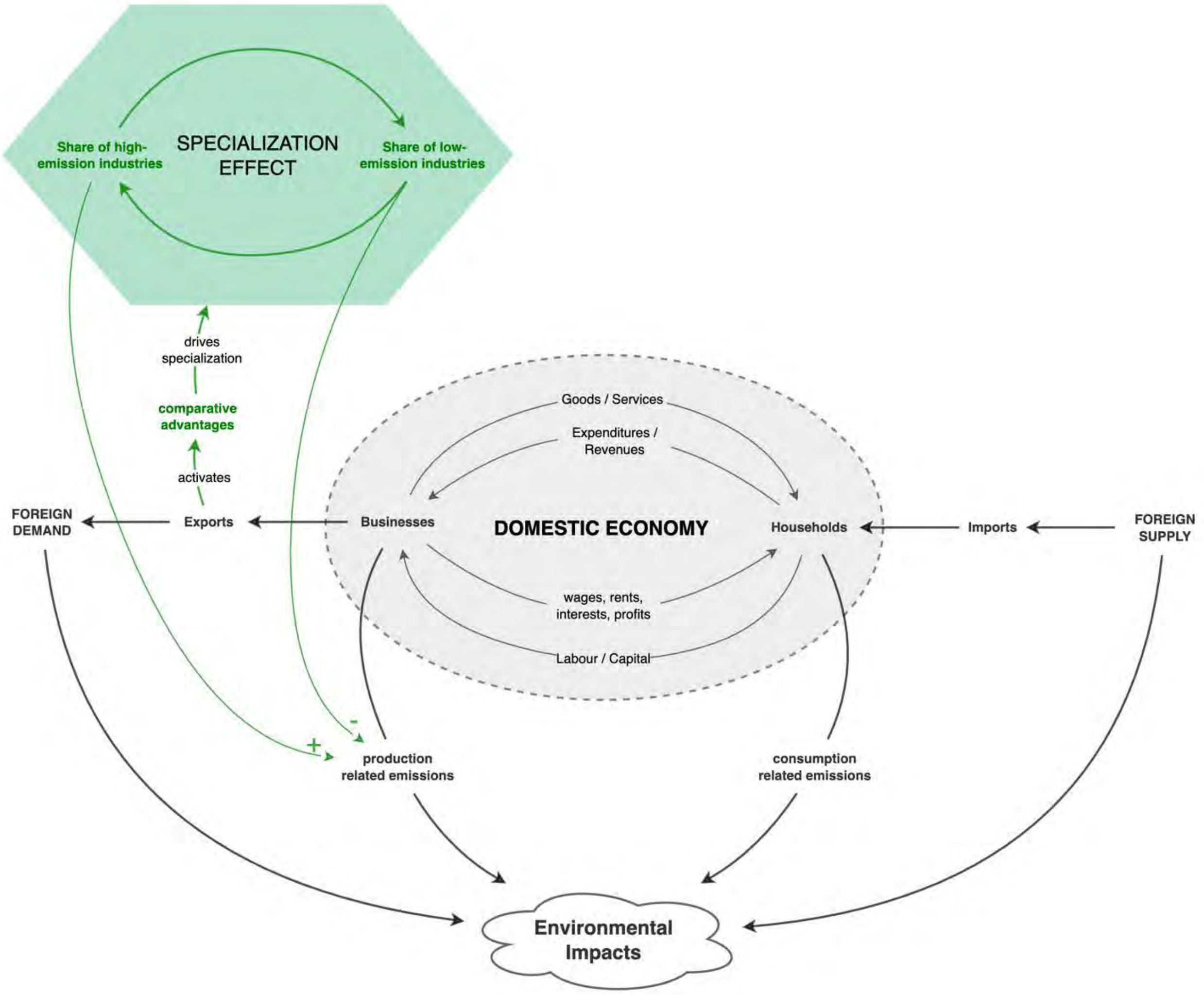

Figure 5. Schematic illustration of the specialization effect. *Source: own illustration.*

A widely used approach to assess the environmental impacts of global supply chains is Environmentally Extended Multi-Regional Input-Output (EE-MRIO) analysis (Stadler et al., 2018a). This method traces carbon flows through production stages, quantifying embodied emissions in trade and identifying key emission nodes across regions (Wiedmann & Lenzen, 2018a). Life Cycle Assessment (LCA) offers a complementary perspective by evaluating environmental impacts across a product's full life cycle (Miettinen & Hämäläinen, 1997), especially when combined with input-output modelling (Castellani et al., 2019; Tukker & and Dietzenbacher, 2013). Another important tool is Consumption-Based Accounting, which adds up and attributes emissions to the location of final consumption rather than the location(s) of production; this reveals how emissions-intensive production often shifts to developing economies, while high-income countries emerge as net importers of embodied emissions – evidence of carbon leakage (Davis & Caldeira, 2010a; Peters et al., 2011a). These methodologies offer a sectoral lens on emissions redistribution and inform debates on carbon leakage and carbon border adjustments.

The specialisation path can depend on a wide set of factors, among them the availability of carbon-intensive raw materials and the comparative stringency of environmental regulations across trading partners. The latter case has been extensively studied through the lens of the Pollution Haven Effect (PHE) and the Pollution Haven Hypothesis (PHH). The PHE suggests that regional differences in environmental regulation stringency create a comparative advantage for pollution-intensive industries in jurisdictions with weaker environmental policies (Levinson & Taylor, 2008a), while the PHH that trade liberalisation leads to the expansion of pollution-intensive sectors in countries with lax environmental regulations, as firms seek to minimise compliance costs (Taylor, 2005a). These perspectives highlight the role of regulatory asymmetries in shaping trade patterns, with potential implications for both global emissions redistribution and environmental policy coordination.

A complementary line of research in the composition effect focuses on firm-level responses to trade liberalisation. Multinational corporations reorganise production stages globally, guided by cost, regulation, and technological factors. The Pollution Offshoring Hypothesis (POH) suggests that firms may relocate pollution-intensive activities to countries with weaker environmental standards, thereby reducing domestic emissions while raising global pollution (Choi, Jaerim et al., 2023a; Duan et al., 2021a). This is very similar to the Pollution Haven Hypothesis but focusses on relocation of the production of emission-intensive intermediary goods e.g. by multinational companies in the context of global value chains.

Empirical evidence supporting this hypothesis includes findings that U.S. manufacturers reduced domestic emissions by relocating high-polluting production processes to countries like China following trade liberalisation policies (Choi, Jaerim et al., 2023a).

A1|3.2.3 Productivity effect: productivity gains and resulting firm selection affect intra-industry composition among heterogeneous firms

A critical part of trade's impact on efficiency lies in its effect on firm selection and productivity growth – the intra-industry composition effect. Standard decomposition approaches based on sector-level data often fail to capture this channel and tend to attribute reductions in pollution to technique effects (see Section 2.3). Yet, as Cherniwchan et al. (2017a) argue, average emission intensities may decline because trade reallocates market shares toward more productive, and typically cleaner and more efficient, firms within the same sector. Trade openness leads to firm-level productivity gains, which in many cases, as a side-effect of cost-saving upgrades, translate into cleaner technologies and environmental benefits: high-productivity firms not only expand but also invest in technological upgrades, further reinforcing emissions reductions (Amiti & Konings, 2007a; Syverson, 2011a). In practice this effect is closely related to the technique effect (see section A1|3.2.4) which stipulates that trade drives innovation and the uptake of cleaner technologies.

Second, the Melitz model of firm heterogeneity (M. J. Melitz, 2003a) predicts that trade liberalisation forces less productive firms to exit the market, a selection process contributing to aggregate productivity improvements: the Pollution Reduction by Rationalisation (PRR) hypothesis suggests that the resilient/remaining, more productive firms are typically cleaner (less carbon-intensive), and thus trade liberalisation results in overall reductions in carbon emissions and pollution (Kreickemeier & Richter, 2014a); empirical studies have found that trade-induced productivity improvements are associated with reduced water pollution, providing evidence for this hypothesis – e.g., in the case of Chinese manufacturing firms (Song et al., 2024).

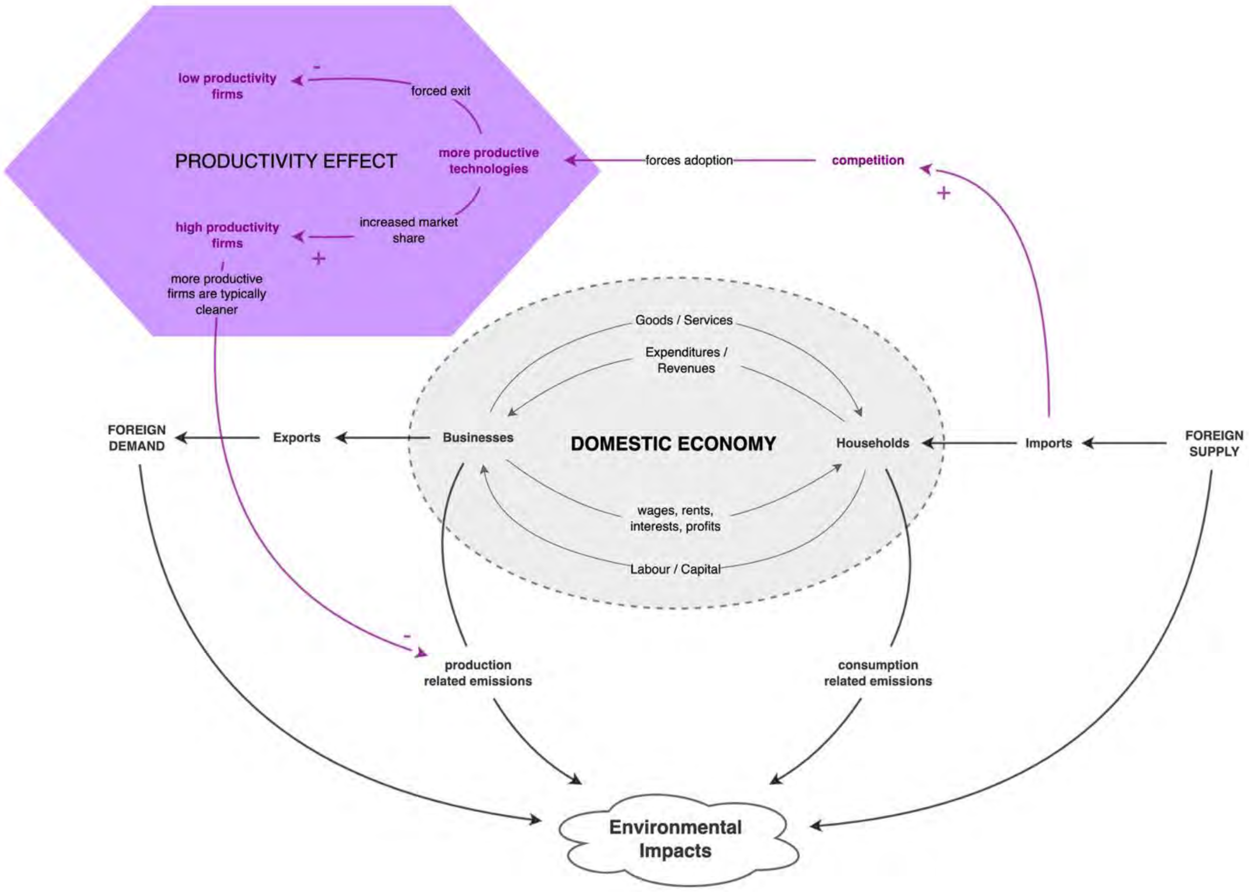

Figure 6. Schematic illustration of the productivity effect. *Source: own illustration.*

A1|3.2.4 Technique effect: technological change and innovation

International trade fosters innovation and technological change, in what is termed as the technique effect, through multiple channels. Melitz and Redding (2021a) identify four primary mechanisms linking trade to innovation: three mechanisms (market expansion, competition, and specialisation) that enhance efficiency and productivity (discussed in Section 0 and 0), and knowledge spillovers that introduce an inherently dynamic effect, in which trade and foreign direct investment (FDI) serve as channels for technology diffusion and long-term productive growth (Keller, 2004a).

International trade facilitates technology transfer across borders, particularly through multinational cooperation and foreign investments, which act as conduits for diffusing advanced production techniques (Keller, 2004a). These knowledge spillovers occur through several channels: vertical linkages (local firms benefit from interaction with foreign suppliers and buyers), labour mobility (employees trained in multinationals transfer knowledge when they move to domestic firms), or demonstration effects (local firms learn from foreign entrants, adapting best practices and technologies). As discussed in Santos (2023a), the extent of knowledge spillovers depends on the absorptive capacity of domestic firms, the type of FDI (greenfield vs. acquisitions), and the institutional framework of the host country. While FDI has the potential to increase productivity and innovation in recipient economies, its effects are highly context-dependent, as also highlighted by Smarzynska Javorcik (2004).

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Innovation can play an important role in reducing carbon emissions, particularly through green technologies, though its impact is context-dependent and can vary across regions, development stages, economic structures, and energy efficiency improvements (Smarzynska Javorcik, 2004). Wu et al. (2024a) find that technological innovation lowers carbon emissions at the provincial level in China while generating positive spillovers in neighbouring regions. Similarly, Demircan Çakar et al. (2021a) show that, in Mediterranean countries, the impact of innovation on emissions varies by development level, with advanced economies being better positioned to adopt cleaner technologies. However, the relationship between innovation and emissions is not always straightforward. Yu et al. (2022a) demonstrate that innovation initially increases emissions by enabling industrial expansion but later leads to reductions, particularly in countries with well-developed financial markets that facilitate green technology adoption. Environmental regulations play a key role in shaping this relationship. Su (2025) shows that strict environmental policies incentivise firms to adopt cleaner technologies, enhancing carbon performance. Similarly, Feng et al. (2025) find that the effectiveness of regulation in reducing emissions depends on the region's technological capabilities: without clean innovation, even stringent policies may fail to achieve meaningful reductions.

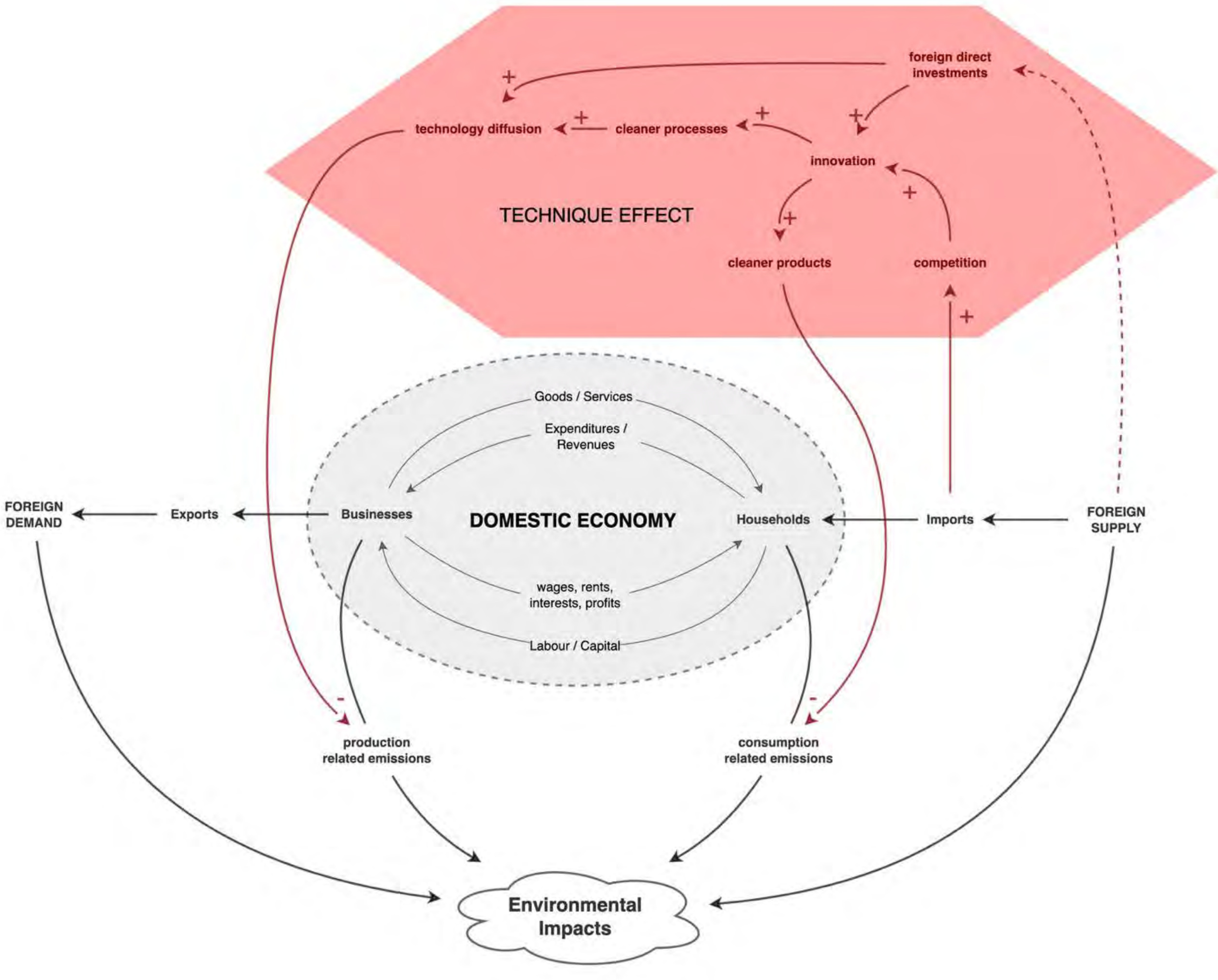

Figure 7. Schematic illustration of the technique effect. *Source: own illustration.*

A1|3.3 Interconnections across channels

The channels discussed above – transportation, scale, composition (including specialisation and productivity), and innovation – can impact the climate in multiple directions and may act as interconnected mechanisms with significant feedback effects, rather than acting in isolation. These interactions can reinforce or offset one another, creating complex and sometimes countervailing dynamics. Some feedbacks manifest rapidly, while others unfold gradually, shaping long-term trajectories of emissions, innovation, and structural change.

International transport is an essential element in determining the extent to which scale, composition and, to a lesser extent, innovation effects will come into play. Indeed, variations in transport costs might influence the overall volume of trade, firms' outsourcing and off-sourcing decisions, the intensity of international competition and, by extension on the domestic market, and therefore incentives to innovate. The impact of international transport on the climate is therefore direct, through the fossil fuel consumption it requires, but also indirect, through its influence on other channels.

Scale effects are a central source of feedback. Upon expanding market size and opportunities, trade liberalisation boosts production volumes and the demand for international shipping and freight transportation, directly raising industry- and transport-related emissions – while market expansion, competition, and specialisation can instead enhance efficiency, yielding environmental gains. Notably, scale can incentivise innovation, as larger markets improve the returns on investments in research and development (R&D) and encourage firms to develop new technologies to enhance their competitiveness in larger global markets – thereby indirectly pushing cleantech innovation and thus contributing to emissions cuts in the long run. This mechanism has been widely studied using trade and growth models – see, e.g., Grossman and Helpman (1993) and Acemoglu and Linn (2004a), who showed that larger markets lead to greater incentives for firms to innovate. Empirical studies show that increased exposure to international competition forces firms to adopt advanced production techniques and improve efficiency (e.g. Bloom et al., 2016a). Additionally, scale supports specialisation and outsourcing – thereby feeding into composition effects – while also enhancing competition, which fosters firm selection and productivity improvements.

Inter-industry composition effects also influence several mechanisms. Whether through comparative advantage, outsourcing, or offshoring, sectoral specialisation can reshape productivity dynamics by prompting the exit of less efficient firms and the expansion of more competitive ones. Specialisation also impacts innovation, as different sectors possess varying capacities and incentives to innovate. Comparative advantage reallocates resources toward innovation-intensive sectors, reinforcing specialisation in technologically dynamic industries (M. Melitz & Redding, 2021a).

Composition effects, from the lens of productivity growth, generate ripple effects as well. More productive firms tend to emit less per unit of output, contributing to improved (lower) aggregate emissions intensity, with their growth shifting sectoral composition toward more efficient industries (Kreickemeier & Richter, 2014a; Martin et al., 2012). Productivity gains can also trigger innovation and accelerate the diffusion of cleaner technologies across firms and/or sectors. At the same time, however, productivity improvements can result in emissions increase (e.g. Dimitropoulos, 2007a). Improved productivity often leads to lower production costs and consumer prices, which in turn stimulate higher consumption; this price-induced demand growth can amplify scale effects and lead to increased overall emissions, particularly if consumption expands in carbon-intensive goods or services.

Finally, innovation and its diffusion facilitate the introduction of new technologies across countries, enhance firm competitiveness, and reshape both productivity and composition dynamics. The overall environmental effect of technological change depends on its direction – i.e., on whether innovations reduce or intensify emissions – and on whether policy actively steers that direction toward low-carbon outcomes (Grubb et al., 2015a). Well directed trade-induced innovation can enable the decarbonisation of international transport, with the development and adoption of cleaner fuels, logistics systems, and vessel technologies. And, although emissions from international shipping have risen alongside global trade volumes over the long term, recent evidence shows that emission intensity has declined due to improvements in fuel efficiency and vessel design, partially mitigating overall emission growth (X. Wang et al., 2025a).

As technologies spread across firms and regions through diffusion, they affect firm efficiency, sectoral carbon intensity, and even global transport systems (e.g., through digital logistics or electric freight solutions). These diffusion processes reinforce earlier productivity and innovation effects and can ultimately reshape the emissions profile of trade. Trade barriers can trigger structural changes that ripple through multiple channels – altering not only sectoral composition but also innovation trajectories and long-term productivity. Akcigit et al. (2018a) for instance find that, while tariffs may generate short-term domestic production gains, they often reduce long-term innovation and aggregate welfare by distorting firms' incentives to innovate.

A1|4 Adding the policy dimension

A1|4.1 Bringing policy domains and economic trade effects into perspective

Having laid out the economic foundations of the interactions between international trade and climate/environmental impacts, we now turn to policies. This section provides a concise discussion on how the three policy domains intervene in the trade economy.

Drawing on the definition of trade policy introduced above, every policy measure that is affecting a country's foreign trade can be classified as trade policy. Related to the five trade effects, the interaction is therefore straight forward. Changes in trade/import tariffs will facilitate or constrain imports and exports and therefore sits at the beginning of the causal chains or each trade effect. Non-tariff measures (NTMs) have a similar effect, but may work through diverse channels. Particularly noteworthy is that the UNCTAD typology of NTMs explicitly differentiates contingent measures, i.e. "measures implemented to counteract the adverse effects of imports in the market of the importing country, including measures aimed at tackling unfair foreign trade practices. These include anti-dumping, countervailing and safeguard measures" (UNCTAD, 2019, p. viii). This means that one and the same measure can fall into different categories depending on whether it is reciprocating on another country's NTMs or not. The scale effect should not be directly affected by import-related trade measures of a given country, but an exporting country will only be able to realize the scale and specialization effects if the importing country is not reciprocating with trade measures. Both the productivity effect and the technique effect are driven by international competition. Tariffs and NTMs that limit the extent to which domestic industries are exposed to international trade will therefore also limit these effects.

Moreover, the idea of reciprocation and the norms outlined in global trade law (GATT/WTO) has also been enshrined in the UNFCCC as one of its principles: "Parties should cooperate to promote a supportive and open international economic system (…) 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. " (United Nations, 1992, Article 3.5). Correspondingly, international trade law has had significant impacts on the way in which climate policies have been designed and implemented.

Industrial policy is defined as any government intervention to guide, oppose or control the transformation of the economic activity in a given country. This "structure of economic activity" corresponds to the "composition" of industries (inter-industry composition) that is at the core of the productivity effect. It may also relate to the intra-industry composition (selection effect), for instance, when industrial policy seeks to promote "national champions" in a selected industrial area. Hence, industrial policies will modulate the performance of the productivity effect and potentially the specialization effect. In practice, however, the causality is often reversed: especially the new wave of protectionist/nationalist industrial policies (including CBAM and the US IRA) are motivated by ongoing or anticipated trade-induced changes in the structure of economic activity and seek to counteract those.

Climate policies are predominantly interacting with the technique and productivity effect. Trade can have positive effects on reducing emissions through productivity effect because more productive firms are typically also more efficient with respect to energy and resource us. However, this correlation is not a necessarily always a given. Economic climate policy instruments are typically designed to internalize negative externalities of industrial production. In other words, they trying to ensure that the correlation holds. If all environmental impacts are priced in and become part of the bottom line of any firm, the most profitable firm will also be the cleanest firm. A secondary effect of this is that internalizing externalities will also change incentives for innovation. In that sense economic climate policies also interact with the technique effect. Of course, this also holds for other types of climate policy instruments that aim at driving innovation and technology diffusion of clean technologies. Climate policies may also affect the inter-industry composition of a given country, but this is typically an unintended consequence. For instance, the objective of the EU ETS is to reduce GHG emissions in an economically efficient manner, but the existence of the Pollution Haven Effect may result in making energy-intensive trade exposed industries less competitive as a side effect. Free allocation of allowances in the EU ETS and CBAM in the future have been part of the climate policy mix precisely to avoid that these industries are driven out of business.

Finally, the academic literature highlights how international trade and trade law drive policy diffusion through learning, competition, and coercion. Countries learn by observing trading partners' policy successes, adapting their own (Cao, 2009; Simmons & Elkins, 2004). Competition pushes states to adjust regulations to enhance economic standing. Coercion, often via powerful states or the World Trade Organization (WTO), imposes policy changes as conditions for trade access or membership, forcing domestic reforms. While leading to policy convergence, this diffusion is shaped by internal political and socio-economic factors.

A1|4.2 Towards a unified taxonomy of TCI policy instruments

As demonstrated in section 0, above, the three policy domains of trade, climate and industrial policy have very different and complementary vantage points. This is also true for the classification of policy instruments that are frequently applied in each domain. No taxonomy of policy instruments exists to date that integrates all three policy domains consistently and unambiguously. But having such a taxonomy is key for the purpose of the ENTICE project. To arrive at such a unified taxonomy of TCI policy instruments, we briefly review existing policy classification systems applied in each field and propose our own integrated taxonomy subsequently.

A1|4.2.1 Trade policy taxonomies

The classification of trade policy instruments has evolved from a simple distinction between tariffs and other barriers to more nuanced systems that capture the complexity of modern trade governance. Tariff Barriers are direct taxes or duties imposed on imported goods. This category can be further broken down by how the tax is levied, for instance, *ad valorem* (based on the value of the goods), *specific* (a fixed fee per unit), or *compound* (a combination of both). Tariffs are transparent and their immediate economic impact is relatively easy to calculate. Meanwhile, Non-Tariff Barriers (NTBs) or Non-Tariff Measures (NTMs) form a broad and heterogeneous category encompassing all other measures that can affect trade. Historically, this included quotas (quantitative restrictions on imports), import licensing, and voluntary export restraints (Geourjon, 2003; Lima-Campos & Gaviria, 2017).

Perhaps the most widely acknowledged taxonomy is contained in UNCTAD's 'International Classification of Non-Tariff Measures' (UNCTAD, 2019). This document which was jointly prepared by the FAO, ITC, OECD, UNCTAD, UNIDO, World Bank, and the WTO[5] groups NTMs into technical and non-technical measures (see Table 3). This classification is also used by academics including by the Global Trade Alert database maintained by University of St. Gallen (Evenett, 2019).

[5] Collectively, these international organisations are also known as the MAST (Multi-Agency Support Team) group.

Table 3. Classification of non-tariff measures. *Source: UNCTAD (2019).*

IMPORTS	**Technical measures**	**A**	Sanitary and phytosanitary measures
		B	Technical barriers to trade
		C	Pre-shipment inspection and other formalities
	Non-technical measures	**D**	Contingent trade-protective measures
		E	Non-automatic import licensing, quotas, prohibitions, quantity-control measures and other restrictions not including sanitary and phytosanitary measures or measures relating to technical barriers to trade
		F	Price-control measures, including additional taxes and charges
		G	Finance measures
		H	Measures affecting competition
		I	Trade-related investment measures
		K	Distribution restrictions
		K	Restrictions on post-sales services
		L	Subsidies and other forms of support
		M	Government procurement restrictions
		N	Intellectual property
		O	Rules of origin
EXPORTS		**P**	Export related measures

Lima-Campos and Gaviria (2017) cover most of the same trade policy tools but group them into six categories:

- **Market access:** tariffs, customs procedures, trade facilitation, and tariff preference programs.
- **Trade remedies:** safeguards, antidumping duties, subsidies and countervailing measures.
- **Currency manipulation.**
- **Regulatory measures:** sanitary and phytosanitary measures, technical barriers to trade, private standards, and rules of origin.
- **Dispute settlement.**
- **Trade agreements.**

Finally, tariffs and NTMs employed in the literature highlights fundamentally different causal mechanisms through which trade policy operates. Tariffs exert influence primarily through price signals, directly increasing the cost of imports. This mechanism is relatively straightforward to quantify and analyse. Conversely, NTMs employ a more varied set of mechanisms, including direct quantity controls, regulatory hurdles, technical specifications, or financial incentives and disincentives. This often results in more complex, less transparent, and sometimes more distortive impacts on trade flows and market access, making their analysis more challenging than that of tariffs. Understanding these distinct operational pathways is crucial for dissecting the effects of trade policies in a complex interdisciplinary framework.

A1|4.2.2 Industrial policy taxonomies

Academic literature frequently distinguishes industrial policy instruments based on their scope and targeting approach. This classification reflects a fundamental choice in industrial strategy (see for example OECD, 2022a). **Horizontal policies** aim to improve the general business environment and framework conditions that benefit all firms and industries across the economy. Examples include strengthening the rule of law, promoting the ease of doing business, general R&D support available to all firms, investments in broad infrastructure, and initiatives to ease immigration requirements for highly skilled labor. While generally applied, some horizontal policies can implicitly favor certain sectors (Andreoni & Chang, 2019).

Vertical Policies represent targeted government interventions aimed at developing or supporting *specific* domestic firms, industries, or narrowly defined economic activities. Historical examples include support for textiles, shipbuilding, and heavy industries, while contemporary examples include targeted support for the wind energy sector or semiconductor manufacturing.

The OECD proposes a new taxonomy (see Figure 8) which goes beyond this dichotomy and explicitly captures the rationale and channels through which industrial policies operate and enables to identify complementarities between them in order to design more effective policy mixes (OECD, 2022a). This taxonomy has also been operationalized in a recent attempt to quantify industrial strategies by the OECD (OECD, 2022b).

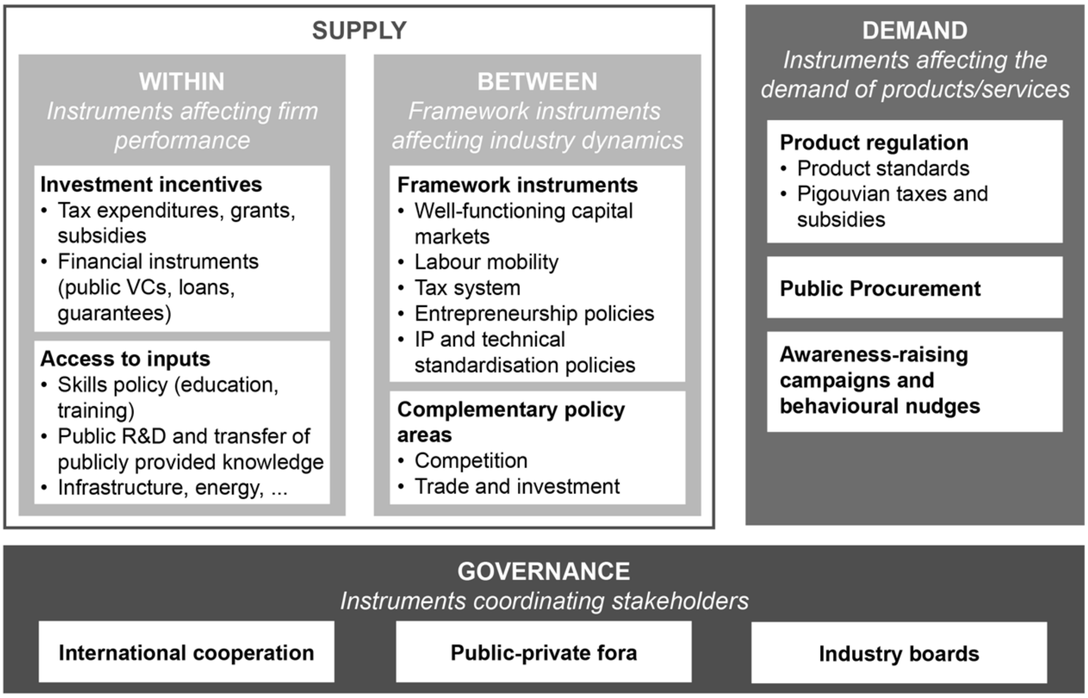

Figure 8. Taxonomy of industrial policy instruments. *Source: OECD (2022a).*

A second industrial policy framework has been proposed by Nilsson et al. (2021b) specifically addressing the decarbonization of energy-intensive industries. They propose a framework based on four pillars:

- **Directionality.** Governments can signal and guide the direction of development and innovation;
- **Knowledge creation and innovation.** Governments provide support for low-carbon innovation and learning throughout value chains;
- **Creating and reshaping markets**. Markets are fundamentally shaped and often created by governments. Industrial policy can intervene to create markets for cleaner products (e.g. through labelling) or reshape markets to enhance competitiveness of desired low-carbon products;
- **Building capacity for governance and change**. Leveraging massive investments of private and public capital will require a high degree of institutional capacity, especially since the timelines required to achieve climate objectives are extremely short in comparison to the long lead times and asset lifetimes in energy-intensive industries;

- **International coherence**. Referrers to the growing need for international coordination on the topic in addition to global agreements on climate and trade (see also Otto & Oberthür, 2022); and
- **Addressing phase-outs and the associated socio-economic implications**. As industries are generally not uniformly distributed, a purposeful transformation of the economic structure will affect some groups and regions differently than others. Industrial policy ought to address significant negative socioeconomic ripple effects where they occur.

In a working paper for UNIDO, Weiss (2015) proposes an industrial policy taxonomy that differentiates between different phases:

- **Initial phase industrial policy** is focused on providing the enabling conditions for early industrial development in developing countries that have been dominated by agricultural economies. It pursues the diversification of exports away from primary goods into simple manufactures, the processing of natural resources into resource-based manufactures, attracting FDI to generate technology, management or marketing links, and encouraging new start-up firms.
- **Middle-stage industrial policy** is relevant for more advanced emerging economies. Key objectives at this stage will include the promotion of advancing technologies and domestic value creation, adapting imported technologies to local circumstances, integrating domestic enterprises in global value chains with distinct marketing/brands, and incorporating environmental policy objectives in industrial policy.
- **Late-stage industrial policy** focuses on innovation at the technology frontier through public investments in R&D and education systems as well as subsidies and public venture capital for new technologies and start-ups. It also frequently involves defensive measures to safeguard competitiveness of established industries vis-à-vis international competition.

Additional to the temporary dimension, Weiss proposes to differentiate policies by the domain that is addressed as well as whether policies are providing public goods or market-based incentives for individual companies. Table 4, below, synthesizes Weiss' industrial policy taxonomy.

Table 4. UNIDO taxonomy of industrial policy synthesized from Weiss (2015).

Policy Domain	Instruments	
	market-based	*direct provision / public goods*
Product market	import tariffs export subsidies duty drawbacks tax credits investment/FDI incentives	procurement policy export market information / trade fairs linkage programmes FDI country marketing one-stop shops investment promotion agencies
Labour market	wage tax credits/subsidies training grants	training institutes skills councils
Capital market	directed credit interest rate subsidies loan guarantees	Financial regulation Development Bank lending Public VC
Land market	subsidized rental	Export Processing Zones EPZs / Specialized economic zones SEZ factory shells, infrastructure incubator programmes
Technology	R&D subsidies / grants	public research institutes tech transfer support technology extension programme

Finally, the New Industrial Policy Observatory is closely related to the Global Trade Alert database mentioned above (Evenett et al., 2024a). Its focus is squarely on the intersection on trade and industrial policy.

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This legacy is also evident when it comes to the categorization of policy instruments which it employs (see Table 5).

Table 5. Policy instruments included in the New Industrial Policy Observatory. *Source: (Global Trade Alert, n.d.).*

Categories	Definition
Export Policy	Such entries cover export bans, export licensing requirements, export quotas, export tariff quotas, export taxes, local supply requirements for exports, and export-related non-tariff measures.
Import Policy	Such entries cover import bans, import monitoring, import licensing requirements, import quota, import tariff, import tariff quota, internal taxation of imports, and import-related non-tariff measures.
Trade Defence	Such entries cover anti-dumping, anti-subsidy and safeguards.
Subsidy	Such entries cover capital injections and equity stakes, financial grants, import incentives, in-kind grants, interest payment subsidies, price stabilisation, production subsidies, state aid, state loans, state aid unspecified, and tax or social insurance relief.
Export Incentive	Such entries cover export subsidies, financial assistance in foreign market, other export incentives, tax-based export incentives, and trade finance.
FDI Policy	Such entries cover FDI: entry and ownership rules, FDI: financial incentives, and FDI: treatment and operations.
Procurement Policy	Such entries cover changes to public procurement law or practice.
Localisation Policy	Such entries include localisation incentives or requirements.
Other Policy	Such entries include measures which were not classified under one of the previous categories.

A1|4.2.3 Climate policy taxonomies

A fundamental and widely adopted taxonomy in climate policy literature, used inter alia by the IPCC (IPCC, 2022c, Chapter 13.6) distinguishes between instruments based on their mode of action:

- **Economic Instruments** create a price for greenhouse gas emissions and/or provide economic incentives for polluters to reduce their emissions. They include: Carbon Taxes, a direct tax on the carbon content of fossil fuels or on greenhouse gas emissions; Emissions Trading Systems (ETS) which set a cap on total emissions, and entities receive or buy emission allowances which they can trade; and Subsidies and tax credits/penalties providing financial incentives for activities that reduce emissions, such as the deployment of renewable energy technologies or energy efficiency improvements.
- **Regulatory Instruments (or Command-and-Control):** These are regulatory measures that mandate or prohibit certain actions or technologies. This category includes: performance standards set limits on emissions from specific sources (e.g., fuel economy standards for vehicles or energy efficiency standards for buildings); technology mandates require companies to use specific technologies (e.g., renewable portfolio standards); phase-out mandates for carbon-intensive technologies and activities (e.g. phase out on coal mining or gas boilers).
- **Other instruments** such as information and voluntary programs comprise initiatives that aim to influence behavior through disclosure of information, labeling, and voluntary agreements. the Innovation and RD instruments also fall into this category.

The OECD further differentiates the last category in its International Forum on Climate Mitigation Approaches (IFCMA) Policy Database (OECD, 2024) including explicit categories for direct government investment or consumption, information instruments, and voluntary approaches (see

Table 6).

Table 6. Examples of policy instruments, classified along IFCMA typology. *Source: OECD (2024, p. 12).*

Instrument category	Instrument type	Instrument examples
Economic instruments	Subsidies	▪ Renewable electricity feed-in tariff or premium ▪ Subsidy for carbon capture, use and storage technologies ▪ Vehicle purchase subsidy ▪ Payment for eco-system services
	Taxes & tax incentives	▪ Carbon tax ▪ Fuel excise tax ▪ Corporate income tax allowance for clean technologies
	Trading systems	▪ GHG emission trading system ▪ Tradable renewable energy quotas
Regulatory instruments	Performance standards	▪ GHG emissions standard ▪ Fuel economy standard ▪ Minimum energy performance standard for appliances, buildings, etc.
	Technology standards	▪ Biofuel quota ▪ Electric vehicle sales mandate ▪ Bans/ phase out of coal-fired power generation
	Framework standards	▪ Requirement to adopt an energy management system (e.g. ISO 50001) ▪ Electricity marked regulations (e.g. priority grid access/dispatch for renewables)
Government investment and consumption	Public investment	▪ Public investment in climate R&D, energy or public transport infrastructure
	Public procurement	▪ Public procurement of electric vehicles
	Public appraisal rules	▪ Project and programme evaluation rules (e.g. requirement to conduct a Strategic Environmental Assessment before adopting a law)
Information instruments	Labels	▪ Energy performance label for appliances, vehicles, etc.
	Reporting requirements	▪ Energy audit requirement for industrial facilities
	Capacity building & public awareness	▪ Public information campaign/education/training
Voluntary approaches	Voluntary information instruments	▪ Voluntary energy performance label ▪ Voluntary green investment label
	Voluntary trading systems	▪ Voluntary GHG emissions trading system (e.g. pilot ETS)
	Voluntary targets	▪ Voluntary GHG emission reduction target ▪ Voluntary energy efficiency target/ energy performance target

The Climate Policy Database operated by the NewClimate Institute provides the most granular policy instrument typology we have come across (see

Table 7).

Table 7. Policy instrument typology of the Climate Policy Database. *Source: NewClimate Institute (2023).*

Category	Sub-category	Policy instrument
Economic instruments	Direct investment	Funds to sub-national governments
		Infrastructure investments
		Procurement rules
		RD&D funding
	Fiscal or financial incentives	CO2 taxes
		Energy and other taxes
		Feed-in tariffs or premiums
		Grants and subsidies
		Loans
		Net metering
		Tax relief
		User changes
		Tendering schemes
		Retirement premium

Category	Sub-category	Policy instrument
		User charges
	Market-based instruments	GHG emissions allowances
		GHG emission reduction crediting and offsetting mechanism
		Green certificates
		White certificates
Regulatory Instruments	Codes and standards	Building codes and standards
		Industrial air pollution standards
		Product standards
		Sectoral standards
		Vehicle air pollution standards
		Vehicle fuel-economy and emissions standards
		Auditing
		Monitoring
		Obligation schemes
		Other mandatory requirements
Information and education	Performance label	Comparison label
		Endorsement label
		Advice and Aid in implementation
		Information provision
		Professional training and qualification
Policy support		Institutional creation
		Strategic planning
RD&D (out)	Research programme	Technology deployment and diffusion
		Technology development
		Demonstration project
Voluntary approaches		Negotiated agreements (public/private sector)
		Public voluntary schemes
		Unilateral commitments (private sector)
Barrier removal		Removal of fossil fuel subsidies
		Removal of split incentives (landlord tenant problem)
		Grid access and priority for renewables
Climate strategy		Formal & legally binding climate strategy
		Political & non-binding climate strategy
		Coordinating body for climate strategy
Target	Energy efficiency target	Formal & legally binding energy efficiency target
		Political & non-binding energy efficiency target
	GHG reduction target	Formal & legally binding GHG reduction target
		Political & non-binding GHG reduction target
	Renewable energy target	Formal & legally binding renewable energy target
		Political & non-binding renewable energy target

Note that all of the above frameworks for classifying climate policies focus exclusively on mitigation. Climate change adaptation research typically classifies adaptation actions and measures which include policies. For instance, Khamis et al. (2022) classify best practice adaptation measures according to five categories: (1) incentives, governance and management; (2) communications & roundtable exchanges; (3) research & innovation; (4) technical solutions; and (5) nature-based solutions.

A notable exception is a recent systematic review by Ulibarri et al. (2022) that surveyed a total of 1549 peer-reviewed articles to compile an assessment of policy tools to support climate chang adaptation. They classify policies according to six categories: direct regulation, plan, economic instrument, information-based instruments, capacity building, and community or inter-organisation networks.

A1|4.3 A unified TCI taxonomy

The review above of existing policy demonstrates that no comprehensive and unambiguous policy taxonomy exists. The diversity and complementarity of taxonomies applied in the three domains mirrors the complementarity of the definitions introduced in section 0. Still, a unified TCI taxonomy is a necessary condition for studying policy interactions at the TCI nexus systematically.

We recognize that a perfect taxonomy is impossible. Instead, we view taxonomies as an analytical tool that needs to be tailored to the specific needs of a research project. For the ENTICE project we therefore propose a pragmatic classification system that strikes a balance between being granular enough to provide sufficient detail for both quantitative and qualitative analyses but also flexible and simple enough to enable effective collaboration across a diverse interdisciplinary consortium.

To this end we started with a version of the climate policy taxonomies as these provide the highest level of detail[6]. We screened the industrial policy and trade policy taxonomies and added complementary categories, sub-categories and specific industries.

The taxonomy comprises 10 categories:

- **Overarching policies** comprise framework legislation such as climate laws but would also cover national adaptation plans, strategic plans such as the European Commission's Clean Industrial Deal or the Chinese recurring 5-year-plans.
- **Economic instruments** cover a wide range of measures creating financial incentives in one way or another. It ranges from carbon pricing to subsidies including through preferential taxation, direct government investments as well as disaster risk insurance.
- **Regulatory instruments** cover what is frequently described as "command and control" policies including pollution standards, energy or CO2 standards, quotas, licensing, and local content requirements.
- **Competition instruments** are particularly relevant from an industrial policy perspective but also affect international trade. The category covers all sorts of instruments affecting the number of market actors through e.g. anti-trust measures, strategic mergers or monopolistic state trading.
- **Trade policies** include both tariffs and non-tariff measures. This also includes measures affecting foreign direct investments. Note that Non-tariff measures may overlap with regulatory instruments above. We reserve this category for regulatory instruments that directly and predominantly affect im- or exported goods.
- **Monetary policies** cover instruments that affect relative currency conversion rates through direct intervention or adjusting interest rates. This includes, for example, Interest rate adjustments, quantitative easing, or foreign exchange market intervention.
- **Innovation policies** are a broad category that will relate indirectly to all three policy domains.
- **Information policies** cover mandatory or voluntary disclosure of information that may affect consumer decisions. Information campaigns and technical information systems such as early warning systems for climate-related disasters also fall into this category.
- **Education and capacity instruments** provide necessary conditions for competitive industry and effective governance. The category includes labour-related measures as well as measures enhancing the administrative capacity.
- Finally, **infrastructure measures** includes government investment or support for physical infrastructure. This can be hydrogen infrastructure, power grids but also major investments in flood protection or other climate-resilient assets and infrastructures.

[6] We draw on a classification of policy instruments previously developed under the Horizon Europe funded EU-China BRIDGE project. This project studies and compares decarbonization pathways and enabling policies for the steel and chemical industry between the EU and China. With this focus, several aspects of industrial policy had already been integrated.

A detailed overview of the unified TCI Policy Taxonomy is provided in Table 8, below.

Table 8. Overview of the unified TCI Policy Taxonomy.

CATEGORY	SUB-CATEGORY	POLICY INSTRUMENTS
OVERARCHING	framework legislation	*overarching goals & objectives; specific targets*
	strategic planning	*Roadmaps; multi-year plans*
ECONOMIC	carbon pricing	*emissions trading; carbon tax; crediting system*
	other market-based mechanisms	*tradable green certificates (e.g. for RE or EE)*
	subsidies (OPEX)	*feed-in tariffs or premiums; tax credits; price caps (e.g. electricity); Contracts for Differences; removal of inefficient subsidies; tariff/fee rebates (e.g. grid tariffs); other OPEX subsidies*
	subsidies (CAPEX)	*grants; low-interest loans; direct investment; tax credits; accelerated depreciation; removal of inefficient subsidies*
	direct investments	*public venture capital; public bail-out*
	procurement	*green public procurement; consumer subsidies*
	insurance	*disaster risk insurance*
REGULATORY	codes & standards	*product standards; pollution standards; GHG emission standards; renewable energy portfolio standards; quotas; local content requirements; licensing; financial taxonomies*
COMPETITION	competitive markets	*measures to remove market entry barriers; anti-trust measures; strategic merger control*
	monopolistic measures	*state trading; sole import agencies*
TRADE	import-related	*import tariffs, bans, quotas; other non-tariff barriers directly affecting imports*
	export-related	*export tariffs, bans, quotas; export subsidies; export credit guarantees*
	foreign direct investments	*FDI entry and ownership rules; FDI incentives*
	trade defence	*remedies: safeguards, anti-dumping, countervailing measures; dispute settlement; trade agreements*
MONETARY	currency manipulation	*foreign exchange intervention; capital controls, exchange rate pegs*
	monetary adjustments	*interest rate adjustments; quantitative easing*
INNOVATION	research programmes	*research grants; research prizes; regulatory sandboxes*
	innovation systems	*stakeholder networks*
INFORMATION	company & product level	*mandatory reporting and auditing; mandatory transformation plans; labelling (e.g. energy efficiency labels)*
	consumer level	*information campaigns*
	societal level	*early warning systems for disaster risk; community and inter-organisation networks*
EDUCATION & CAPACITY	labour	*educational programmes*
	administration	*streamlined planning & permitting; reinforcing administrative capacity*
	individual	*special training / capacity building for adaptation*
INFRASTRUCTURE	physical (e.g. power, H2, adaptation)	*direct investment; coordination of emerging demand & supply*

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A1|5 A value chain perspective and the role of commodities

Policy interventions, whether designed for trade, climate action, or industrial development, inherently reshape global flows of commodities, the corresponding networks of production and consumption, and their associated environmental and economic consequences. This chapter delves into the intricate relationship between the three policy domains and the diverse commodity types, examining their environmental and economic outcomes in both exporting and importing nations.

A comprehensive understanding of commodity trade impacts necessitates a full life cycle perspective, extending beyond direct operational emissions (scope 1 and 2) to encompass the entire value chain (scope 3). This includes both upstream emissions, generated before a company's direct operations, and downstream emissions, occurring after products leave the company's control. Upstream activities typically involve the extraction of raw materials, their initial processing, and inbound logistics, while downstream activities cover product use, distribution, and end-of-life management. Table 9 provides an overview of key commodity categories and their associated upstream and downstream impacts.

Table 9. Commodity Categories and Primary Emission Hotspots (Upstream vs. Downstream).

COMMODITY CATEGORY	PRIMARY UPSTREAM EMISSION HOTSPOTS	PRIMARY DOWNSTREAM EMISSION HOTSPOTS	KEY ENVIRONMENTAL IMPACTS
Energy	Extraction/Mining, Processing, Inbound Transport (Fossil Fuels); Raw Material Mining, Manufacturing (Renewables)	Combustion (Fossil Fuels); Use Phase/Operation (Renewables)	GHG Emissions, Land Degradation, Water Contamination (Fossil Fuels); Resource Depletion (Renewables)
Raw Materials	Extraction/Mining, Initial Processing, Inbound Transport	Limited (often processed further by others)	Land Degradation, Habitat Loss, Water Contamination, Air Pollution, GHG Emissions, Biodiversity Loss
Basic Materials	Production of Feedstocks, Energy-Intensive Manufacturing, Inbound Transport	Limited (often intermediate products)	Direct GHG Emissions (process & combustion), Energy Consumption, Water Use
Food & Agriculture	Land Use Change (Deforestation), On-farm Production (Fertilizers, Livestock), Processing, Transport	Transport (perishable), Consumption, Waste	Deforestation, GHG Emissions (Methane, Nitrous Oxide), Water Scarcity/Pollution, Biodiversity Loss, Land Degradation
Manufacturing Equipment	Raw Material Extraction, Component Manufacturing, Assembly, Inbound Transport	Use Phase (Energy Consumption), End-of-Life Disposal	Embodied Carbon (GHG), Resource Depletion, Waste
Consumer Goods	Raw Material Extraction, Component Manufacturing, Assembly, Inbound Transport	Use Phase (Energy Consumption), End-of-Life Disposal/Waste	Embodied Carbon (GHG), Downstream Waste, Resource Depletion

Energy commodities are the first and most obviously relevant category when it comes to the TCI nexus. **Fossil fuels**, including coal, oil and natural gas, exhibit significant emissions across their entire value chain. Upstream emissions arise from extraction activities such as mining and drilling, subsequent fuel processing like refining, and the transportation and distribution of these fuels. Downstream emissions are predominantly associated with their combustion during energy generation or direct use in industries,

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transport, buildings and agriculture. While natural gas is often considered a cleaner-burning alternative to other fossil fuels, its extraction and use still involve greenhouse gas emissions, notably methane which may cancel out the lower specific emission factors at the combustion (Cooper et al., 2021). While trade in other **low-carbon energy commodities** such as green hydrogen and its derivatives is currently limited, trade is expected to increase globally and may become a key enabler for the transformation of major industrial value chains such as steel (OECD, 2025a; Watari & McLellan, 2024) and basic chemicals (Bauer et al., 2023; Chung et al., 2023; Pal & Kumar, 2024; Scholz et al., 2025).

The extraction and initial processing of **raw materials** such as ores and minerals is particularly emissions-intensive and carry profound environmental impacts. These impacts include extensive land degradation, significant habitat loss, widespread water contamination (e.g., from acid mine drainage and hazardous chemicals), soil erosion, and substantial energy consumption for heavy machinery and smelting processes. Yet the production methods and the corresponding environmental impacts vary dramatically based on geological circumstances and environmental regulation in place and enforced (de Haes & Lucas, 2024). The environmental effects of changing trade patterns of raw materials are therefore determined by the relative environmental performance of competing suppliers on global commodity markets.

Critical raw materials such as lithium, cobalt, and copper require particular attention as they are indispensable inputs for the burgeoning clean technology sector. For instance, the production of lithium demands large quantities of water and can have substantial negative environmental effects (Blair et al., 2024). Due to the profound and long-lasting environmental impacts of raw material extraction, particularly for critical minerals, stringent environmental safeguards are paramount to avoid simply shifting environmental burdens from one region to another rather than achieving an overall improvement in environmental performance. If an importing country implements policies to secure domestic supply, it might increase mining within its own borders. Without robust domestic environmental regulations, this could lead to localized environmental damage, potentially undermining broader climate goals if not managed properly.

Basic materials such as steel, cement, and chemicals are inherently highly energy- and carbon-intensive to produce and often rely on fossil fuels for both energy generation and as feedstock or reactant. The chemical industry, for example, consumes vast amounts of fossil fuel but also uses fractions of oil (naphta) and natural gas as a key hydrocarbon feedstock for a vast array of products, including plastics and fertilizers. Furthermore, the heavy reliance on fossil-derived feedstocks in basic materials means that shifting trade patterns for these commodities due to policies like the Carbon Border Adjustment Mechanism (CBAM) could lead to significant carbon leakage. If a country imposes a carbon cost on these materials, producers might relocate to regions where these feedstock emissions are not priced or regulated, or where low-carbon alternatives are less available. This could result in emissions being shifted rather than genuinely reduced globally.

Agriculture is a significant contributor to global environmental impacts, accounting for approximately one-quarter of global greenhouse gas (GHG) emissions, utilizing half of the world's habitable land, and consuming 70% of global freshwater withdrawals. Emissions from this sector arise from various sources across the supply chain, including land use change (e.g., deforestation), on-farm production (e.g., methane from livestock, nitrous oxide from fertilizers), processing, transport, packaging, and retail (Ritchie et al., 2022). International trade is a primary driver of deforestation, particularly through commodity-driven agricultural expansion for products such as palm oil, cattle, coffee, cocoa, and soya. High-income countries bear responsibility for a substantial share of these "hidden" deforestation emissions embedded within their imports (Tang et al., 2025). The significant share of deforestation driven by international trade and consumption in high-income countries indicates that trade policies, such as import regulations (e.g., the EU's Deforestation Regulation), are crucial for addressing embedded land-use emissions in food and agricultural commodities. Such policies shift responsibility towards importing consumers and directly influence land management practices in exporting countries. While transport emissions for food are generally small when compared to the emissions from production, air transport for perishable goods can be exceptionally carbon-intensive, multiple times more CO2 equivalent per tonne-kilometre than shipping by boat.

Manufacturing equipment, particularly **clean technologies** like renewable energy equipment, electric vehicles (EVs), and heat pumps, plays a dual role in the context of emissions. While these technologies have their own embodied emissions stemming from their production/manufacturing, they also enable significant emissions reductions during their consumption or operational phase as they directly replace fossil-based technologies. The lifecycle emissions of manufacturing equipment encompass raw material extraction, manufacturing, processing, and distribution. For clean technologies, this often involves the use of critical minerals and energy-intensive production processes. Despite these upstream impacts, clean technologies are pivotal for global decarbonization efforts. For example, advanced battery systems are essential for addressing the intermittency of variable renewable energy sources, and green hydrogen offers low-carbon alternatives for various industrial processes (i.e. for steelmaking). The rapid growth and cost reduction of clean energy technologies create new trade opportunities and shifts in comparative advantage, potentially favouring countries with abundant and low-cost renewable energy resources and strong manufacturing capabilities (Samadi et al., 2023; Verpoort et al., 2024). Beyond clean technologies, other types of **manufacturing equipment** also contribute to embodied emissions throughout their production lifecycle. Policies that affect the trade of such equipment can influence the overall carbon footprint of industrial sectors e.g. if trade facilitates the diffusion of more energy-efficient technologies.

Consumer goods exhibit significant emissions across their entire lifecycle. Upstream emissions primarily stem from the production of purchased goods and materials, including the energy-intensive manufacturing processes and the transportation of components to assembly plants. Downstream emissions are particularly pronounced for energy-consuming consumer goods, such as electrical equipment, appliances and cars and other transport equipment like vehicles, where the use phase contributes substantially to the overall carbon footprint. For consumer goods, policies targeting downstream emissions, such as energy efficiency standards for appliances or vehicle emissions standards, are critical in importing countries to reduce the environmental impact of product use (Bocken et al., 2025). Concurrently, policies addressing upstream emissions, such as those promoting material efficiency or cleaner manufacturing processes, are vital in exporting countries. Trade policies can either facilitate or hinder the global diffusion of cleaner products. For example, policies that promote the adoption of electric vehicles globally can significantly reduce downstream emissions from the transport sector, demonstrating how trade policies can influence the overall emissions profile of consumer goods.

While a more granular breakdown of commodities might be necessary for other purposes, we believe that the proposed classification is sufficient for the purposes of the TCI framework. A particular challenge is, however, to align the proposed categories with the existing sectoral classification implemented in the Global Trade Analysis Project (GTAP) database which currently features 65 sectors (Aguiar et al., 2022). As part of the ENTICE project it is planned to further disaggregate the GTAP database with a particular focus on four areas:

- a detailed representation of power generation activities, which splits electricity into 11 power generation activities and transmission and distribution;

- a detailed representation of primary, secondary, and recycling activities for metals (steel, aluminium, copper) and plastics that is highly relevant for Circular Economy representation;
- disaggregated representation of cement and fertilisers (3-types: N, P and K); and
- the explicit representation of the main critical minerals' lifecycle (such as lithium, nickel, cobalt, rare earth elements), from extraction to end-use in technologies' manufacturing processes (including production of PV panels, wind turbines, Li-Ion batteries and EVs).

While the exact matching of GTAP sectors to the main categories proposed in the TCI framework will remain work in progress and will be reported later, Table 10 below provides a starting point for that conversation.

Table 10. Overview of TCI commodity categories and corresponding GTAP sectors.

TCI commodity categories	GTAP 11 sectors (GSEC no.: Code)	ENTICE enhancements of GTAP
Energy	coal (#15: coa); oil (#16: oil); gas (#17: gas); petroleum, coal products (#32: p_c); electricity (#46: ely); gas manufacture, distribution (#47: gdt)	differentiated representation of electricity by generation
Raw materials	other extraction (#18: oxt)	dissagregation into extraction of iron, aluminium, copper, lithium, nickel, cobalt, and rare earth elements
Basic materials	textiles (#27: tex); paper products, publishing (#31: ppp); chemical products (#33: chm); mineral products (#36: nmm); ferrous metals (#37: i_s); metals NEC (#38: nfm);	dissagregation of mineral products (nmm) into cement and fertilizers and representation of production with/without carbon capture; representation of high-value chemicals in naphta steamcrackers, via methanol-to-olefins/aromatics routes; differentiation of ammonia production with grey vs. green H2; representation of production routes for steel (BF BOF, H2 DRI, EAF recycling); detailed representation of primary, secondary, and recycling activities for metals (steel, aluminium, copper) and plastics
Food & agriculture	paddy rice (#1: pdr); wheat (#2: wht); cereal grains, NEC[7] (#3: gro); vegetables, fruits, nuts (#4: v_f); oil seeds (#5: osd); sugar cane, sugar beet (#6: c_b); plant-based fibres (#7: pfb); crops NEC (#8: ocr); cattle, sheep, goats, horses (#9: ctl); animal products NEC (#10: oap); raw milk (#11: rmk); wool, silk-worm cocoons (#12: wol); forestry (#13: frs); fishing (#14: fsh); meat: cattle, sheep, goats, horse (#19: cmt); meat products NEC (#20: omt); vegetable oils and fat (#21: vol); dairy products (#22: mil); processed rice (#23: pcr); sugar (#24: sgr); food products NEC (#25: pfd); beverages and tobacco products (#26: b_t); wood products (#30: lum)	
Manufacturing Equipment	electrical equipment (#41: eeq); machinery and equipment NEC (#42: ome)	dissagregation of PV panels, wind turbines, and batteries
Consumer Goods	wearing apparel (#28: wap); leather products (#29: lea); basic pharmaceutical products (#34: bph); rubber and plastic products (#35: rpp); metal products (#39: fmp); computer, electronic and optical products (#40: ele); motor vehicles and parts (#43: mvh); transport equipment NEC (#44: otn); manufactures NEC (#45: omf)	dissagregation of electric vehicles
Other	Water, transport, construction, and other services	

[7] NEC = not elsewhere classified

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A1|6 Synthesis and conclusion

A1|6.1 Synthesis of the TCI Framework

The preceding chapters have explored the intricate and complex dynamics of trade, industrial, and climate policies, underscoring their individual characteristics and profound interdependencies. A central finding is the inherent overlap and non-exclusivity of these three policy domains. Rather than operating in isolation, most, if not all, policy instruments – regardless of their primary intent – exert a bearing on all three areas, leading to complex and often synergistic or conflicting outcomes. This comprehensive perspective is fundamental to understanding the full spectrum of impacts within the TCI nexus.

The Multifaceted Impact of Trade Policy on Climate and Environment

Trade policy, a powerful driver of global economic integration, significantly influences climate and environmental outcomes through both direct and indirect mechanisms. The most direct impact arises from **transport emissions**, as the movement of goods across borders contributes substantially to global greenhouse gas emissions. Beyond this, trade policies induce five critical indirect effects: The **Scale Effect** suggests that increased trade can stimulate economic growth, leading to a larger scale of production and consumption, which may intensify environmental pressures unless accompanied by significant decoupling of economic growth from resource use and emissions. The **Income Effect** indicates that higher incomes generated through trade can alter consumption patterns, potentially increasing demand for energy-intensive goods and services, thereby influencing environmental footprints. The **Specialization Effect** highlights that trade encourages countries to specialize in producing goods where they hold a comparative advantage; this can lead to environmental benefits if production shifts to regions with cleaner technologies or stricter regulations, or conversely, to environmental detriments if it moves to areas with weaker environmental standards or more carbon-intensive production. The **Productivity Effect** posits that enhanced competition and efficiency gains spurred by trade can boost productivity, potentially leading to more resource-efficient production processes and lower emissions per unit of output. Finally, the **Technique Effect** demonstrates that trade facilitates the innovation and global diffusion of technologies, including cleaner production methods and environmental innovations, thereby improving the environmental performance of economic activities over time.

Industrial Policy's Strategic Influence

Industrial policy plays a pivotal role in shaping economic structures, primarily by influencing the specialization effect and the productivity effect. By strategically supporting or disincentivizing specific sectors, industrial policies can steer a nation's economic composition towards more environmentally sustainable pathways or, conversely, entrench existing carbon-intensive industries. For instance, investments in green technologies or renewable energy manufacturing directly foster specialization in these areas and enhance their productivity through innovation and economies of scale.

Climate Policy: A Catalyst for Change with Potential Trade-offs

Climate policy is designed to directly address environmental challenges and acts as a crucial catalyst for change. It significantly enhances the effectiveness of the productivity effect by internalizing environmental externalities, such as carbon emissions, through mechanisms like carbon pricing or cap-and-trade systems. This ensures that the most profitable firm is also the cleanest one. Moreover, climate policies fre-

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quently incentivize businesses to innovate and adopt more efficient, less polluting production methods thus becoming a driver of the technique effect. However, it is also important to acknowledge that climate policy, particularly stringent measures, may have unintended consequences for inter-industry composition (specialization), potentially leading to shifts in competitiveness and production locations that need careful consideration to avoid carbon leakage or adverse economic impacts.

Developing a Pragmatic TCI Policy Taxonomy

Given the complex interplay described, it becomes clear that a 'perfect' and universally applicable taxonomy for policy instruments across trade, industry, and climate domains is elusive. Existing taxonomies, often developed for specific disciplinary analyses, are not directly compatible for a holistic TCI framework. Therefore, a pragmatic approach is essential for developing a unified taxonomy that effectively captures the diverse nature of policy interventions. Our proposed taxonomy categorizes policies into the following overarching groups: overarching policies, economic policies, regulatory policies, competition policies, trade policies, monetary policies, innovation policies, information policies, education & capacity building, and infrastructure. This framework allows for a structured analysis of how different policy levers can be utilized and combined to achieve integrated TCI objectives.

Differentiating TCI Policy Effects by Commodity Type

Finally, a critical aspect of this framework is the recognition that TCI policy effects must be considered with careful differentiation for various types of commodities. The environmental and economic impacts of policy interventions are highly dependent on the specific characteristics of the goods in question, particularly concerning their associated emissions across the entire value chain. Shifting trade patterns for commodities characterized by high upstream emissions (e.g., raw materials, agricultural products with significant land-use change impacts) will lead to different emission shifts and economic consequences compared to commodities with high downstream emissions (e.g., energy-intensive manufactured goods, or products whose use phase is emissions-intensive). Understanding these nuances is paramount for accurately assessing the environmental and economic effects of TCI policies in both exporting and importing countries, ensuring that policy interventions are tailored to achieve desired outcomes across the global economy.

A1|6.2 Promise and Potential of the TCI Framework

The TCI framework, with its unified taxonomy of policy instruments and its value chain perspective, offers a novel approach to guide research within the ENTICE project and beyond. By moving beyond traditional silos, the framework provides a structured methodology to analyse the complex interactions within the trade, climate, and industrial policy nexus. Its promise lies in its ability to enable more systematic, granular, and policy-relevant research than previous methods.

First, the framework is uniquely suited to **analyse policy alignment and conflict management** in an era of increasing geopolitical tensions and industrial policy nationalism. As Andreoni and Chang (Andreoni & Chang, 2019) emphasize, effective industrial policy hinges on managing the political economy conflicts that arise from structural interdependencies. The TCI framework's taxonomy of policy instruments provides a structured lens to examine how different governance systems combine and deploy tools – from subsidies and tax credits to export controls, import tariffs, and procurement rules – to create a coherent national strategy. This allows researchers to systematically identify points of friction and evaluate how countries navigate domestic and international disputes, thereby moving beyond descriptive accounts to comparative, causal analysis.

Second, the framework is a crucial tool for **mapping the new geoeconomic competition in decarbonization**. Meckling (2025) highlights that climate policy has evolved into a strategic competition for the economic benefits of the green transition. The TCI framework enables a detailed mapping of this international competition. By applying the framework's value chain perspective to critical clean energy technologies – such as solar panels, batteries, and wind turbines – researchers can trace where different policy instruments are being used along the value chain. This will allow for a comprehensive assessment of how countries are using their policies to secure specific stages of production, identify potential chokepoints, and analyse the resulting shifts in global value chains.

Third, the framework provides a robust foundation for **quantifying the negative spillovers on developing countries**. The literature consistently notes the risk of industrial policy nationalism disadvantaging the global South (Andreoni et al., 2025; Hauge et al., 2025; Park, 2024). The TCI framework's value chain approach offers a granular way to measure these effects. By tracing how new trade barriers and shifting supply chains impact the trade and structural change of nations in the global South, researchers can move from qualitative concerns to a detailed, quantitative analysis of specific sectors and regions/countries. This will help assess whether new supply chains and foreign direct investment can create "trickle-down" benefits or if they simply exacerbate existing economic divides, building directly on the equity concerns raised by Meckling (2025).

Fourth, the framework can be used to **evaluate the trade-offs between efficiency and resilience**. The current shift in policy prioritizes supply chain resilience and national security over pure economic efficiency (Mercurio, 2024). Using the framework's policy taxonomy, researchers can model and compare how different policy mixes affect the cost of decarbonization and the security of supply chains. This will allow for a more nuanced understanding of the optimal balance between securing domestic or "friend-shored" production and maintaining open trade to ensure the most cost-effective global climate action.

A1|6.3 Limitations of the Framework

While the TCI framework is a powerful analytical tool, it is important to acknowledge its inherent limitations. As with any framework, it is a simplification of a more complex reality and should be used in conjunction with other research methods.

First, the framework is highly dependent on **data availability and granularity**. A comprehensive application requires detailed data on government subsidies, procurement contracts, R&D spending, and other policy instruments across multiple countries and sectors. The ENTICE project will address existing data gaps inter alia by enhancing data and modelling capacities as well as establishing a detailed TCI database of policy instruments and measures. But despite these efforts data availability and granularity will inevitably limit its practical application.

Second, the framework's structured approach may not fully capture the **nuanced political dynamics and informal institutions** that shape policy. While it can map the tools used, it may not fully account for the influence of powerful domestic lobbies, bureaucratic capacities, or the informal political relationships that can determine a policy's success or failure (Juhász & Lane, 2024). These qualitative factors are crucial for understanding why certain policies are adopted and how they are implemented, and they require supplementary political science research.

Finally, the TCI nexus is a **dynamic and rapidly evolving field**. New technologies, geopolitical alliances, and policy innovations are emerging at a fast pace. The framework, as a static model, will need to be continuously updated to remain relevant. For example, the rapid evolution of carbon capture, hydrogen, or other energy technologies could introduce new policy instruments, geopolitical dynamics, and value chain configurations that are not yet fully captured in the framework.

In conclusion, the TCI framework is a promising starting point for the systematic study of the trade, climate, and industrial policy nexus. While it has significant potential to enable structured analysis and granular insights, it must still prove its usefulness in practice. We anticipate that the framework will be thoroughly tested in the remainder of the ENTICE project and will be revised and further enhanced based on the lessons learned from that experience.

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ANNEX II – Perspective Article: Trade and Climate in a Changing Policy Landscape

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A2|1 Introduction

As strategic trade intervention gains momentum(Global Trade Alert, 2025; Gregori, 2021) and climate commitments face mounting urgency, the intersection of trade and climate policy demands renewed scrutiny (Martínez-Martínez et al., 2023; Ortiz et al., 2021). For decades, the literature has largely examined this relationship through the lens of trade liberalisation, highlighting how asymmetric climate ambition can lead to industrial relocation, carbon leakage and competitiveness concerns (Copeland et al., 2021; Paroussos et al., 2015).

Recent strategic shifts in economic governance suggest a potential departure from the liberalisation paradigm that has shaped trade and economic policy for decades, with governments increasingly implementing policies perceived to yield short-term domestic competitiveness (Bussière et al., 2011) and/or measures directly limiting or banning imports (Rogers et al., 2024). While trade-restricting measures (tariff and non-tariff measures, import bans, etc.) directly limit market access, certain industrial policies aiming to strengthen domestic competitiveness (subsidies, local content requirements, etc.) indirectly affect trade too (Evenett et al., 2024b). The United States (US) has exemplified both trends in the past decade, with tariffs, trade agreement renegotiations and policies emphasising domestic industrial growth linked to clean technologies (e.g., the Inflation Reduction Act). The European Union (EU) has also increasingly linked industrial competitiveness to trade and climate policy: indicatively, despite retaining a climate rationale, the EU carbon border adjustment mechanism (CBAM), industrial subsidies, targeted tariffs on Chinese clean technologies, and countermeasures to US trade actions reflect a broader shift in EU's trade and industrial strategy (Cosbey et al., 2019; European Commission, 2023). Emerging economies like China and India have likewise ramped up domestic production mandates, particularly in key green sectors (Hayashi, 2020). Such measures risk weakening international collaboration and multilateral institutions, distorting markets and resource allocation, and reprioritising domestic competitiveness over global cooperation – including for climate. Notably, the US withdrawal from the Paris Agreement illustrates how domestic priorities can override commitments to international climate goals.

As national competitiveness-oriented trade measures increasingly interact with or even override climate priorities, it is unclear whether their environmental consequences mirror those of liberalisation or whether complex structural, temporal, and political asymmetries generate fundamentally different dynamics. Understanding these differences is essential to assessing whether evolving trade regimes threaten or, under the right conditions, could favour climate objectives.

A2|2 Understanding trade–climate linkages: channels, dynamics, and enabling conditions

Trade affects the environment through multiple inter-connected mechanisms – some direct (e.g., transport emissions), while others indirect (changes in production structure and scale, consumption, firm behaviour, or innovation). These effects interact, amplifying or offsetting each other in context-dependent ways. This section provides a conceptual overview of the channels through which trade influences climate outcomes and their complex interactions across time. It also identifies critical dimensions – regulatory, institutional, and political – that shape the magnitude and direction of their effects (Supplementary Table 1 summarises these channels, their interactions, and relevant analytical approaches).

A2|2.1 Key channels linking trade and emissions

One of the most obvious environmental effects of trade is rising transport emissions. Cross-border goods movement relies on maritime shipping, aviation, and land transport, which constitute important sources of greenhouse gas (GHG) emissions. In 2023, international aviation and shipping were responsible for roughly 3% of global fossil CO_2 emissions, with emissions continuing to rise in 2024 (Friedlingstein et al., 2025b; International Transport Forum, 2015a). Research has focused on emissions quantification (Ferrario et al., 2019; Friedlingstein et al., 2025b; IEA, 2023; Liu et al., 2020b), decarbonisation pathways across transport modes (Fragkos, 2022b; Jonkeren et al., 2023b; Mundaca et al., 2021b; Verschuur et al., 2024b), and systemic feedbacks using integrated assessment models (IAMs) and computable general equilibrium (CGE) models (Cristea et al., 2013b; Müller-Casseres et al., 2024a; Speizer et al., 2024b) (see Supplementary Notes 1 and 2, and Supplementary Table 2, for data sources and models used to analyse international transport and other trade–climate channels). As trade openness increases, so do travel distances and freight activity, making *international transport* the most direct trade–climate channel, though imports from cleaner production regions may partly offset this effect (Payen et al., 2015b). Protectionism may reduce emissions by lowering trade volumes and shortening travelled distances, though it could also induce inefficiencies or longer routes via trade diversion (Q. Wang et al., 2022b).

Beyond transport, trade indirectly shapes emissions through structural shifts in global production. It reallocates activity across countries based on their comparative advantages and specialisation, driving efficiency gains that influence consumption, production, and supply chains, with environmental consequences. Decomposition analysis identifies three key mechanisms through which trade influences the climate: the scale, composition, and technique effects (Copeland & Taylor, 1994b; G. M. Grossman & Krueger, 1991b).

First, the *scale effect* arises when economic growth or trade liberalisation expands market size (Backus et al., 1992b), boosting energy and resource demand. Without strong environmental regulation, this increases emissions (Lindmark, 2004b). The Environmental Kuznets Curve (EKC) hypothesis suggests emissions rise with income until a turning point, after which environmental preferences and policies strengthen (Kukla-Gryz, 2009b), yet empirical evidence remains inconclusive (Dinda, 2004b; Leal & Marques, 2022b). While reflecting third-order effects – where trade boosts income and income influences preferences – EKC dynamics are commonly classified under scale effects in decomposition studies. If protectionism leads to economic inefficiencies and dampens scale effects, it could also result in emissions reductions. More uncertain outcomes may arise from income-induced shifts in consumer preferences, where consumer awareness of the consequences of climate change plays a key role.

Second, the *inter-industry composition effect* refers to how trade changes production allocation across sectors, shifting the geographical distribution of sectors and associated emissions. Depending on comparative advantage, specialisation may increase or reduce emissions. Beyond inter-industry exchange of final goods, comparative advantages also drive trade fragmentation, particularly through global value chains, which have expanded with advances in logistics and digitalisation. Intermediate goods now account for 50–60% of global trade (Vasudevan & and Manalaya, 2023b). Although inter-industry trade patterns manifest at the sector level, they often originate from firms' decisions. From the perspective of firm-level strategies, outsourcing and offshoring of production stages are often driven by cost minimisation. While efficient in terms of internalised costs, this redistributes emissions across borders (Peters et al., 2011b). When environmental regulations are asymmetric across countries – internalising environmental costs in some regions but not others – this can create incentives for firms to relocate their pollution-intensive activities towards countries with laxer environmental regulations. Such dynamics are captured by the Pollution Haven Hypothesis and Effect (PHH/PHE) and the Pollution Offshoring Hypothesis (POH), which suggest that laxer environmental regulation can attract emissions-intensive sectors or production stages (and are increasingly studied using firm-level data) (Choi, Jaerim et al., 2023b; Duan et al., 2021b; Levinson & Taylor, 2008b; Taylor, 2005b). Trade restrictions dampen inter-industry reallocation, but their net impact on emissions remains unclear. This ambiguity partly stems from the interaction between trade and environmental regulation: differences in regulatory stringency across countries can lead to offshoring, industrial relocation, and carbon leakage. The climate outcome of protectionist shifts thus depends on the relative emissions intensity of trading partners and on whether protectionism substitutes or complements environmental ambition.

Third, the *intra-industry composition effect* involves productivity growth through firm selection and efficiency gains. Sector-level data and modelling often miss this channel, attributing emissions changes to technique effects (see below). As Cherniwchan et al. (2017b) note, lower average emissions may reflect cleaner, more productive firms gaining market share. The Melitz model (M. J. Melitz, 2003b) predicts that less productive firms exit the market under trade liberalisation, and the Pollution Reduction by Rationalisation (PRR) hypothesis suggests that surviving firms are both more efficient and cleaner (Kreickemeier & Richter, 2014b), though empirical validation of this hypothesis is limited. In parallel, trade-induced competition can boost efficiency within firms, spurring technology adoption (Amiti & Konings, 2007b), with productivity gains often – but not always – linked to cleaner processes (Syverson, 2011b). Trade restrictions may weaken these channels, with potential implications for both productivity growth and decarbonisation, though the strength of these links remains uncertain.

Fourth, trade fosters innovation and technological change; this constitutes the *technique effect*. Building on Melitz and Redding (2021b), who identify four trade-induced drivers of innovation – competition, market expansion, specialisation, and diffusion – we distinguish two channels of technical change: (i) innovation, driven by the first three mechanisms (previously discussed); and (ii) diffusion, through knowledge spillovers. Trade and foreign direct investment (FDI) support both channels, enabling the creation and dissemination of new technologies and long-term growth (Keller, 2004b). Knowledge spillovers occur through vertical linkages (interactions with foreign buyers and suppliers), labour mobility (staff moving from multinationals to domestic firms), and demonstration effects (local firms adopting foreign, often cleaner, practices and technologies). Their effectiveness depends on domestic absorptive capacity (including skilled labour), the nature of FDI, and institutional quality (Santos, 2023b; Smarzynska Javorcik, 2004). While FDI can spur green innovation, its effects are often context-specific (Smarzynska Javorcik, 2004). Indeed, green technology uptake varies by region and financial systems (Demircan Çakar et al., 2021b; Wu et al., 2024b; Yu et al., 2022b). The relationship between innovation and emissions is thus shaped by broader enabling conditions, as discussed below, and so is the way in which protectionism may influence climate outcomes through the innovation channel.

A2|2.2 Interconnections across channels and time

Rather than acting in isolation, the channels discussed above – transportation, scale, (inter-industry and intra-industry) composition, and technical change – interact through feedbacks that may reinforce or offset one another, resulting in complex and sometimes contradictory dynamics.

International transport enables or constrains other channels. For example, variations in transport costs influence trade volumes, outsourcing decisions, international competition, and thus domestic production structures and innovation incentives. Therefore, transport affects the climate both directly, through fossil fuel use, and indirectly, by shaping how other trade–emissions mechanisms unfold. Scale effects are central to these interactions. The expansion of the market size increases shipping volumes and emissions. Yet larger markets also amplify composition and productivity effects. Scale incentivises R&D by raising returns and enhancing competitiveness in global markets (Acemoglu & Linn, 2004b; Bloom et al., 2016b; G. Grossman & Helpman, 1993). Specialisation reallocates resources toward sectors of varying innovation intensity (M. Melitz & Redding, 2021b) and may displace inefficient (and usually dirtier) firms, reinforcing innovation. Productivity growth can stimulate innovation by increasing returns to technology adoption, while also lowering production costs and consumer prices. This can drive higher consumption, amplifying scale effects (Dimitropoulos, 2007b). Innovation and diffusion interact with all of the above, with innovation's net environmental effect depending on its direction and policy support (Grubb et al., 2015b). Well-directed trade-induced innovation can help decarbonise transport through the uptake of cleaner fuels and improved logistics systems (Kassouri & Alola, 2023; X. Wang et al., 2025b). Yet even targeted clean innovation can carry trade-offs: by diverting R&D from other areas, it may slow down broader technological progress and dampen scale-driven growth (Goulder & Schneider, 1999), which may in turn have ambiguous effects on emissions. Diffusion spreads innovation gains across firms and regions, reinforcing both productivity and technological change. Yet trade shocks can disrupt these dynamics – for instance, tariffs may alter sectoral composition, innovation pathways, and productivity. As Akcigit et al. (2018b) show, such measures may yield short-term benefits but ultimately discourage innovation and undermine long-term welfare, complicating their climate implications.

Temporal dynamics are key to understanding these feedbacks. Some effects are immediate; for instance, trade-driven growth in transport emissions. Others unfold more gradually and often face considerable delays (lead-in times), as it is the case for innovation, diffusion, and shifts in consumer preferences. These temporal asymmetries shape long-term emissions trajectories and patterns of structural and technological change, intersecting with path dependence and irreversibility. Innovation trajectories can lock economies into lasting technological pathways, while short-term trade shocks may trigger enduring shifts in production or trade relations, as illustrated by energy efficiency gains following the 1970s oil shocks. Channels with short-term effects – like transport and scale – typically raise emissions, while longer-horizon channels – like clean innovation and diffusion – have a more ambiguous effect or tend to reduce emissions.

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A2|2.3 Enablers: regulations, institutions, politics

Besides temporal dynamics, three additional dimensions – regulatory frameworks, institutional quality, and stakeholder influence – act as enabling conditions shaping the magnitude and direction of trade's climate impact.

Regulation is a critical enabler, particularly the design and enforcement of environmental rules, shaping international dynamics in several ways. First, it can steer innovation and diffusion toward low-carbon technologies, aligning trade-induced innovation with climate goals. Its effectiveness also depends on technological capabilities, without which even ambitious policies may fall short (Feng et al., 2025; Grubb et al., 2015b; Su, 2024). Second, regulatory asymmetries across countries can instead undermine climate goals, as wide differences in standards encourage polluting industries to relocate, leading to carbon leakage and worse global climate and economic outcomes (PHE). Regulation harmonisation reduces this risk (King & van den Bergh, 2021). Third, tools like carbon tariffs aim to address such asymmetries by levelling the playing field (Otto, 2025b), though they may provoke retaliation or fairness concerns, challenging coordination even more (Perdana & Vielle, 2022).

Regulatory instability adds complexity, while frequent changes or weak enforcement erode credibility and weaken investment signals. While some change stems from democratic processes and can be anticipated, instability from poor governance or arbitrary enforcement creates deeper uncertainty. This leads to a second enabler: institutional quality. Weak institutions undermine regulation, policy consistency, and investment credibility. More broadly, institutional quality shapes a country's ability to turn trade openness into environmental gains. It includes regulatory stability, absorptive capacity, innovation ecosystems, finance access, and human capital. Strong institutions better support clean technology development and scale-up (Dube & Horvey, 2023) and provide a comparative advantage in clean industries (Shapiro, 2025), while limited capacity risks locking countries into carbon-intensive paths (Antosiewicz et al., 2020). Institutional quality thus affects both the depth and pace of emissions reductions achievable through trade.

A third critical dimension is stakeholder influence. Trade instruments are not merely economic tools; they are also political signals, and their climate impact depends on the strategic considerations that shape them. Sequencing is rarely neutral; it often reflects political calculations and stakeholder pressures. Protectionist measures targeting clean technologies, like tariffs on electric vehicles or environmental standards for battery production, are frequently introduced to create space for domestic cleantech sectors, protect nascent industries, retain strategic capacity, and foster local supply chains, as in the cases of photovoltaics and battery-electric vehicles. Though such measures may raise short-term costs for clean technologies, they can build support for the transition. Yet, when trade measures are driven by lobbying from carbon-intensive incumbents, they can entrench polluting industries and delay greener competitors. This undermines the credibility of climate policy signals and investors' confidence, especially when decisions seem reactive or politically driven. For example, lobbying may push for trade barriers that protect incumbents at the expense of greener alternatives (Kono, 2019). Figure 1 illustrates key trade–emissions channels, their timing, and how enabling conditions shape their magnitude and direction.

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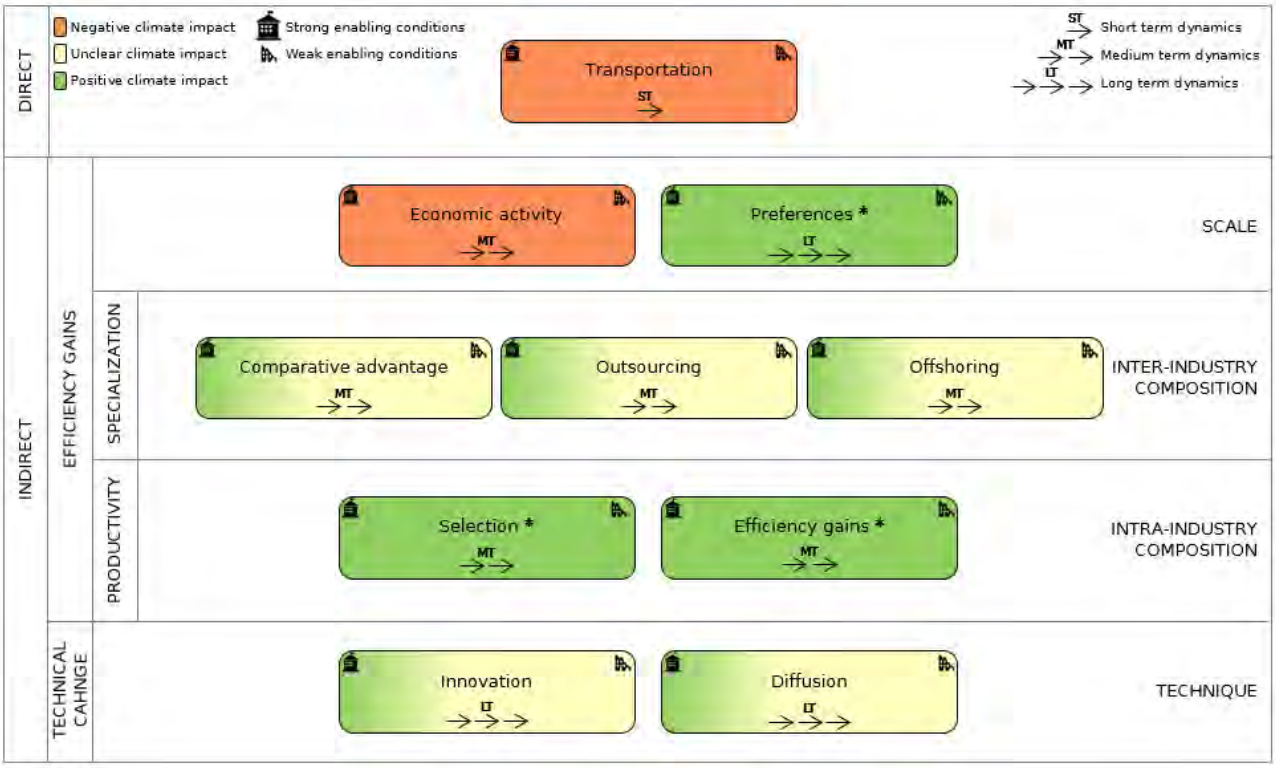

Figure 9. Key channels linking trade to emissions, their temporal dynamics and role of enabling conditions for trade's GHG emission impact. Source: own elaboration.

**Climate benefits are theoretically expected, but empirical evidence supporting this channel is mixed or context dependent.*

A2|3 Building analytical capacity and designing scenarios for future trade-climate projections

The previous sections outlined how trade influences emissions through multiple, interacting channels, and how their effects depend on time and context. Building on that classification, this section turns to the analytical approaches needed to assess the climate implications of evolving trade patterns. What tools are needed? Which aspects of the trade–climate relationship should be prioritised to advance understanding and inform decision-making? And how can we identify the risks and opportunities for the low-carbon transition?

While existing studies have advanced our understanding of economic impacts of trade liberalisation – like competitiveness, reallocation, and welfare – less is known about how current protectionist dynamics affect environmental outcomes. Bridging this gap requires progress on three interlinked fronts: improved data (detail), enhanced modelling capabilities, and an expanded scenario space. These tools must be structured to capture trade–emissions channels and enabling dimensions, supporting robust, policy-relevant insights.

A2|3.1 Improving the granularity and type of available data

Numerous public datasets support empirical and modelling work to assess the climate implications of trade. Emission inventories like EDGAR (Ferrario et al., 2019), the Global Carbon Project (Friedlingstein et al., 2025b), and those published by the IEA (IEA, 2023) and Eurostat (Eurostat, 2024) offer historical, sectoral GHG estimates. Newer initiatives like Carbon Monitor (Liu et al., 2020b), GRACED (Dou et al., 2022), and Climate TRACE (Climate TRACE, 2023b) provide high-frequency or spatial emissions data for timely assessments. Environmentally extended input–output (EEIO) databases – GTAP (Aguiar et al., 2019), EXIOBASE (Stadler et al., 2018b), FIGARO-E3 (Cazcarro et al., 2025), Eora (Lenzen et al., 2013), and GLORIA (IELAB, 2021) – offer harmonised multi-regional input-output (MRIO) tables with environmental extensions. Complementary datasets – like Climate Watch (World Resources Institute, 2023), OECD PINE (OECD, 2023b), and the Quality of Government Environmental Indicators (Povitkina et al., 2021) – offer insights into policy, governance, and institutions (see Supplementary Note 1 and Supplementary Table 2 for details on key datasets). Despite this richness, important data gaps remain.

One issue is the limited integration between granular trade data and macroeconomic datasets, which hinders tracing emissions in global value chains (Wiedmann & Lenzen, 2018b). There is a growing need to track the trade and use of key technologies and materials – such as critical raw materials, batteries, low-carbon industrial inputs – as well as clean technology components and intermediate products (e.g., PV modules, wind turbine parts, heat pumps, electrolysers) embedded in global value chains.

Moreover, two aspects are often underrepresented in EEIO tables and national accounts. First, trade-related costs, especially transport and logistics, are poorly captured. These influence trade's carbon intensity and supply chain structure. Yet most databases link emissions to trade flows using a simplistic proportional method, overlooking transport mode, distance, and logistics efficiency, limiting the analysis of shifting trade patterns (Cristea et al., 2013b; Peters & Hertwich, 2008; Wood et al., 2015). Improving transport emissions and trade cost data would enhance emissions accounting and scenario analysis. Second, financial data, cost structure, and particularly investment costs are often missing from macroeconomic datasets. This limits assessments of the feasibility and diffusion of technologies like electric vehicles, green hydrogen, or heat pumps. While not trade-specific, these are essential for assessing how climate policy and technology deployment shape comparative advantage and future trade patterns. Including capital costs, risk, and support mechanisms would improve the modelling of clean tech manufacturing, trade, diffusion and its trade–climate implications (IEA, 2023).

Better alignment between firm-level data and sectoral aggregates also holds promise. Firm-level data reveal heterogeneity in emissions and energy use, often masked at aggregate levels (Cherniwchan et al., 2017b; Nicoletti et al., 2020). Integration could thus improve estimates of abatement costs and policy responses (Dechezleprêtre et al., 2020), especially with standardised classifications linking micro and macro data.

Detailed statistical information on innovation remains relatively modest. The IEA produces R&D expenditure data for energy technologies (IEA, 2025), but this only concerns public investment even if attempts are being made to establish data for private investment (Pasimeni et al., 2019). The tracking of knowledge flows is important element for understanding the impacts of knowledge spillovers, with analyses based on patent data (Fernández et al., 2022; Jaffe & de Rassenfosse, 2017), PATSAT, or FDI data, the latter with limited industry-specific detail (OECD, 2025b).

Finally, including institutional indicators – such as governance quality indicators – can help capture the pace and effectiveness of low-carbon transitions (Hallegatte et al., 2011; Mealy & Teytelboym, 2022; Povitkina, 2018; Rodrik, 2014). Although rarely included in trade–environment assessments, such indicators are available in datasets like OECD PINE, the World Bank's WGI, and the Quality of Government data.

A2|3.2 Advancing economy-wide modelling frameworks

Numerous modelling approaches analyse trade–climate interactions, each suited to different dynamics. These include engineering and energy system models, which simulate technology-specific mitigation options, particularly in transport and industry (Doukas et al., 2021b; Fragkos, 2022b; Jonkeren et al., 2023b); microeconomic and firm-level models, like heterogeneous-firm trade models and econometric analyses of policy responses; and EEIO models – especially MRIO frameworks – which are widely applied to trace embodied emissions, outsourcing effects, and carbon leakage (Stadler et al., 2018b; Wiedmann & Lenzen, 2018b). Life Cycle Assessment (LCA) and consumption-based accounting (CBA) offer complementary product-level and demand-based perspectives on emissions (Davis & Caldeira, 2010b; Sacchi et al., 2022; Tukker & Dietzenbacher, 2013). Finally, economy-wide models – including CGE and macro-econometric models and IAMs – are used to assess systemic trade–climate effects like reallocation, innovation, socio-economic impacts and carbon pricing (Cristea et al., 2013b; IPCC, 2022d; Müller-Casseres et al., 2024a). Each approach has strengths and limitations; combining them in ways that complement the strengths and help overcome the limitations of one another helps quantify trade–climate impacts (see also Supplementary Note 2).

To assess the climate and environmental impacts of trade (policy) and the impacts of climate policy on trade through the identified channels, economy-wide frameworks – capturing direct responses and effects from income redistribution, production and trade shifts, sectoral interdependencies, and competitiveness – are particularly well suited. This section focuses on this modelling approach, outlining priorities and limitations.

A key development area lies in integrating insights from new trade theories into broader general equilibrium frameworks. Traditional trade models often assume representative firms and comparative advantage driven by factor endowments. By contrast, newer approaches emphasise firm heterogeneity, particularly in productivity and market access (M. J. Melitz, 2003b; M. J. Melitz & Redding, 2014). Such approaches build on earlier work introducing increasing returns, firm entry, and monopolistic competition (Krugman, 1980), showing how trade liberalisation drives intra-industry reallocations and productivity gains. Yet, in practice, many CGE models still rely on simplified trade representations, such as Armington elasticities, which assume consumers differentiate goods by country of origin, and iceberg costs, which consider trade frictions as a loss of goods in transit. Incorporating firm heterogeneity would allow richer analysis of trade dynamics, including differentiated effects of liberalisation or protectionism on firms by size, efficiency, and environmental performance. As Balistreri et al. (2024) show (Balistreri et al., 2024), trade model structure can influence modelling outcomes often more than variations in parameter values, underscoring the importance of carefully chosen and empirically validated assumptions when assessing trade–climate interactions.

Moreover, multinational corporations (MNCs) play a key role in transmitting trade policy shocks and diffusing innovation via FDI, technology transfer, and supply chain integration (Marano et al., 2024). Modelling their behaviour involves capturing endogenous mark-ups and cost pass-through, both of which vary with market structure. MNCs may respond to trade barriers through "tariff-jumping" – by reallocating production or investment across borders (Blonigen et al., 2004; Ghodsi, Mahdi et al., 2024; Lee et al., 2020). Their actions are shaped by both economic and political factors (Hiscox, 2004). Explicitly representing these mechanisms in modelling tools – combining consistent and comprehensive macroeconomic structures with firm-level and innovation modules – could improve the impact assessments of emissions, competitiveness, and innovation under alternative trade regimes.

Higher sectoral and technological resolution can also improve models' ability to represent policy impacts. Several strategies exist to incorporate technological dynamics. One is to retain a top-down structure, while allowing endogenous switching between technologies based on cost or policy signals (Schäfer & Jacoby, 2005). Another embeds bottom-up modules for specific technologies and sectors (Böhringer & Rutherford, 2008). A third approach links CGE models to engineering or techno-economic models to explicitly represent sector-specific constraints (Martinsen, 2011). Coupling sectoral detail with macroeconomic dynamics enables hybrid frameworks that better capture trade–environment linkages. Integrating CGE models with agent-based models (ABMs), techno-economic models (TEMs), or operational transport models supports richer representations of behaviour, innovation pathways, and spatial constraints (Nikas et al., 2019).

Two further dimensions for model improvement relate to temporal dynamics and enabling conditions including regulation, institutional quality, and political economy. As discussed, temporal dynamics play a crucial role in evaluating trade–climate interactions. This is particularly important for assessing protectionist measures, which often involve trade-offs that unfold over time. For example, tariffs might initially reduce emissions from international transport by promoting local production, but near-term capacity constraints or dirtier domestic activities could offset these gains. Over time, outcomes depend on whether domestic production becomes cleaner than the displaced imports – and whether global supply chains for inputs are still needed, potentially shifting rather than reducing trade-related emissions. Capturing such dynamics requires models with temporal depth. Existing models span a spectrum – from static to recursively dynamic, with a few intertemporally optimising structures. While static or myopic models remain popular due to their computational simplicity, enhanced temporal treatments would better capture investment responses, endogenous innovation, and learning-by-doing effects (Keppo et al., 2021; Nikas et al., 2019). Moreover, many models used to support climate strategies tend to smooth over short-term impacts (Gambhir et al., 2022) and have thus been criticised over their ability to examine disruptions and crises (Koasidis et al., 2023). Strengthening the temporal logic of models – especially for innovation and sectoral reallocation – would enable more accurate evaluation of such effects.

Finally, enabling conditions like regulatory stringency, institutional capacity, and political economy dynamics critically shape the implementation and effectiveness of trade–climate measures. These factors influence not only emissions outcomes but also the speed and direction of technological change (Brutschin & Andrijevic, 2022). Several modelling strategies can capture these layers. Coupling general equilibrium models with other modelling frameworks can help capture differences in sectoral regulation or institutional settings across countries. Enhancing the treatment of capital flows, investment risk, and financial constraints helps reflect institutional features relevant to technology uptake and trade responses. Econometric estimates – such as responsiveness to innovation incentives – can proxy institutional capacity. Above all, scenario-based approaches provide flexibility to explore different regulatory and political economy trajectories (Davidson et al., 2024), as discussed in the following section.

A2|3.3 Expanding the scenario space

Equally important as improving models is how they are used. Scenario design is key for assessing the climate and economic impacts of trade policy. While the scenario literature, including that reviewed by the IPCC, spans a wide range of futures, it still lacks explicit treatment of emerging geopolitical and trade dynamics. Other missing dimensions of relevance to trade include human capital/labour (Ram et al., 2022), circular economy (Nikas et al., 2022; Pauliuk et al., 2017), and different types of extremes (McCollum et al., 2020).

More targeted, trade-focused scenarios can help illuminate how trade policy and climate policy interact. They enable exploring first-order dimensions that may not be endogenous to models. They enable “what if” analysis of key drivers. Moreover, scenarios provide common assumptions that can be tested across different modelling tools, leveraging their respective strengths. When applied consistently, such exercises can help identify areas where different models converge, offering more robust insights for policymakers, and where they diverge, highlighting key sources of uncertainty.

The critical dimensions previously discussed – including environmental ambition, institutional and financial capacity, and political economy – can serve as a foundation for more policy-relevant and trade-focused scenarios. Scenarios often span dimensions and trade-offs using quadrant (2x2 matrix) structures (Amer et al., 2013). A well-known example is the Shared Socioeconomic Pathways (SSP) framework, which organises future worlds by challenges related to mitigation and adaptation (O’Neill et al., 2014). While trade is implied in SSPs, and barriers are inherently considered in the SSP3 (regional rivalry) and SSP4 (inequality) narratives, the characterisation could better represent – and quantify – the recent paradigm shift on trade and industrial policy.

A similar structure could thus frame trade–climate scenarios along two axes: trade openness (from protectionism to globalisation) and climate ambition (from global inaction to stringent collective climate policy). This spectrum spans four extremes – green internationalism, low-carbon nationalism, fossil-fuelled protectionism, and grey globalisation – though arguably more plausible futures lie between these endpoints. Figure 2 exemplifies five such scenarios, including a green multilateralism reboot, where climate ambition is restored through cooperative trade, as well as fragmented trade and decarbonisation, where climate action persists despite rising protectionism.

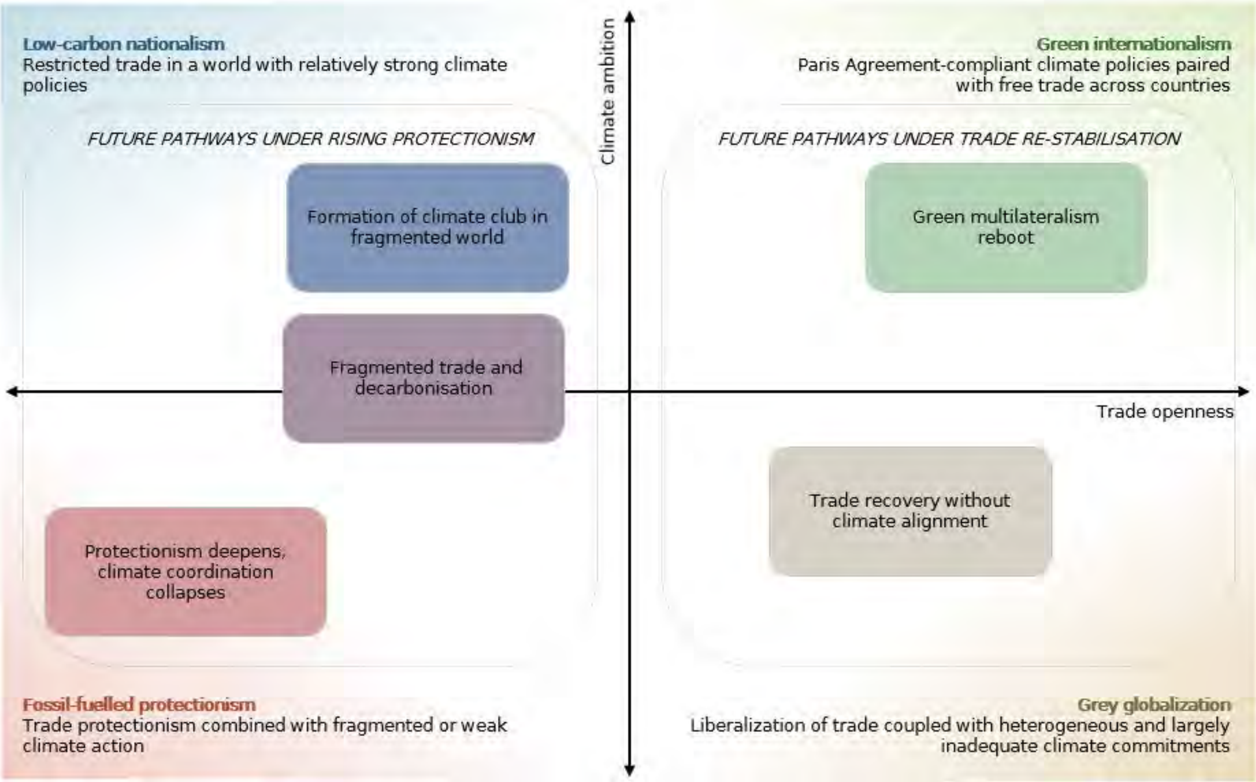

Figure 10. Illustrative scenario framework to examine climate action vis-à-vis trade openness and better capture the climate-trade interactions. Source: own elaboration.

Additional factors like institutional capacity and strategic political behaviour – already embedded in SSP narratives (O'Neill et al., 2017) – could enrich these scenarios. A structured scenario space combining these elements would enable more robust ex-ante assessments of how protectionist trade measures, and their interaction with climate policy, could shape long-term emissions and sustainability outcomes. Looking ahead, emerging machine learning approaches can complement traditional modelling by generating consistent, diverse mitigation scenarios at scale (Li et al., 2025).

A2|4 Conclusions

The relationship between trade and climate outcomes is complex and context-specific, operating through multiple economic channels that interact in complex, non-linear ways. Protectionist measures can either increase or reduce emissions, depending on the mechanisms, specific contexts, and time horizons involved. These effects depend on broader regulatory, institutional, and policy environments, which influence how trade policies translate into environmental outcomes. By providing a conceptual framework that identifies key trade–emissions channels, their temporal interactions, and the conditions shaping their strength and direction, this paper provides a foundation for reflecting on policy implications and improving analytical tools to assess the climate impact of protectionist trade measures.

One of the policy implications that the proposed frame helps capturing is that the effectiveness of trade-related climate policy is strongly conditioned by enabling factors. Institutional quality, regulatory stringency, and the political economy of stakeholder influence affect how trade–climate channels operate, as these conditions largely mediate whether protectionist measures worsen environmental risks or support green industrial development. This is particularly important for amplifying the positive potential of channels such as preferences, composition, and innovation. Their environmental impact is uncertain, but they influence many other trade–climate mechanisms and should be steered toward climate-positive outcomes. Strengthening such enablers is thus central to shaping the climate relevance of trade policy.

This complexity also highlights the need to account for environmental consequences when evaluating trade retaliation or industrial strategies. Trade policies, particularly when responding to foreign measures, should not be assessed solely by competitiveness or geopolitical criteria. A broader perspective is needed – one that considers feedback on emissions, technology diffusion, economic growth, and global cooperation. Such assessments are especially relevant in a context of fragmented global governance and regionally diverging climate ambitions.

Another policy implication concerns the assumption that the climate impact of protectionism simply mirrors that of liberalisation. While this may hold for certain channels in isolation, the overall impact depends on complex interdependencies, time asymmetries, and enabling conditions that may generate path-dependent or irreversible effects. These factors make the climate consequences of protectionism potentially non-symmetric and highlight the need for further analysis and empirical evidence to better understand them.

Improving modelling, increasing the detail of available data, and considering more nuanced sets of assumptions in the development of policy-relevant and trade-focused scenarios is not only a technical task but also an analytical priority. As this paper has shown, trade affects emissions through multiple, complex and inter-connected channels that evolve over time and interact with regulatory, institutional, and behavioural conditions. However, many existing models or scenario considerations do not fully reflect these dynamics, often omitting elements like firm heterogeneity, regulatory asymmetries, or innovation feedbacks. Addressing these limitations will require not just greater detail, but an expansion of what is represented in standard modelling frameworks and captured in established databases. Future efforts should focus on incorporating these dimensions into macroeconomic and sectoral models, and on developing scenario frameworks that jointly explore trade policy and climate ambition under uncertainty.

Looking ahead, future research should address several emerging questions. As the trajectory of global trade liberalisation becomes increasingly uncertain while climate urgency intensifies, how can policy reconcile evolving trade strategies with climate ambition? Under what conditions can trade and industrial policy deliver co-benefits for both competitiveness and decarbonisation, instead of reinforcing trade-offs? And, in an era of weaker multilateralism and more regional trade measures, what institutional arrangements or cooperative frameworks are needed to ensure that climate remains a shared global priority? Addressing these questions with robust analytical frameworks will support more informed, climate-aligned trade policy decisions.

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