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DISCUSSION PAPER-19
DECEMBER 2024

Developing a Framework for CGE Model

Analysing the Implications of CBAM

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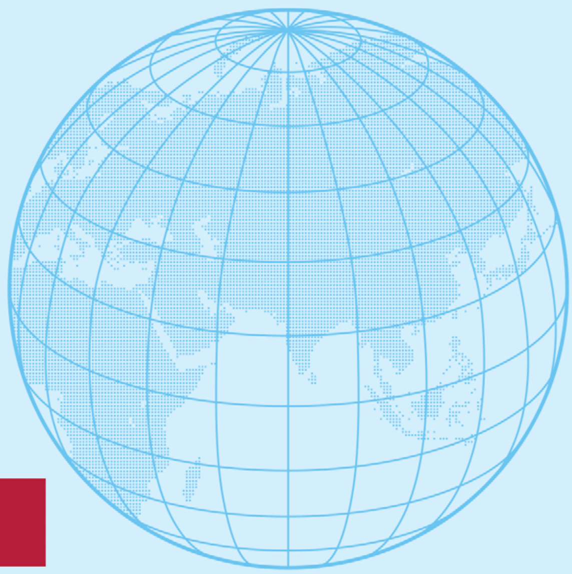

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Recommended citation:
Verma, R. and Agarwal, S. (2024). *Developing a Framework for CGE Model: Analysing the Implications of CBAM* (CSEP Discussion Paper 19). New Delhi: Centre for Social and Economic Progress.

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Developing a Framework for CGE Model

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The authors are respectively Associate Fellow and Research Analyst at the Centre for Social and Economic Progress (CSEP). The authors are grateful to Rajesh Chadha, Joydeep Ghosh, and Ganesh Sivamani for their invaluable support. We are indebted to the reviewers, Constantino Xavier and Sharath Rao for their useful comments. Thanks are also due to Bishwanath Goldar, Basanta Pradhan, A. Ganesh Kumar, Sanjib Pohit, Devender Pratap, Surabhi Joshi, Chetana Chaudhuri, Rakesh Mohan, Laveesh Bhandari, Janak Raj, Renu Kohli, Prerna Prabhakar, and Amshika Amar for their constructive feedback at the roundtable. The authors also thank Shifali Goyal for her research assistance. Views expressed in this work are solely those of the authors and do not necessarily represent the organisation they are affiliated with. All errors present in this document are the authors' responsibility. For further inquiries, please email rverma@csep.org.

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List of Abbreviations

CBAM	Carbon Border Adjustment Mechanisms
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CDC	Common but Differentiated Convergence
CES	Constant Elasticity of Substitution
CO_2	Carbon Dioxide
DART	Dynamic Applied Regional Trade
EC	European Commission
ETS	Emission Trading System
EITE	Emissions-Intensive Trade-Exposed
EPPA	Emissions Prediction and Policy Analysis
EMPAX-CGE	Environmental Policy Analysis-Computable General Equilibrium
ESAM	Environmentally-extended Social Accounting Matrix
EUAs	European Union Allowances
EU	European Union
GHG	Green House Gases
GST	Goods and Services Tax
GTAP	Global Trade Analysis Project
LES	Linear Expenditure System
LDC	Least Developed Countries
MPS	Marginal Propensity to Save
NIT	Net Indirect Taxes
NTM	Non-Tariff Measure
ROW	Rest of the World
SAM	Social Accounting Matrix
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Executive Summary

This academic paper investigates the potential economic and social ramifications of the European Union's Carbon Border Adjustment Mechanism (CBAM) on the Indian economy. CBAM, designed to mitigate carbon leakage and ensure a level playing field for EU industries, introduces a carbon price on imported goods, potentially impacting developing economies reliant on carbon-intensive exports. Given the complex economic structure and trade relationships of India, this study develops a model framework for a tailored Computable General Equilibrium (CGE) model—the CSEP-CGE—to assess CBAM's multifaceted effects.

The paper begins by providing a comprehensive overview of CBAM, its evolution from the EU Emissions Trading System (ETS), and its potential implications for developing countries. Existing literature analysing CBAM's impact often employs gravity models, input-output analysis, or accounting approaches, each with inherent limitations. This study argues that a CGE model provides a more comprehensive and nuanced analysis due to its ability to capture the interconnectedness of economic sectors, incorporate dynamic adjustments, and assess distributional impacts across diverse household income groups.

The CSEP-CGE model framework developed here utilises a detailed production structure, distinguishing between fossil fuel and non-fossil fuel sectors, along with varying substitution possibilities for inputs. This allows for an in-depth analysis of potential shifts in production methods and technology adoption in response to carbon pricing. The model is built on the CSEP Environmentally-extended Social Accounting Matrix (ESAM) 2019–20 for India, offering a rich dataset with disaggregated sectors, households based on income quintiles, and environmental factors. This enables a granular assessment of the impacts on GDP, employment, welfare, trade, emissions, and social equity.

A key contribution of this study lies in its incorporation of a specific breakdown of trade and customs duties for EU and non-EU countries, addressing a gap in existing single-country CGE models analysing CBAM. This enables the assessment of trade diversion possibilities for Indian firms in response to CBAM. The model can further be utilised for examining the interplay between CBAM and existing domestic carbon pricing policies in India, exploring optimal strategies for carbon pricing and revenue recycling to minimise adverse effects and promote technological advancement in relevant sectors.

The CSEP-CGE model framework provides a valuable tool for policymakers to evaluate the complex interplay of economic and environmental considerations associated with CBAM. It allows for the exploration of diverse policy scenarios, including the absence of domestic carbon pricing, optimal carbon pricing strategies, and alternative policy responses such as tariffs or a global carbon policy. With its nuanced sectoral focus, household disaggregation, and specific trade breakdown for EU and non-EU countries, it offers a valuable resource for navigating the complexities of CBAM and its implications for the Indian economy. This can enable policymakers to examine the distributional impacts across different household income groups and thus design effective redistribution policies and promote an inclusive energy transition. Future research can utilise this model to further investigate specific sectoral vulnerabilities, assess the efficacy of various carbon pricing mechanisms, and explore alternative taxation strategies for revenue mobilisation to support a sustainable energy transition.

1. Introduction

Climate change has emerged as a global concern, with far-reaching impacts on the economy, society, and environment. As the world shifts towards achieving net-zero emissions, the transition from conventional carbon-intensive (dependence of energy systems on fossils) to a net-zero economy will require a complete overhaul of the production and consumption patterns of society. Such widespread changes will come at a significant economic cost, which will also have distributional implications across society, as the people employed in the conventional energy sectors will eventually lose their jobs, albeit some may be absorbed in the non-conventional energy-producing sectors (renewables) or other sectors of the economy. There are intrinsic frictions involved in such structural shifts, which are seldom swift unless some policy measures are specifically designed to address these concerns. Thus, it is imperative to examine the implications of these fundamental changes on various facets of the Indian economy, society, environment, and government.

Global climate mitigation policies, such as the Carbon Border Adjustment Mechanism (CBAM), have repercussions beyond national borders. This is because CBAM is a carbon equalising pricing mechanism that seeks to harmonise emissions prices for the goods entering the EU market with the emissions price paid by EU manufacturers domestically. This, therefore, is expected to negatively impact the export earnings of non-EU countries, which will have ramifications on the overall societal welfare as well. Such a border adjustment mechanism aims to offset differences in pricing carbon for goods imported by the EU from different countries, which will negatively impact economic parameters such as exports, imports, welfare, and GDP of the trade-exposed economies. Computable General Equilibrium (CGE) models have been extensively used to comprehensively assess the effects of such policy shifts (Duarte et al., 2018). These models analyse the effects of macroeconomic policies and the change in the allocation of resources in the economy, among their several other uses. While these models can assess the impact of both domestic and foreign policies, this paper focuses on how to design a CGE model framework that can assess the impacts of CBAM in India, among its other uses.

This study begins by discussing the backdrop of CBAM by explaining its present context, evolution, implementation, and implications. Various methods in the literature, such as Gravity models, Input-Output, Accounting approaches, and CGE models, have been discussed in Section two, which can evaluate these ramifications. We describe these methods that have been used to quantify the impact of carbon pricing mechanisms. We provide a critique of these methods, and hence this study attempts to provide a unique context of critically reviewing the methods for computing the effects of carbon pricing policies and gives the nuances of the CSEP-CGE model under development. This paper emphasises some of the specific features of using CGE models to bring out additional analytics of CBAM implementation in section three. In section four, the framework of the CGE model has been discussed, which can examine the likely impacts of various carbon pricing and other macroeconomic policies. This study is restricted in its scope by focusing only on carbon policies such as CBAM and their potential impact on India. We do not analyse or compare the potential impacts of CBAM, or any other policy designed in countries such as South-East Asia and the Rest of Asia. These cases are nonetheless important for examining the relative position of India *vis-à-vis* its neighbours. These can be largely studied using a multi-country model that uses a global database such as the Global Trade Analysis Project (GTAP), which has been planned for future work.

1.1 What is CBAM?

The Context

In 2015, members of the United Nations Framework Convention on Climate Change (UNFCCC) entered into a binding international treaty known as the Paris Agreement, which aimed at keeping the range of global average temperature change below 2°C and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Several countries and regional blocs are committed to formulating climate mitigation policies, such as the Emissions Trading System (ETS) and domestic carbon taxes, to mitigate their GHG emissions and fulfil commitments of Paris Agreement. However, due to disparities in carbon pricing and variations in the implementation of policies across countries, concerns have been raised about the potential for carbon leakage[1] and imbalances in the trade competitiveness of the developed countries, which have a history of stringent environmental regulations either in the form of command and control and/or carbon pricing mechanisms. To address these challenges and incentivise countries to engage in addressing climate change, the European Commission introduced the EU CBAM in line with the 'Fit for 55 Package' in July 2021.[2]

The CBAM is a tool designed to establish an equitable pricing mechanism for the carbon emissions generated during the manufacturing of carbon-intensive products (such as cement, iron and steel, aluminium, fertilisers, thermal electricity, and hydrogen) that are imported into the EU. The goal is to mitigate the risk of carbon leakage and create a balanced environment for European industries striving to decarbonise the economy and taking responsibility for their local emissions by paying a carbon price. The European Commission seeks to strengthen global climate change actions and meet its current commitment as part of the UN's Paris Agreement on climate change (European Commission, 2021).

The Evolution of EU CBAM

The proposal for the EU CBAM emerged from the EU ETS that started in 2005 as an aftermath of the Kyoto Protocol.[3] The EU ETS is a 'cap and trade' system that imposes a ceiling on the total emissions permitted from electricity and heat generation, energy-intensive industries,[4] and the aviation sector. These caps on emissions progressively decrease in alignment with the EU's climate targets, which leads to a gradual reduction in overall emissions over time. Under this framework, producers are required to procure European Union Allowances (EUAs) equivalent to their annual emissions of carbon dioxide, nitrous oxide, and perfluorocarbon emissions. This process increases the cost of energy inputs, creating a disadvantage for producers situated in the European Union relative to those in countries where a carbon price is not imposed. The scheme provides incentives to producers to shift their production processes outside the EU while keeping the overall emissions in the world the same, resulting in carbon leakage. Initially, the EU allocated 100% free allowances to industries and sectors perceived to have the highest risk of leakage due to energy intensity or trade exposure. Since 2013, 57% of allowances have been auctioned, and the rest are provided based on the benchmark value.[5] The EU CBAM, on the other hand, aims to address this issue of leakage by equalising the cost of carbon across countries, which is discussed in detail subsequently.

In 2019, the European Union increased its climate goals, aiming to become climate-neutral by 2050 through the European Green Deal, in line with its Paris Agreement commitments. The EU also set a short-term goal of reducing net greenhouse gas emissions by at least 55% by 2030, relative to 1990 levels. However, as the EU's emissions reduction goals become more ambitious, the divergence between the EU's climate action and other developing countries is anticipated to widen, increasing the possibility of carbon leakage. Addressing these challenges, in July 2021 the EC released a comprehensive proposal for CBAM , outlining key features of CBAM, including its scope, the sectors to be covered, the computation of embedded emissions, and compliance requirements for importers. The proposal aims to emerge as a potential solution to address carbon leakage and equalise conditions for industries in the EU. CBAM can ensure that both domestic and foreign products face comparable carbon costs by pricing the carbon content of imported goods entering the EU. This arrangement aligns with the EU's climate objectives and promotes the adoption of low-carbon practices within and beyond its borders. Figure 1 depicts the phased implementation of the EU ETS and the evolution of CBAM. Such a policy will have unintended consequences of impacting developing countries' exports and, more importantly, jobs, which are further discussed.

[1] Carbon leakage occurs when industrial production shifts from regions with stringent greenhouse gas emission regulations to areas with less stringent regulations, thus undermining the effectiveness of climate policies in the stricter regions.

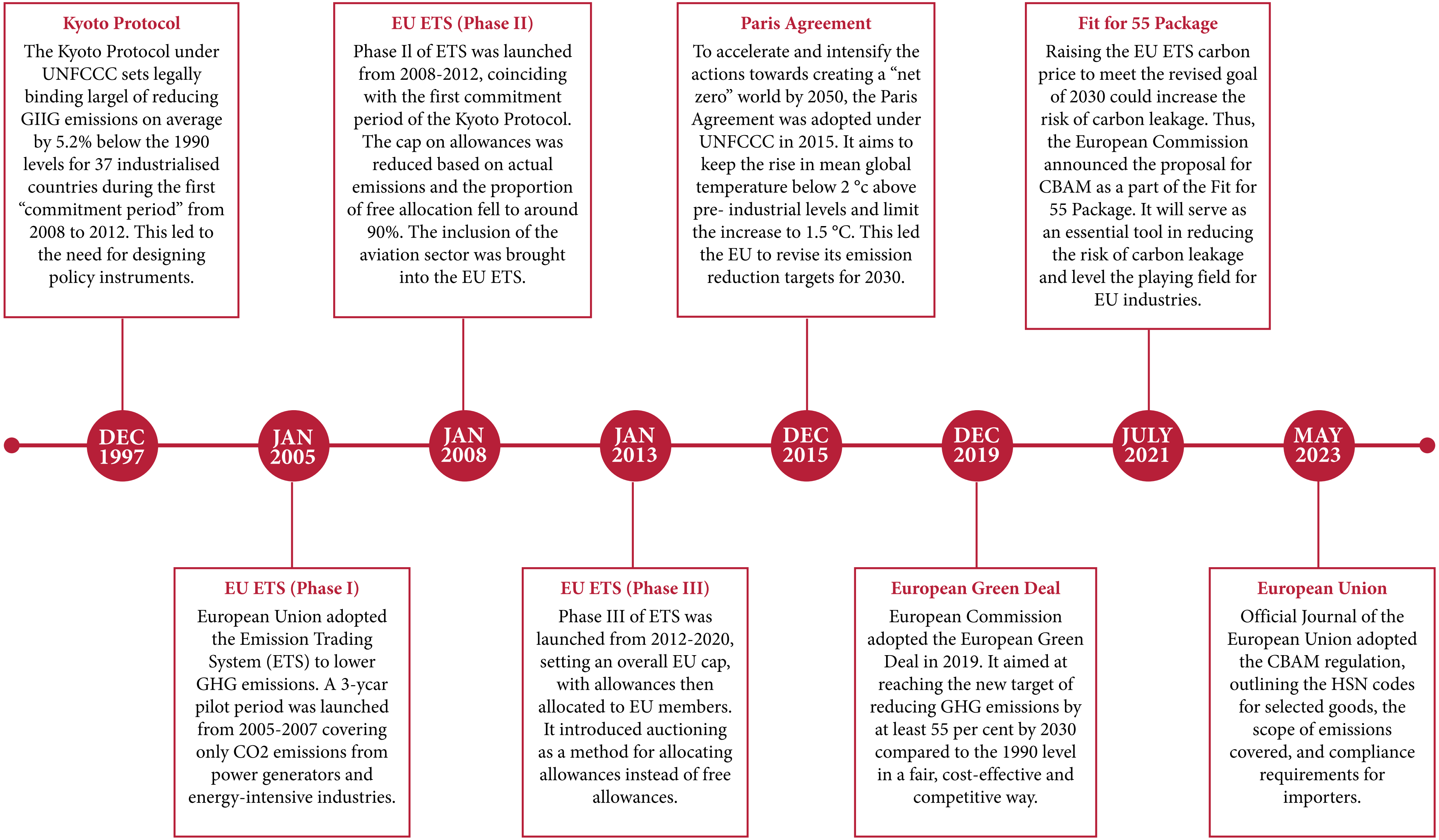
[2] 'Fit for 55' represents the EU's objective of attaining at least a 55% reduction in net emissions by 2030, compared to 1990 levels, with the aim of becoming the first climate-neutral continent by 2050.

[3] The Kyoto Protocol, an international treaty adopted under the UNFCCC in 1997, establishes legally binding targets for reducing GHG emissions in industrialised countries, based on individually agreed targets.

[4] Energy-intensive industries covered under the EU ETS include oil refineries, steel works, and producers of iron, aluminium, metals, ceramics, cement, pulp, lime, glass, paper, cardboard, acids, and bulk organic chemicals (Korpar et al., 2023).

[5] The benchmark values for the free allowances in EU ETS are based on the average performance of the 10% best installations, the risk of carbon leakage of each sector and the historical activity level of each installation. See https://www.iea.org/reports/implementing-effective-emissions-trading-systems/ets-in-industry

Figure 1: Evolution of CBAM in the European Union



Source: Authors' representation.

Implementation of EU CBAM

The European Commission has implemented CBAM to fight against carbon leakage and level the playing field for EU manufacturers. While it can be seen as an import tariff on carbon-intensive imported goods, unlike conventional tariffs, it operates through a unique mechanism, which requires importers in the EU to acquire carbon certificates matching the carbon price that would have been incurred if the goods were manufactured within the EU, thereby ensuring its compatibility with World Trade Organization (WTO) law. Although this can have similar effects on trade by adversely affecting the competitiveness of imported goods, it is advocated under sustainability-driven[6] international regulations and an environmental incentive scheme. This could act as a barrier to free trade, often referred to as protectionist Non-Tariff Measures (NTMs). Thus, it can be expressed as a price control measure within NTMs, which includes measures other than traditional tariffs that increase the cost of imports in a similar manner.

The implementation of CBAM is planned in two phases: a transitional phase that began on October 1, 2023, and a permanent system commencing on January 1, 2026 (European Commission, 2023). During the transitional phase, importers are mandated to disclose the quantity of goods imported into the EU in the previous year and their associated emissions from the six key polluting sectors: iron and steel, cement, aluminium, fertiliser, hydrogen, and electricity. The list of associated greenhouse gases is provided in Appendix A. The carbon intensity computations will include direct emissions (Scope 1)[7] and indirect emissions[8] from electricity (Scope 2). However, in certain sectors, such as aluminium and iron and steel, only Scope 1 emissions will be included. These sectors use electricity extensively to process the respective scrap metal. Also, the electricity used by these sectors receives compensation from the EU ETS for their indirect emissions (Maliszewska et al., 2023).

Under the permanent system, importers in the EU will continue to declare the quantity of CBAM imported goods and their associated Greenhouse Gas (GHG) emissions annually. In addition, they will also have to buy CBAM certificates through national authorities, where each certificate will be equivalent to one metric tonne of CO_2 emissions. The value of these certificates will be equal to the price differential between the carbon price paid in exporting country and weekly average auction carbon allowances' price in EU ETS. Similar to the EU ETS, EU importers can sell the certificates back to the national authority after declaring their CO_2 emissions. This way, CBAM is expected to create an economic incentive for exporting countries to reduce their carbon footprint and adopt cleaner production practices. Further, this will create a balance between the carbon prices in the EU and non-EU countries. The EU has also proposed that the list of six polluting sectors will be gradually enhanced to include all imported polluting sectors that are subject to the EU ETS under the ambit of CBAM by 2030. Implementation of CBAM by the EU is not expected to just incentivise its trading partners to reduce their carbon footprint or equalise the carbon price across countries, but it will have significant implications for the economic and environmental parameters of its trading partners, which are discussed in the next section.

Implications of EU CBAM

The introduction of CBAM to fulfil the EU's climate neutrality goals by 2050 has sparked various concerns. The objective of reducing global leakage would not be met through the imposition of carbon tariffs only on EU imports of carbon-intensive goods. However, this measure has the potential to restrict the exports of trading partners, thereby impacting the welfare and employment of developing countries (UNCTAD, 2021).

The anticipated effects of CBAM across the literature vary considerably, as discussed in Table 1. Given that CBAM will take the form of an import tax, it is anticipated to negatively affect exports from non-EU countries, especially developing countries, although with significant variations between countries. In the specific case of India, multiple studies recognise India as one of the developing countries in which

[6] Sustainability-driven regulations are Non-Tariff Measures implemented by developed countries to address sustainability, environmental, and climate change issues.

[7] Scope 1 emissions are direct emissions from production processes under the producer's direct control.

[8] Indirect emissions encompass Scope 2 and Scope 3 emissions. Scope 2 emissions result from the production of purchased electricity, heat, or steam used by the company in its manufacturing process. Although linked to the company's energy consumption, these emissions occur off-site, making them an indirect source. Scope 3 emissions, also indirect, occur across the firm's value chain, which includes upstream and downstream activities.

CBAM will have the most impact. Some anticipate a substantial fall in exports, with a potential drop as high as 65% for non-metallic metals exports, while others estimate more moderate effects. Meanwhile, the expected fall in CO_2 emissions remains relatively small, suggesting that its effectiveness in mitigating climate change would be limited, even though it effectively addresses carbon leakage. The affected sectors in exporting countries would eventually diversify their exports to new trading partners (UNCTAD, 2021; Perdana and Vielle, 2022; Pyrka et al., 2020).

The impact on employment and wages is expected to be relatively modest across the majority of economies. In the EU, employment will increase by 0.2% in iron and steel, 0.9% in aluminium, and 2.6% in the fertiliser sector while declining by 0.5% in the cement sector by 2030 (European Commission, 2021). In developing countries and Least Developed Countries (LDCs, CBAM is expected to increase unemployment as they heavily rely on exports of carbon-intensive goods. This rise in production cost can diminish the demand for labour and negatively affect real wages. Conversely, developed countries that already specialise in the production of energy-intensive products with relatively lower CO_2 emissions may witness a decrease in unemployment because of the competitive price advantage in exports (UNCTAD, 2021).

Furthermore, the imposition of CBAM could lead to other countries implementing similar import taxes on EU products as retaliatory action. Although this could complicate global trade dynamics and result in trade disputes between the EU and its trading partners, it remains to be seen to what extent CBAM can incentivise countries to move toward decarbonisation.

Table 1: Comparison of Recent Estimates on the Effects of CBAM

Method	Study	Exports		CO_2 Emissions		GDP	
		From EU to India	From India to EU	EU	India	EU	India
Computable General Equilibrium Model	Xiaobei et al. (2022)	N/A	–65.2% to –11.8%	N/A	N/A	N/A	-0.04%
	Devarajan et al. (2022)	N/A	Approximately -7% to -18%	N/A	N/A	N/A	N/A
	Perdana and Vielle (2022)	N/A	N/A	-1,564 Mt CO_2	-87 Mt CO_2	-3.50%	-0.20%
	Pyrka et al. (2020)	N/A	N/A	0.00%	-0.30%	N/A	N/A
	UNCTAD (2021)	N/A	N/A	8.86 to 13.14 mn of Mt CO_2	-5.11 to -7.81 mn Mt CO_2	N/A	N/A
Gravity Model	Mortha et al. (2023)*	Overall Exports -1.01% to -0.25%	Overall Exports -9.54% to -0.77%	-5.50% to -0.69%	-6.14% to -0.70%	N/A	N/A
	Korpar et al. (2023)	Overall Exports -0.04%	Overall Exports–0.33%	0.24%	-0.16%	0.03%	–0.03%
Input-Output	Zhong and Pie (2022)	N/A	N/A	N/A	N/A	Total Output 0.19% to -0.38%	N/A
Accounting Approach	World Bank (2021)	N/A	N/A	N/A	10.61 mn tCO_2	N/A	-0.02% to -0.01%

*Note: N/A implies not applicable. *The authors have considered EU-31 countries for their analyses.*

Source: Compilation by authors using the aforementioned sources.

The following section reviews the literature to evaluate diverse methods used for assessing the impacts of CBAM, as this poses a major challenge to the competitiveness of the CBAM-affected Indian exporting industries. It focuses on the advantages *vis-à-vis* the disadvantages of these methods and outlines the essential features of CGE models in examining the implications of CBAM.

2. What Does Current Literature Do to Compute CBAM Impacts?

The literature employs numerous methods to assess the impacts of CBAM. The majority of studies employ CGE models to estimate its effects on trade, welfare, and output. However, other quantitative studies adopt diverse methods, including structural gravity models, input-output analysis, and various accounting approaches. The following sections briefly explain the various methods and their limitations in assessing the impact of CBAM.

2.1 Gravity Model

Given that CBAM is a trade policy instrument, its effects on international trade can be analysed by examining the trade flows based on factors such as country sizes, distances, and multilateral resistance.[9] Larch and Warner (2017) developed a structural gravity model that allows analysis of the impacts of carbon tariffs on trade, welfare, and emissions. Their model quantifies the decomposition of the emission changes into scale, composition, and technique effects. The findings reveal that carbon tariffs can lower global emissions but at the cost of trade and welfare. Using a similar approach, Korpar et al. (2023) and Mortha et al. (2023) analysed the impacts of EU CBAM on exports, welfare, and emissions. Their findings indicate that while CBAM will have a very small negative impact on welfare, it is likely to reduce exports and production for trading partners of the EU. Notably, middle-income economies will be affected relatively more, experiencing a larger decrease in exports, production, and emissions. For example, a sharp decrease in exports across all CBAM sectors is evident for countries like India (-1.0% to -10.8%), Russia (-1.1% to -7.7%), and Mongolia (-5.8% to -27.9%) (Mortha et al., 2023).

However, it is important to acknowledge that the structural gravity model is the framework for analysing trade policies. Its primary focus is explaining bilateral trade patterns, which may limit the scope to assess the multilateral implications of trade relationships within a framework involving many countries (Arkolakis et al., 2012). In addition, the framework presented by Larch and Wanner (2017) assumes constant expenditure shares, constant factors of production, and homothetic preferences, making it less adaptable to adjust for structural changes. Additionally, EU CBAM does not treat countries geographically closer to them differently, hence the use of the gravity model to assess its impact will be limiting, highlighting the need to review other models used to assess the implications of measures like CBAM.

2.2 Input-Output Analysis

The input-output analysis serves as a technique to measure the interconnectedness of diverse economic activities and addresses some of the limitations faced by the gravity model when analysing implications of measures that do not treat countries differently based on geographical distance. Through input-output analysis, one can estimate embodied carbon content, allocate emissions, and determine environmental trade balances. It incorporates all forms of resource utilisation, including direct and indirect effects (Miller and Blair, 2009).

Numerous studies have examined EU CBAM impacts on competitiveness and welfare by employing a multi-regional input-output framework (Zhong and Pie, 2022; Beaufils et al., 2023; Magacho et al., 2022). They systematically assess the multidimensional exposure of countries exporting to the EU. These studies conclude that CBAM could pose an implicit threat to countries without carbon pricing, and they would suffer an opportunity cost of not instituting policies for pollution mitigation. However, if only direct effects are considered, it may not be considered a useful mechanism to minimise leakage. For instance, Zhong and Pie (2022) estimate that CBAM could help reduce carbon leakage, but the impact on global carbon emissions remains modest, with a potential reduction ranging from 0.1% to 1.5%. Meanwhile, Magacho et al. (2022) suggest that the degree of exposure of economies exporting CBAM products to Europe will vary significantly, with many

[9] Multilateral resistance refers to the impacts on a third country arising from changes in the trade relationship between two other countries. For example, shifts in relative trade costs could alter this relationship and lead to trade diversion.

developing economies experiencing more than a 2% impact on their exports and 1% on their production.

Similarly, while focusing on the potential sectoral impact of EU CBAM on a single country, Input-Output analysis was utilised to examine the impacts on the Turkish economy, indicating that CBAM could impose a carbon-related cost of EUR 1.1 to 1.8 billion on Turkish exporters to the EU market (Acar et al., 2021).

Input-Output analysis is based on certain assumptions, such as fixed input proportions and constant returns to scale, and assumes away any technological advancement, which imposes limitations on its utilisation for impact analysis. It underestimates the bi-directional causality between income and expenditure, as well as economic linkages among regional markets. Moreover, the absence of elasticities of substitution on the supply side of the economy hinders its ability to account for adjustments or technological changes that might arise in response to climate-related alterations (Ardent et al., 2009). It can analyse the impacts of only marginal changes in activities as it accounts for the emissions covered by CBAM and not the subsequent adjustments due to such policy interventions (Turner et al., 2003). Considering these limitations of the Input-Output model, there exist other approaches that have been used in the literature to assess the impacts of CBAM.

2.3 Accounting Approach

Some studies also analyse the implication of CBAM using an accounting approach. For instance, Overland and Sabyrbekov (2022) constructed a multidimensional CBAM Opposition Index using data from multiple global development indicators to identify countries likely to resist CBAM. Their findings indicate that countries with a high share of CBAM-exposed exports to the EU and carbon intensity with low levels of technological innovation will exercise their rights within the WTO to oppose CBAM. Whereas based on the CO_2 emissions embodied in EU imports, Lowe (2021) estimates that applying CBAM to all goods covered by the EU ETS could lead to US$16 billion worth of exports of developing countries subject to additional carbon border adjustment charges. However, exempting these countries' exports from CBAM would not significantly undermine EU efforts to reduce carbon emissions. For example, the CO_2 embodied in final EU demand imported from India accounts for just over 1% of total EU emissions (Lowe, 2021). Additionally, the World Bank (2021) computed the average annual trade volumes and values from 2017 to 2019 and found that exporters of Emissions-Intensive, Trade-Exposed (EITE sectors from Thailand, India, and Vietnam would incur annual costs of EUR 109 million, EUR 434 million, and EUR 36 million, respectively, due to the imposition of CBAM.

Accounting approaches have significant limitations in their analyses because they do not factor in potential behavioural changes or dynamic economic adjustments that may occur in response to policy changes like carbon pricing. The next section explains how using CGE models can overcome these and other shortcomings of Gravity and Input-Output models.

2.4 CGE Model

The majority of studies analysing the impacts of CBAM employ CGE modelling as the mechanism's economy-wide impacts can be simulated comprehensively using this approach. CGE models are preferred because they provide counterfactual, ex-ante comparisons, helping assess policy reform outcomes against business-as-usual scenarios. They can analyse the implications of climate policies due to their ability to capture economic interconnectedness, flexibility in incorporating policy inputs, and capacity to assess a wide range of impacts over medium- to long-term time horizons.

Devarajan (1988) highlights three reasons why CGE models are preferred over other models. First, CGE models can simulate price changes. They are distinctive because they consider prices as endogenous variables; prices and quantities are determined simultaneously when modelling the effects of external shocks or policy changes. Second, these models are designed to solve for various markets (e.g., goods and factor markets), institutions, and their interlinkages simultaneously. Third, CGE models comprehensively represent the economic structure and allow for the inclusion of non-market activities alongside market mechanisms by incorporating their imputed costs. This is achieved through explicitly modelling their altered price levels within the behavioural equations.

Although CGE models offer many benefits, they have a complex design and rely heavily on critical economic parameters, like elasticities, to model how people and businesses respond to policy changes. Their main merit lies in the inclusion of market activities through price- and income-responsive supply and demand.

Moreover, CGE models can systematically measure the efficiency implications and distributional effects of policy measures beyond the structural changes induced by prices in the agents of production and consumption (Böhringer et al., 2021).

Numerous empirical studies using CGE models emphasise the efficacy of border carbon adjustments in mitigating carbon leakage. These studies highlight the full implementation of border carbon adjustments as the optimal approach to increase the global cost-effectiveness of unilateral emission pricing. Additionally, they emphasise that implementing border carbon adjustments can lead to output reduction for EITE industries in developing countries (Böhringer et al., 2010; Fischer & Fox, 2012). Table 2 summarises all the methods examined in this study and provides their strengths and weaknesses. Section 3 enumerates how CGE models can be used to analyse the effects of climate policies such as carbon pricing.

Table 2: Comparison of Approaches Used to Assess Economic and Trade Impacts of Climate Policies

	Gravity Model	Input-Output Model	Accounting Approach	CGE Model
Description	A spatial interaction model that estimates the volume of interactions between two geographies based on factors like country size, distance, etc.	Measures interdependence among sectors and tracks the flow of goods and services across those sectors.	An accounting exercise to estimate CBAM-exposed trade and potential carbon payments.	A theoretical model consisting of numerous simultaneous non-linear/linear equations used to compute the implications of various policies or shocks in the economy. This makes it a 'computable' general equilibrium model where all markets interact simultaneously.
Purpose	To assess bilateral trade patterns and the impacts of various trade policies.	To estimate direct and indirect consequences and multiplier impacts of an impetus across the sectors in an economic system.	To map the flow of trade and emissions between countries/ regions to comprehend the potential impacts of EU-CBAM.	To simulate the economy-wide impacts of various governmental policies, including climate policies like carbon taxes and CBAM.
Strengths	● Captures bilateral trade flows. ● Can be used to examine the impacts of geo-economic issues other than international trade.	● Incorporates both direct and indirect effects. ● Provides detailed sectoral analysis.	● Provides an understanding of the potential implications of a trade policy in a relatively simpler yet effective framework.	● Provides a comprehensive view of the entire economy. ● Incorporates the supply side of the economy, allowing for price movements. ● Allows for substitution effects in production and consumption. ● Allows for the inclusion of non-market activities alongside market mechanisms.
Weaknesses	● Focuses only on bilateral/bi-regional trade, limiting the scope to assess the multilateral implications of policies involving many countries. ● Less adaptable to structural changes. ● Inappropriate to use for analysing the trade impact of policies like CBAM, which do not treat trading partners differently based on geographical distance.	● Certain assumptions like fixed input proportions, constant returns to scale, and no technological advancement limit its use for impact analysis. ● Lacks elasticities of substitution, hindering its ability to account for adjustments or technological changes.	● Does not consider behavioural changes or dynamic adjustments that may occur in response to policy changes.	● Highly complex; requires accurate parameter estimation. ● Dependence on key economic parameters, like elasticity parameters, to capture behavioural responses.

Source: Authors.

3. Literature on Single Country CGE Models Simulating Carbon Pricing Policies

CGE models have been extensively utilised in the literature to examine the impacts of various climate policies. The CGE models used in these studies are largely multi-region and multi-sector. Multi-country CGE models encompass two or more countries (or regions), providing a comprehensive depiction of their economies, including production, consumption, trade, taxes, and tariffs. The economies in these models are interconnected through trade and sometimes through flows of capital or labour (Burfisher, 2020). The primary data source for estimating the parameters of these models is the Global Trade Analysis Project (GTAP) database, which consists of Social Accounting Matrices (SAMs) of 65 production sectors and 141 countries and regions (Aguiar et al., 2019).

In contrast, single-country models are less commonly used to examine the impact of trade. Analyses focusing on a specific country typically adopt a single-country SAM (Bao et al., 2012; Banerjee, 2021). These focus more on the sectoral description of the domestic economy without delving into other countries. This helps to analyse the results based on country-specific economic structure and data, which is challenging to do with the GTAP database due to the complexities involved in aggregating the global economy data. This section briefly describes the structure of these models in analysing carbon pricing schemes.

3.1 Modelling Structure

In the conventional framework of CGE models, all economic activities—such as production, consumption, investment, trade, and income distribution—are included (Thissen, 1998). When evaluating climate mitigation policies using CGE models that incorporate interactions with the energy system, a crucial distinction arises between carbon-intensive and non-carbon-intensive industries. This helps in capturing variations in carbon intensity within the production process across different regions and accounts for the substitution between inputs with high carbon intensity and those with low carbon intensity (Klepper, 2003). Consequently, the climate policy framework incorporates the effects on terms of trade, GDP, welfare, global emissions, and other economic factors resulting from carbon abatement policies.

Most research has focused on differentiating their nesting structures based on the type of intermediate inputs utilised by non-fossil fuel sectors into energy (coal, oil, gas, and electricity) and non-energy inputs, as these activities are primarily responsible for emissions (see Bao et al., 2012; Devarajan, 2022; Banerjee, 2021). Further segregation of the power sector into thermal, renewable, nuclear, and CCS technologies has been undertaken in some studies to analyse the impacts on the electricity generation mix and the socio-economic impacts of decarbonisation (for instance, see Pradhan & Ghosh, 2012). In contrast, Ojha (2009) employs a nesting structure of inputs that varies among sectors, as in the EPPA (Emissions Prediction and Policy Analysis) model. The author extends sectoral disaggregation beyond the conventional fossil and non-fossil sectors to enhance the representation of energy substitution possibilities.

These CGE studies analyse the economic impact and propose different policy designs for border carbon adjustments, which are discussed in Section 3.4. What follows next is the level of disaggregation of the accounting matrices that these models use.

3.2 Disaggregation of Accounting Matrices

In both single-country and multi-country CGE models, complexity is determined by the number of regions and sectors included in the model (An et al., 2023). These models use sectorally disaggregated accounting matrices, such as Input-Output (I-O) and SAM/ESAM, as their primary databases. The number of sectors included in a CGE model is usually determined by the study's specific goals and the availability of data. In general, CGE models use fewer sectors compared to I-O or SAM/ESAM models. This simplification is done for several reasons. First, a focused sectoral approach helps in the meaningful interpretation of results, allowing for a clearer understanding of the implications on specific sectors. Second, obtaining elasticity parameters for a detailed list of sectors is often difficult (Devarajan, 2022; Xiaobei, 2022; UNCTAD, 2021).

The majority of existing standard CGE models in the literature have not classified households or have categorised them into two broad groups—Rural and Urban—and hence these models do not examine the inequality issue of an exogenous policy shock on the economy. A handful of studies in the Indian context disaggregate households to analyse the welfare allocation and social equity effects of mitigation policies (see Banerjee, 2021; Pal et al., 2015; Ojha et al., 2009). They separate households into more heterogeneous types, ranging from four (as in Banerjee, 2021) to nine (Pal et al., 2015), allowing for a meaningful analysis of the impacts of climate mitigation policies on household welfare and social equity. The disaggregation of households in the Indian context is based either on their expenditure levels or the occupation of the households in rural and urban areas. However, depending solely on the occupation of the households, which is determined by the head of the family, is not an appropriate indicator for classifying them, as this cannot be the only reason for explaining the divergence in factor incomes across households. Social groups, gender, and region are more meaningful ways of classification.

Despite the availability of data on the sectors and institutions, there has been relatively limited attention given in international trade-oriented CGE models to the disaggregation of exports/imports and customs duty for the specific region of interest. For instance, if the objective is to examine CBAM, then trade and customs data can be disaggregated into EU and non-EU countries. This appears to be a major lacuna in existing studies. This has been attempted in the present study by developing a single-country CGE model for India. In Section 4.2, this point will be further elucidated.

3.3 Simulating the Carbon Pricing

Carbon pricing is one of the major climate mitigation policies that existing CGE models have simulated. The other is the cap-and-trade system (also known as emissions trading), which is implemented at a regional or national level. In the Indian context, Pradhan & Ghosh (2012) analyse two different policy scenarios. In the first scenario, the authors put a global carbon tax on the quantity of carbon emitted from coal, oil, and gas and redistribute the revenue back to households through transfers. In the second scenario, they analyse the impacts of emission trading permits, wherein permit distribution uses the Common but Differentiated Convergence (CDC) approach. This approach assumes that per capita emissions of all countries converge, with developing countries initiating their convergence path after reaching a certain threshold. Here, they introduced a variable on international capital flows in the model that impacts trade competitiveness and domestic prices. These capital flows are channelled through foreign savings back to the households, which is similar to transfer payments from the rest of the world, depending on the difference between emission allowances and the actual emissions level of a polluting firm.

The other model by Ojha (2009) attempts to evaluate the implications of carbon taxes and an international tradable emission permit scheme in India by integrating an endogenously determined price system that balances supply and demand along with an income distribution module. The model aggregates CO_2 emissions from coal, natural gas, refined oil, and crude petroleum across 11 sectors and models carbon taxes based on the proportion of carbon content in each fuel consumed by the non-government sector. Furthermore, it incorporates carbon taxes into the cost structure for producers and accounts for the non-uniform increases in fossil fuel prices[10] resulting from instituting carbon taxes. This incentivises a shift towards lower-carbon fossil fuels, leading to an overall reduction in fuel consumption.

Pal et al. (2015) developed a comprehensive model to analyse the economy-wide impact of market-based policy instruments for mitigating emissions in India. This model considers GHG emissions (CO_2, N_2O, and CH_4) in the economy by accounting for fossil fuel inputs in the production process, gross outputs, and household and government consumption demands. Carbon taxes have been simulated on emissions arising from the production process, exempting emissions from households and government consumption. The cost associated with CO_2 emissions is calculated based on the net quantity of CO_2 emissions after deducting the domestic CO_2 quotas and offsets purchased by each industry. The revenue generated from carbon taxes is subsequently channelled back to households through government transfers, thus impacting both government revenue and expenditure.

Thus, numerous models have studied the impact of a carbon tax within a single-country model for the Indian economy. However, it is crucial to examine the effects of CBAM, considering both the presence

[10] A non-uniform increase in fossil fuel prices from a carbon tax refers to varying degrees of price increases across different fossil fuels. This means the rate of increase will differ for coal, oil, and gas following the implementation of the carbon tax. This scenario can lead to both fuel switching and an overall decrease in fuel consumption.

of a domestic carbon tax and the implementation of a revenue recycling[11] scheme using a single-country CGE framework.

3.4 Effects of CBAM

The effects of CBAM are influenced by several factors, including how countries trade with one another, how much carbon is emitted during production, and the carbon policies of trading partners. Studies have compared the potential effects of CBAM with alternative approaches, such as output-based rebates,[12] and have assessed their impacts on trade, welfare, and emissions (Bohringer et al., 2010; Bohringer et al., 2012; Fischer & Fox, 2012; Monjon & Quirion, 2011). Their results suggest that CBAM can reduce the disadvantages in competitiveness faced by EITE sectors by effectively reducing the risk of carbon leakage. However, they also highlight the drawbacks of CBAM, such as reduced exports, exacerbated regional inequalities among exporters, and challenges in implementation due to legal issues arising from WTO treaties (Bohringer et al., 2010; Monjon & Quirion, 2011; Boehringer et al., 2012).

The effect of CBAM based on a hypothetical EU ETS price also suggests that CBAM will significantly reduce carbon leakage from the EU and alter trade patterns in favour of countries with relatively carbon-efficient production processes (Morsdorf, 2022; UNCTAD, 2021). While *ex-ante,* these studies establish that CBAM reduces carbon leakage, specific country studies analysing the impacts of CBAM depict mixed results. In the case of Japan, a study by Takeda & Arimura (2023) shows an increase in GDP and overall welfare, although EITE sectors experience marginal output declines. Similarly, the effects of CBAM on Finland's economy show reduced imports from non-EU countries and a shift towards imports from EU countries. Exports from Finland increase in the EU market but have a small negative impact on Finland's GDP (Kuusi et al., 2020). However, in the case of India, the effects on energy-intensive products vary across different studies. For instance, Xiaobei et al. (2022) estimate that CBAM will lead to a 58.5% fall in India's iron and steel exports to the EU; in contrast, Majumder et al. (2024) find that CBAM sectors, like fertilisers, cement, aluminium, and iron and steel in India, would experience only marginal declines, with the highest quantum of about 0.6% realised by the cement sector. Banerjee (2021) evaluated the combined policy of border carbon adjustment on Indian exports along with existing domestic carbon adjustment policies in India.[13] Assuming these domestic policies enhance energy efficiency and induce a regime change in fuel-switching technologies and industrial processes, the author found that a combination of domestic and border carbon policies effectively reduces carbon leakage when both schemes' rates are close to each other. As India has higher emission-intensive imports than exports, targeting emission reduction through stricter domestic carbon adjustment policies is deemed more effective. Additionally, the study suggested that direct compensation to enterprises involved in production activities through carbon revenue recycling schemes could help the Indian economy recover from the distortions caused by carbon taxation policies.

As the economic effects of the proposed CBAM and other border adjustment mechanisms announced by countries such as Australia and the US become more significant, concerns about their socio-economic impacts and the comparison of climate change mitigation efforts across countries will grow. Given the varying range of results in the literature, it is crucial to conduct a detailed analysis of the impact of CBAM on the Indian economy. This study focuses on designing a single-country CGE model framework for India using CSEP's ESAM 2019–20 to analyse the impacts of CBAM on macroeconomic indicators—such as GDP, employment, price level, trade, and welfare—among others. The discussion on these issues is provided in Section 4.

[11] Revenue recycling is the use of revenue generated from carbon pricing to mitigate the impact on social groups disproportionately affected by such policies.

[12] Output-based rebates provide economic incentives or subsidies to domestic production for emission-intensive and trade-exposed firms instead of making adjustments at the border to alleviate the effects of emissions regulations on domestic production costs (Fischer & Fox, 2012).

[13] Domestic carbon adjustment policies in India include the National Electricity Policy (2005), the Integrated Energy Policy (2006), the Energy Conservation Building Code (2007), the National Policy on Biofuels (2009), the National Clean Energy Fund (provided by the Finance Bill 2010–11), the National Clean Energy Cess Rules (2010), and the National Electricity Plan (2012) (Banerjee, 2021).

4. The Solution—Developing a Well-Designed CGE Model Framework

This study adapts and builds upon the CGE framework proposed by Pradhan & Ghosh (2012) to design a comprehensive CGE framework that represents the fundamental features of the Indian economy and makes necessary alterations for examining the impact of carbon pricing in a single-country framework. This recursive, dynamic, multisectoral, neoclassical, and price-driven CGE model captures interactions with energy systems. The energy system in this model captures interactions between the energy sector[14] and the rest of the economy through impacts on energy prices and output. The static part of the model is based on Lofgren et al. (2022), while the energy system has been derived by Pradhan & Ghosh (2012) from a combined version of DART 97, EPPA, and EMPAX-CGE models.

In contrast to multi-country CGE models, the standard CGE model by Lofgren et al. (2022) is a single-country static framework, facilitating single-period comparative static analysis. The model allows researchers to evaluate the potential effects of policy changes by comparing the results of the model with and without the policy in place. This allows for a focused examination of country-specific issues without the added complexity of interactions among multiple countries. Additionally, the uncertain and varied responses of countries to CBAM introduce complexity in multi-country CGE models, which requires advanced modelling techniques to capture individual country or regional reactions comprehensively for a thorough analysis of global economic impacts.

Since this study concentrates on the Indian economy, a single-country CGE model is more suitable as it provides a comprehensive analysis of the policy impacts on sectoral growth, income distribution, and trade balance. Additionally, single-country models are easier to calibrate and interpret, which makes them more suitable for addressing domestic economic challenges effectively (Peichl, 2008). Another constraint of working with a multi-country CGE model is that the data structure for the countries is standardised for comparison purposes, which limits the possibilities of disaggregating the SAM to contextualise the issues persisting only in the domestic country. For instance, social groups play a dominant role in India in determining income distribution; however, this is not an issue with other countries, as factors such as race and culture may play a greater role. In this section, we develop the model framework for a single-country CGE model by providing details of the production structure, institutions, international trade, and macroeconomic closures.

4.1 Production Structure

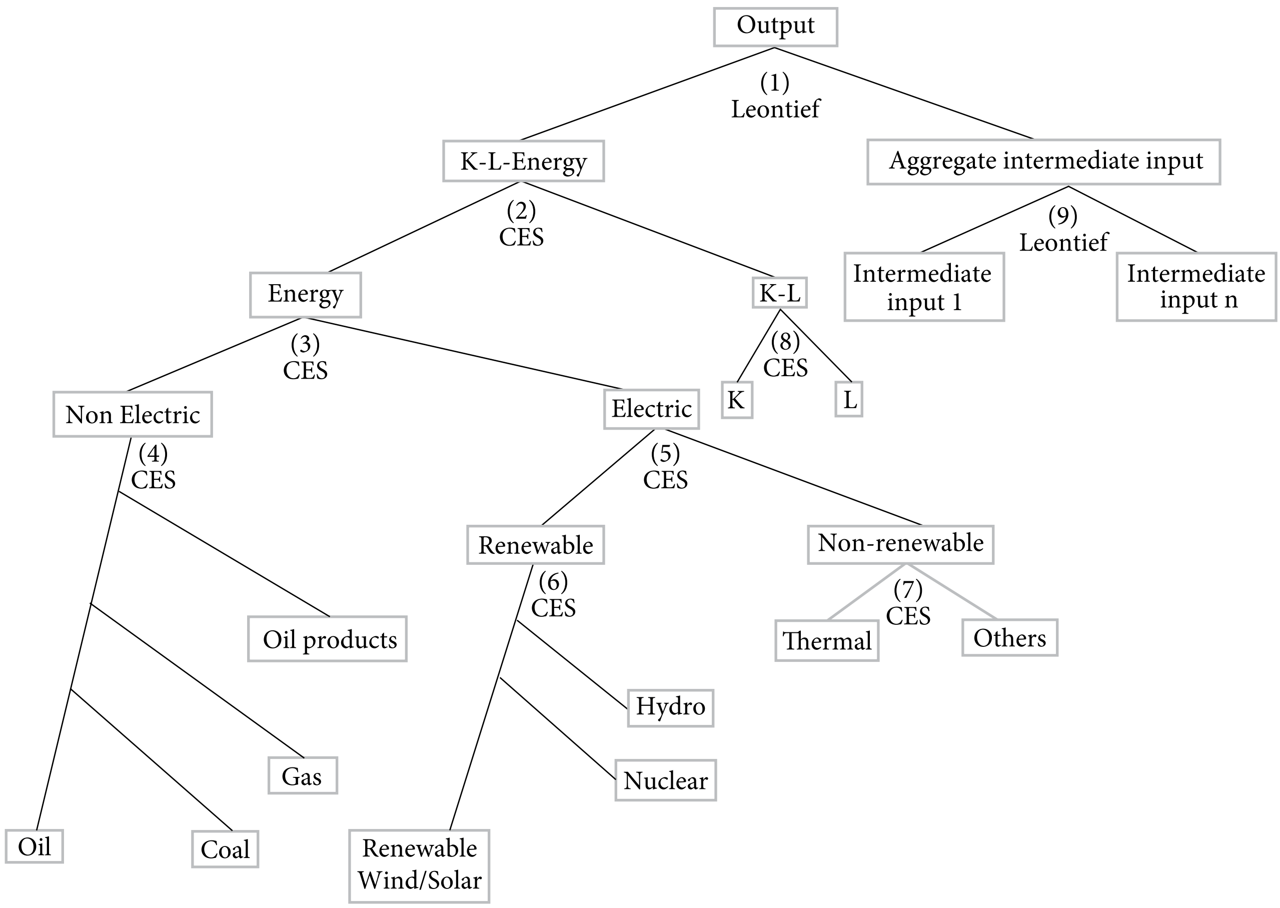
The production structure in CGE models depicts how the production process is broken into parts and how sub-processes are nested within the process. Two separate nesting structures are used to depict the production of non-fossil fuel and fossil fuel sectors (Figures 2 and 3) to capture the varying substitution possibilities of the inputs used in the production processes of these sectors. This is evident from the nesting structure at Node 3 of Figure 2, where the production structure of the non-fossil fuel sectors has been decomposed into electric and non-electric sectors, whereas this is not the case for the fossil fuel sector represented in Figure 3. Such a nesting structure further helps monitor the physical flows of carbon-based fuels and resources in the economy (RTI International, 2008).

In Figure 2, the first node depicts the aggregate output of the non-fossil fuel sector, for which the Leontief function[15] has been used for the capital-labour-energy composite and an aggregate intermediate input. The aggregate of capital-labour-energy has been further decomposed into the energy composite and value-added composite (capital and labour) to account for the substitutability among the value-added and non-value-added inputs at the second node. This provides flexibility for simulating the changes in technology utilised for production processes. For instance, a carbon price levied on an EITE sector will increase the fuel cost, which would incentivise the producer to shift towards a technologically efficient plant that uses less fuel at the margin. Such shifts in technology can be reflected in the CGE framework through the Constant Elasticity of Substitution (CES) production function used at this node. At the third node, the energy composite has been disaggregated into the non-electric composite and the electric aggregate. The non-electric composite has been further decomposed into coal, oil, gas, and petroleum products.

[14] The energy sector here comprises all-electric sectors (hydro, nuclear, wind/solar, and thermal) and non-electric sectors (coal, oil, and gas).
[15] The Leontief production function assumes that the output is be produced using fixed proportions of inputs.

In contrast, the electric aggregate has been bifurcated into renewable electricity (hydro, nuclear, and wind/solar electricity) and non-renewable electricity (thermal and other electricity). This distinction is imperative for representing the substitutability between the two, which is at the core of the energy transition process. The renewable electricity has been decomposed into hydro, nuclear, and wind/solar electricity at the sixth node. The seventh node disaggregates non-renewables into thermal and other thermal electricity. It should be noted that the substitutability between renewables and non-renewables is imperfect because the power generated from renewables suffers from the problem of intermittency of supply—their energy source, such as the availability of sunlight and appropriate wind speed, is non-uniform (Gowrisankaran et al., 2011). The CES functional form has been used for all the nodes mentioned above (from two to eight), as these inputs can be substituted for each other, and CES makes this technically feasible. The Leontief functional form has been used for aggregated intermediate inputs at Node 9.

Figure 2: Production Structure of Non-Fossil Fuel Sectors



Source: Pradhan and Ghosh (2012).

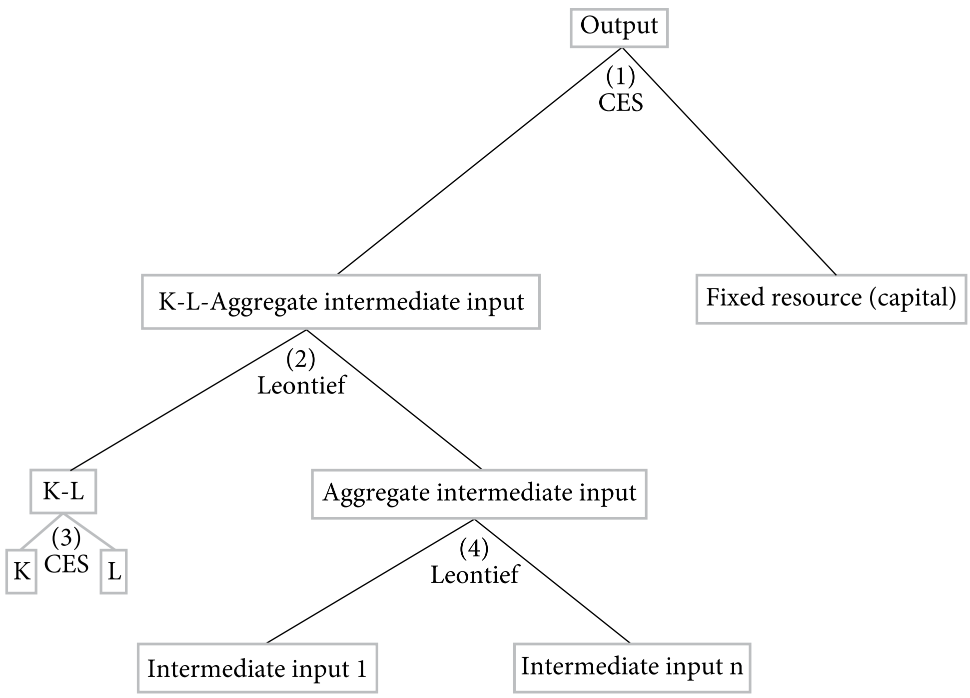
The nesting structure for fossil fuels is represented in Figure 3. Herein, the aggregate output is a CES function of the macro good (a composite of capital, labour, and aggregate intermediate inputs) and the fixed capital resource.[16] At the second node, the Leontief function has been assumed for aggregating the composite of the value added (capital and labour) and the integrated intermediate input into the macro good. At Node 3, capital and labour are combined using a CES function. The aggregate intermediate input is a Leontief function of individual intermediate goods represented at Node 4.

At each node of Figure 2[17] and 3, the micro-theoretic assumption has been incorporated; that is, the producers have been assumed to operate as profit maximisers in a perfectly competitive market, such that they consider factor and output prices (including taxes) as fixed and determine factor demand to minimise the unit production cost.

4.2 Data and Institutions

SAMs are the primary database for CGE models. They are comprehensive economic datasets that represent interlinkages between various economic entities, including producers, households, government, and other institutions. This study utilises CSEP's ESAM 2019–20 for India, published by Chadha et al. (2023), to examine the impact of carbon pricing strategies, such as CBAM and emissions trading permits, on India's emissions-intensive sectors. The ESAM is an extended framework of the standard SAM, which is augmented with information related to energy use and emissions, among other environmental factors. It captures the reciprocal interactions between economic systems and the environment, facilitating *ex-ante* impact analysis of climate-related policy interventions.

Figure 3: Production Structure of Fossil Fuel Sectors



Source: Pradhan and Ghosh (2012).

[16] Fixed fossil fuel resources are specific to the coal, gas, and oil production sectors in each region and play a crucial role in regulating short-term supply, determining the production rate from these resources. Production in the fossil fuel sector relies on natural resources with a fixed supply, leading to an increase in the cost of extracting fossil fuels as they deplete.

[17] For the simulations in the upcoming work, nodes 6 and 7—the further categorisation of renewables and non-renewables have been omitted for simplicity.

CSEP's ESAM 2019–20 for India consists of 45 production sectors, 318 categories of labour and capital, 80 classes of households, and three environmental pollution categories. Labour is disaggregated using region, social groups, household occupation, education, and gender.[18] Households are classified into 80 categories based on their social groups and deciles of annual consumption expenditure across rural and urban regions. The three types of pollution considered are air emissions, wastewater generation, and land degradation.

For this study, the ESAM has been aggregated into 24 production sectors[19] (comprising three fossil fuel sectors—coal, oil, and natural gas—and 21 non-fossil fuel sectors), two factors of production (labour and capital), and 10 households evenly divided based on their quintiles of annual expenditure between rural and urban regions. The SAM also includes institutions such as private enterprises, public enterprises, government, Net Indirect Taxes (NIT), a capital account, and Rest of the World (ROW). The ROW accounts for the export and import of merchandise and services between India and all other countries. These 24 production sectors were selected to distinguish between carbon-intensive sectors and those which are not. For instance, the 24 sectors consist of energy-intensive sectors such as coal, oil, gas, and thermal power; the electricity sector has been disaggregated into renewables (such as wind, hydro, and nuclear) and non-renewables (thermal). Using the CGE model, one can examine the substitutability between these sectors, which is imperative for transitioning towards net zero. Further, the EITE sectors—such as iron and steel, aluminium, and cement—are also included to assess the impact of carbon pricing policies on the Indian economy.

For a meaningful analysis of the *ex-ante* impact of climate policies on poverty and inequality, the aggregated SAM includes elaborative consumption patterns across households consisting of five quintiles each in rural and urban regions of India. Further, both NIT and ROW accounts are disaggregated between EU and non-EU, which attempts to address the missing links in the literature for single-country CGE models that have attempted to examine the impact of policies such as CBAM. This differentiation helps in analysing the impact of CBAM on government revenue and trade. Also, this model could be used for simulating trade diversion possibilities for Indian firms in response to EU CBAM.

The model includes four main institutions: households (divided into rural and urban), enterprises (private and public), government (including NIT), and a foreign institution—ROW. Households maximise utility subject to their incomes and prices. They receive income from supplying labour and capital, as well as transfers from the government and ROW. Households also save part of their income after paying taxes to the government, which is modelled through the linear expenditure system.

Enterprises earn income from the capital factor of production in the form of profits, and they also receive transfers and interest on debt from the government. The remainder of income after paying direct taxes forms part of their savings. Government income is derived from taxes (direct and indirect) and capital in the form of entrepreneurship and the rest of the world. Indirect taxes include Goods and Services Tax (GST), excise duty, import tariffs, sales tax, stamp duty, service tax, and other indirect taxes. Government expenditure encompasses spending on goods and services, transfers to households and businesses, subsidies, and taxes. Thus, government savings are the residual of its income and expenditure.

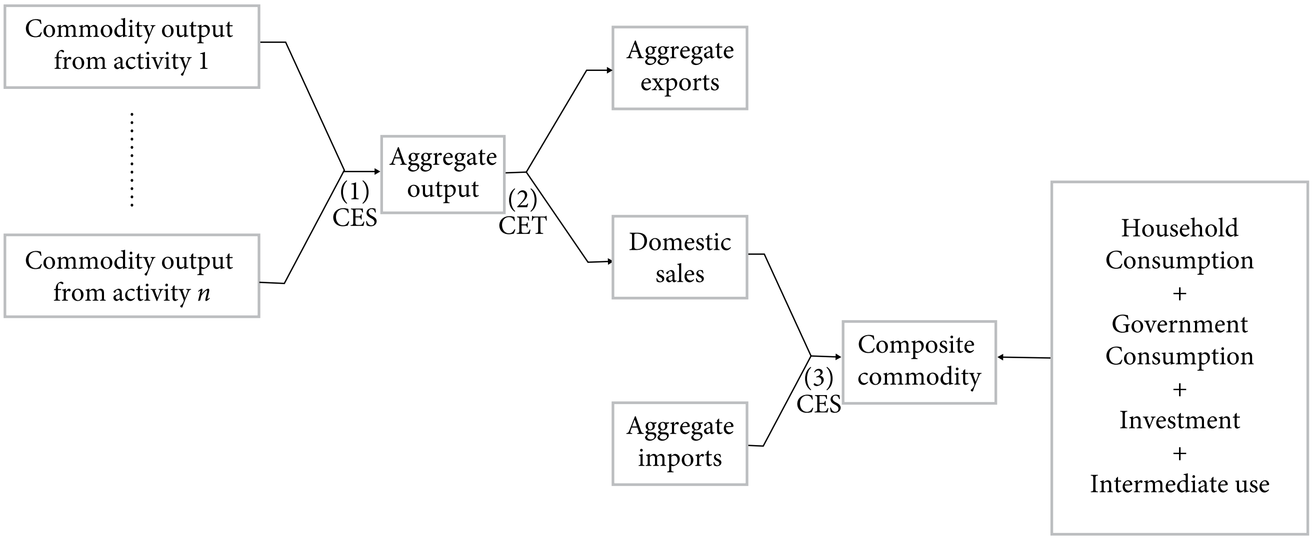
4.3 International Trade

When modelling international trade, the Armington assumption is applied, which represents imperfect substitution between domestic and international goods. This suggests that producers and consumers are free to sell or consume goods from either domestic or foreign markets, depending on the relative prices. The Constant Elasticity of Transformation (CET) function is assumed to allow for the substitution possibilities between the sales of domestically produced goods and services in domestic and foreign markets. The export supply function assigns the amount of exports that depend on the proportion of domestic to export prices. Similarly, total domestic demand, also

[18] There are two regions: rural and urban. The occupation of households in rural areas is categorised based on six classes (self-employed in agriculture; self-employed in non-agriculture; regular wage; casual labour in agriculture; casual labour in non-agriculture; and others). The occupation of households in urban areas has been categorised using four classes (self-employed, regular wage/salary earning, casual labour, and others). Education is divided into illiterate, informal below primary, formal higher-senior secondary, and graduate and above. Gender is divided into male and female Chadha et al. (2023).

[19] A mapping of these 24 sectors to the original 45 sectors is provided in Appendix B.

Figure 4: Flows of Marketed Commodities



Note: At Node 1, the cost of supplying aggregate output is minimised, subject to imperfect substitutability between the outputs from n production activities, represented by a CES function. The CET function at Node 2 is utilised to maximise the producer's sales revenue, given a specific level of aggregate output, considering imperfect substitution for domestically produced goods that are exported and sold domestically. Similarly, at Node 3, the CES function is used to minimise domestic demanders' costs, subject to imperfect substitution between imports and domestic commodities.

Source: Lofgren et al., (2022).

termed a composite commodity, includes domestically produced goods and imports, which are aggregated using a CES function. The Armington function gives the demand for imports which is a function of the domestic and import prices ratio. A schematic representation of the physical flow of marketed commodities under the Armington assumption is represented in Figure 4.

4.4 Macroeconomic Closures

Macroeconomic closure rules are utilised for modelling the constraints in economic systems that result from macroeconomic identities. There are three such balances employed in a CGE model: the equilibrium between government savings and income, the exchange rate and current account deficit for the ROW account, and savings and investments for households. The results of any CGE model depend on the closure rules used. These closures are depicted in Table 2. For the balance in the government account, it is assumed that government consumption expenditure is fixed for a specified period, and after that, two alternative closures are widely used. First, government savings are kept flexible—that is, they are endogenously determined from the model, and direct tax rates for households and enterprises remain constant. The second closure assumes government savings as fixed, and therefore, direct tax rates are kept flexible, with uniform changes for different institutions. There is also a third possibility in which direct tax rates are varied proportionally while keeping government savings fixed.

In the case of the balance in the ROW account, there are only two possibilities. The first closure assumes that foreign savings are constant while the real exchange rate is kept flexible, and *vice versa* for the second closure. Five different closure rules could be employed in the savings-investment balance for households; however, these can be grouped into two broad categories: Investment-driven and Savings-driven. In the former case, real investment is assumed to be flexible, while savings are considered fixed. The latter assumes that household and enterprise savings rates remain flexible, and investment/capital formation is fixed. There can be different possibilities under this scenario, and these depend on various permutations of the change in savings rates for different institutions (refer to Table 2 for more details).

Table 3: Alternative Closure Rule for Macroeconomic Constraints

Government	Rest of the World	Saving- Investment
Government savings are flexible, and direct tax rates are fixed.	Foreign savings are fixed, and the real exchange rate is flexible.	Capital formation is fixed, with a uniform MPS point change for selected institutions.
Government savings are fixed, with a uniform direct tax rate point change for selected institutions.	Foreign savings are flexible, and the real exchange rate is fixed.	Capital formation is fixed, with scaled MPS for selected institutions.
Government savings are fixed, with scaled direct tax rates for selected institutions.		Capital formation is flexible, with a fixed MPS for all non-government institutions.
		Investment and government consumption absorption shares are fixed (with flexible quantities), with a uniform MPS point change for selected institutions.
		Investment and government consumption absorption shares are fixed (with flexible quantities), with scaled MPS for selected institutions.

Note: Among the specified closure rules, selecting one of the three constraints does not limit the choice for the other two. Selected domestic non-government institutions include households and enterprises.

Source: Lofgren et al., 2022.

When deciding on macroeconomic closures, researchers must consider the specific goals and context of their analysis. To accurately measure the impact of CBAM, it is important to choose the most suitable closure rule for the study. For instance, given that China follows a managed float system against major currencies, it would be reasonable to fix the exchange rates while allowing foreign savings to remain flexible to balance external accounts.

4.5 Utilisation of the CSEP-CGE Model Framework

The CSEP-CGE model framework is a single-country, multi-sector model built using the latest ESAM 2019–20 dataset for India. It has been structured to analyse different climate policy scenarios, especially those associated with climate mitigation policies such as carbon taxes, emissions trading schemes, and CBAM. Given that these mitigation policies could lead to a structural transformation in the economy through shifts in production methods, an *ex-ante* modelling framework becomes imperative to inform policymakers about choices and the potential consequences of such actions. In this context, this model serves as a useful tool for evaluating the consequences of various fiscal and other energy transition policies on macroeconomic indicators, such as GDP, employment, price level, trade, welfare, and environmental parameters. The CGE model framework focuses on the sectoral details of the Indian economy, which is likely to bring useful insights while assessing the impacts of such policies on EITE sectors. Moreover, the model facilitates assessment of the effects on poverty and inequality, as this model is coupled with disaggregated data on household expenditure classes. This feature further allows for a more detailed analysis of the socio-economic impacts of climate policies, including insights into distributional impacts.

Additionally, the model is appropriate for analysing the effects of EU CBAM on India. The disaggregation of NIT and ROW into EU and non-EU countries enables examination of the differential impacts of international carbon pricing policies. Some of the policy scenarios that will be useful to examine using this model are:

Scenario 1: No Domestic Carbon Pricing Policy

- Impact on GDP, employment, trade, emissions, inequality, etc.
- Identify redistribution policies to minimise the impacts of CBAM.

Scenario 2: With Domestic Carbon Pricing Policy

- To devise an optimal carbon pricing strategy for India.
- To simulate the generated revenue for technological advancement of the CBAM industries and redistribution.

Scenario 3: Other Policy Responses

- Imposition of equivalent trade measures like tariff and non-tariff barriers.
- To examine the impact of a global carbon policy in curbing emissions efficiently.

This feature of the model can be used to analyse how India might react to these policies, such as by considering the potential for shifting trade away from EU countries and towards non-EU nations.

Like any economic model, the CSEP-CGE model framework relies on assumptions and parameters that may be subject to uncertainties. The study does not appear to provide a detailed sensitivity analysis to assess the robustness of the results to changes in key assumption.

5. Way Forward

The introduction of EU CBAM comes at a critical juncture in global cooperation on trade and climate. It aims to reduce carbon leakage and secure a level playing field for EU producers while potentially reshaping how countries conduct international trade. This paper provides a concise overview of CBAM and the methodologies used in analysing climate mitigation policies, such as CBAM, within the existing literature. It underscores the advantages and drawbacks associated with existing economic models—such as gravity, Input-Output, and accounting approaches—in assessing the impact of CBAM on competitiveness, carbon leakage, and social welfare. While diverse approaches exist in the literature, CGE models emerge as the preferred choice for conducting economy-wide impact assessments of CBAM. Notably, CGE models demonstrate the capability to incorporate interactions with energy systems, enabling the representation of variations in carbon intensity across sectors and accounting for substitutions between carbon-intensive and non-carbon-intensive inputs in production.

The paper provides the structure for a single-country CGE model framework that can examine issues relating to the impact of CBAM on the Indian economy and attempts to address the gap in the literature for single-country CGE models by incorporating the economic and environmental linkages of the CBAM sectors. To delve into the distributive implications of EU CBAM, this model framework incorporates sector-specific classifications for energy-intensive and trade-exposed sectors, household disaggregation, and a breakdown of EU and non-EU countries.

As emerging issues take precedence, there is potential for further expansion and enhancement of this model to capture evolving complexities and considerations within climate policy analysis. The distinction based on the disaggregated NIT and ROW accounts is crucial for our long-term research agenda, which will enable us to focus on specific economic sectors and their interactions with the rest of the world in the context of environmental policies. The proposed CGE model framework will also help examine the impacts of policy interventions—with and without those interventions perceived as crucial for an inclusive development agenda for the Indian economy. Future studies will delve into the issues surrounding CBAM, the efficacy of carbon pricing, and taxation alternatives for revenue mobilisation to fulfil energy transition goals, among others.

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Appendix

Appendix A: List of EU CBAM Sectors and Associated Greenhouse Gases

Sectors	Greenhouse Gases
Iron and Steel	Carbon dioxide
Aluminium	Carbon dioxide and perfluorocarbons
Cement	Carbon dioxide
Fertilisers	Carbon dioxide and nitrous oxide
Chemicals	Carbon dioxide
Electricity	Carbon dioxide

Source: European Commission, (2023).

Appendix B: Concordance Between CGE SAM and CSEP ESAM Production Sectors

Sl. No.	CGE SAM	CSEP ESAM
1	Agriculture	Paddy
		Agriculture
		Livestock
		Forestry and Logging
		Biomass (energy)
		Fishing & Aquaculture
2	Coal and Lignite	Coal and Lignite
3	Crude Petroleum	Crude Petroleum
4	Natural Gas	Natural Gas
5	Non-Fuel Mining	Iron Ore
		Manganese Ore
		Bauxite
		Copper Ore
		Other Metallic Minerals
		Limestone
		Other Non-Metallic Minerals
6	Petroleum Products	Petroleum Products – Combustible
		Petroleum Products – Non-Combustible
7	Fertilisers	Fertilisers
8	Chemicals	Chemicals
9	Cement	Cement
10	Iron and Steel	Iron and Steel
11	Aluminium	Aluminium

Sl. No.	CGE SAM	CSEP ESAM
12	Other Manufacturing	Food and Tobacco
		Textiles and Leather
		Wood and Wood Products (Except Furniture)
		Paper, Pulp, and Print
		Rubber and Plastic Products
		Non-metallic Mineral Products
		Non-ferrous Basic Metals (and Alloys)
		Machinery
		Transport Equipment
		Industry NEC
13	Construction and Construction Services	Construction and Construction Services
14	Coal Electricity	Coal Electricity
15	Other Thermal Electricity	Other Thermal Electricity
16	Hydro (Large) Electricity	Hydro (Large) Electricity
17	Renewable Energy Sources Electricity	Renewable Energy Sources Electricity
18	Nuclear Electricity	Nuclear Electricity
19	Railway Transport	Railway Transport
20	Land Transport	Land Transport
21	Water Transport	Water Transport
22	Air Transport	Air Transport
23	Transport NEC	Transport NEC
24	Services	Commerce and Public Services

Source: Authors.

About the authors

Rajat Verma is an Associate Fellow in CSEP. He specialises in Input-Output/SAM Modelling and ecological taxation. He recently published a book titled "Fiscal Control of Pollution: Application of Ecotaxes in India", wherein he critically examined the theoretical and pragmatic application of optimal rates of ecotaxation and their distributional impacts on households in India. In addition to his interest in Public Finance, he has also published innovative research papers on environmental taxes and international trade. He received PhD in Economics with a specialisation in Environmental Economics from the Institute for Social and Economic Change (ISEC), Bangalore which is affiliated with the University of Mysore.

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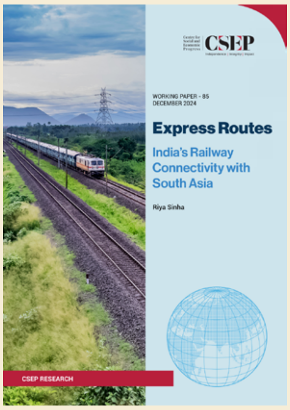
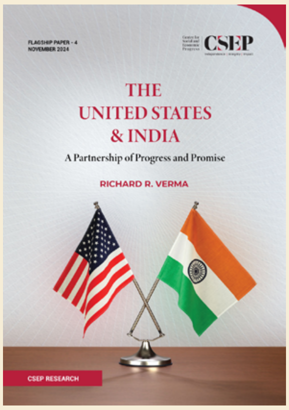
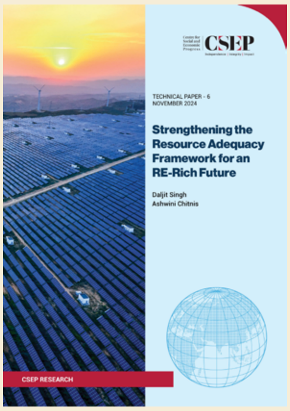
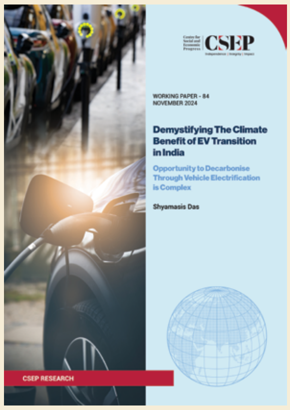
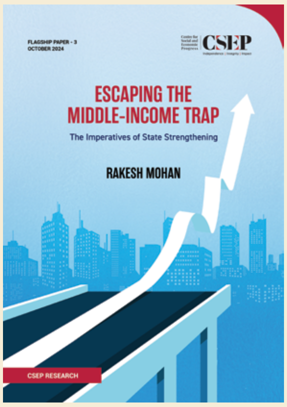
Other publications

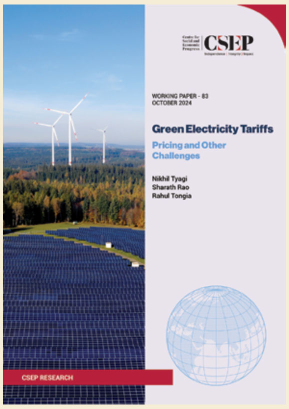


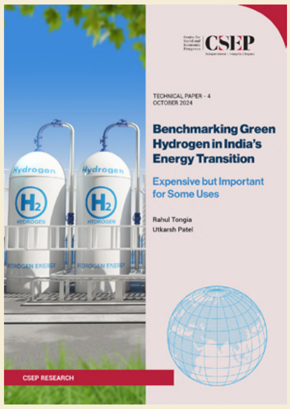


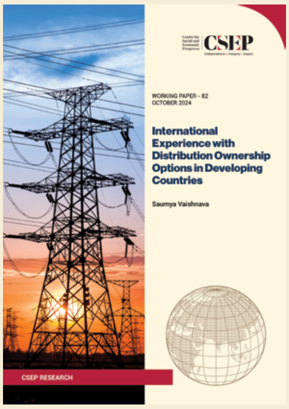


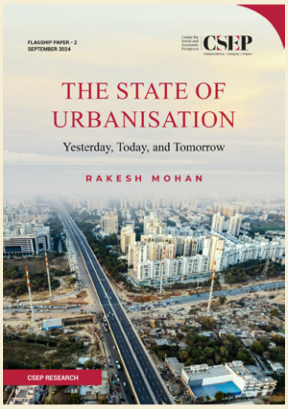


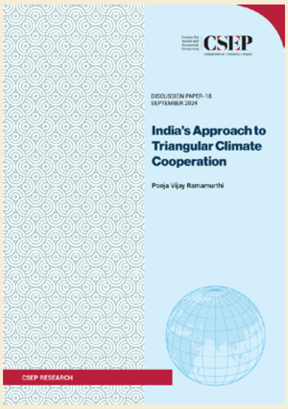


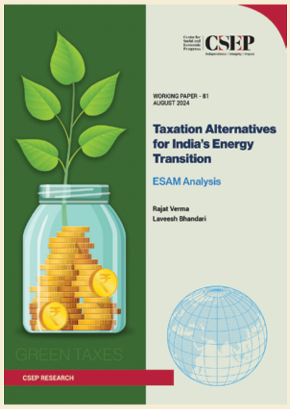


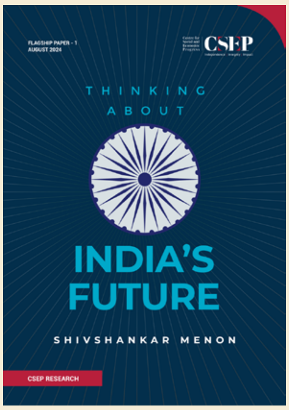


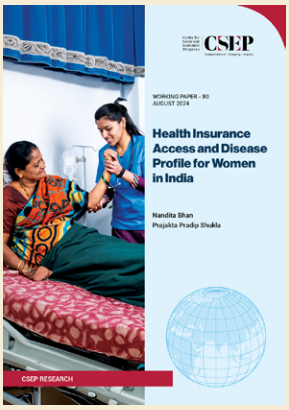


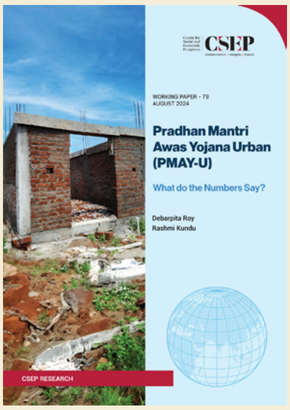












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