INDIAN INSTITUTE OF FOREIGN TRADE

WPS No. EC-21-56

WORKING PAPER

ESTIMATION OF CARBON EMISSIONS EMBODIED IN INDIA'S EXPORTS

Shifali Goyal
Areej A. Siddiqui

Working Paper Series

Aim
The main aim of the working paper series of IIFT is to help faculty members share their research findings with professional colleagues in the pre-publication stage.

Submission
All faculty members of IIFT are eligible to submit working papers. Additionally, any scholar who has presented her/his paper in any of the IIFT campuses in a seminar/conference will also be eligible to submit the paper as a working paper of IIFT.

Review Process
All working papers are refereed

Copyright Issues
The copyright of the paper remains with the author(s).

Keys to the first two digits of the working paper numbers
GM: General Management
MA: Marketing Management
FI: Finance
IT: Information and Technology
QT: Quantitative Techniques
EC: Economics
LD: Trade Logistics and Documentation

Disclaimer
Views expressed in this working paper are those of the authors and not necessarily that of IIFT.

Printed and published by
Indian Institute of Foreign Trade
Delhi Centre | IIFT Bhawan, B-21, Qutab Institutional Area, New Delhi 110016
Kolkata Centre | 1583 Madurdaha, Chowbagha Road, Borough XII, Kolkata 700107

Contact: workingpapers@iift.edu

List of working papers of IIFT
See end of the document

Series Editors
Dr. A K S Chand, Dr. Neha Jain, Dr. Sugandha Huria

WPS No. EC-21-56

Estimation of carbon emissions embodied in India's exports

Shifali Goyal* & Areej A. Siddiqui**

ABSTRACT

This study tries to estimate the carbon emissions embodied in India's exports to five of its major trading partners, i.e.USA, UAE, Hong Kong, China and Bangladesh, for the year 2015.In order to quantify the same, Bilateral Trade Input-Output (BTIO) model is being used. The study found huge emission embodiment in India's exports, and also calculated the emission intensity of the goods exported. Once the calculation of emissions embodied in exports is done, the paper further highlights that carbon emissions embodied in India's exports is not determined by just the quantum of the goods exported, but composition of goods traded and emission intensity of the traded goods also have a substantial impact over emission embodiment. Hence, the study suggests to shift India's energy consumption patterns from carbon intensive ones to the cleaner and renewable ones, and to reduce its emission intensity

JEL Classification: C67, F18, F64, Q56.

Keywords: Carbon emissions, Bilateral Trade, Input-Output Analysis, Bilateral Trade Input-Output Model (BTIO)

* Research Scholar, Indian Institute of Foreign Trade, New Delhi. Email: shifali_phd2019@iift.edu

** Assistant Professor, Indian Institute of Foreign Trade, New Delhi. Email: areej@iift.edu

Estimation of carbon emissions embodied in India's exports

1. Introduction:

Rising carbon emissions and climate change is one of the world's most concerned challenges in recent times. Since pre-industrial times, average global temperature has increased by more than 1℃ and to fight this rising global temperature and climate change, UN member countries have agreed and set a target in the Paris Agreement, of limiting the average global warming to 2℃above the pre-industrial temperature levels. This sharp increase in global average temperature is largely because of rising emissions of greenhouse gases of which one major component is Carbon emissions[1] which generally stem from burning fossil fuels, cement manufacturing, produced during consumption of gas, liquid and solid fuels, gas flaring, etc.[2]. Carbon emissions are the major cause behind human induced global warming and hence climate change (as human activities are major reason of climate change), which needs more attention across the world[3]. Contribution of countries in global CO^2 emissions is generally measured on the basis of production of carbon emissions within their territory.Major international organizations like IPCC which aims at reducing the carbon emissions and keeping them within the pre-determined limits held countries accountable for the carbon emissions produced within their respective domestic territory and not for carbon emissions that are being consumed by the country. However over decades the trajectory of carbon emissions of countries has changed massively, as since 1751 up till mid-20th century carbon emissions were largely concentrated among developed countries especially the European Union (including UK) and the USA as they accounted for majority of carbon emitted globally, but since mid-20th century share of emissions of developing countries started rising, while many of the historically largest emitters are no more the largest emitters today (Ritchie Hannah, 2019)[4].

As per the data retrieved from World Bank WDI indicators and Global Carbon Atlas, since many years global carbon emissions are dominated by China, the United States, the European Union (all member countries), India, Russia and Japan. Hence on the basis of many guidelines proposed for reporting and reducing the emissions, these largest carbon emitting nations are also burdened by hugeinternational pressures to restrict their production of emissions and take necessary steps in order to combat climate change. In recent years, many developed countries including USA, Germany, United Kingdom, etc. haveclaimed that they have actually decoupled their carbon emissions and economic growth. However, in today's world, countries are not only trading the goods and services but also trading the carbon emissions in terms of trade embodied carbon emissions. In other words, since many developed countries have shifted their manufacturing units to various developing countries, thereby instead of producing carbon emissions domestically, developed countries have outsourced their carbon emissions to developing countries, as a result of which they are consuming carbon emissions even by relatively lowering their production of the

[1] The Paris Agreement, United Nations Climate Change. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

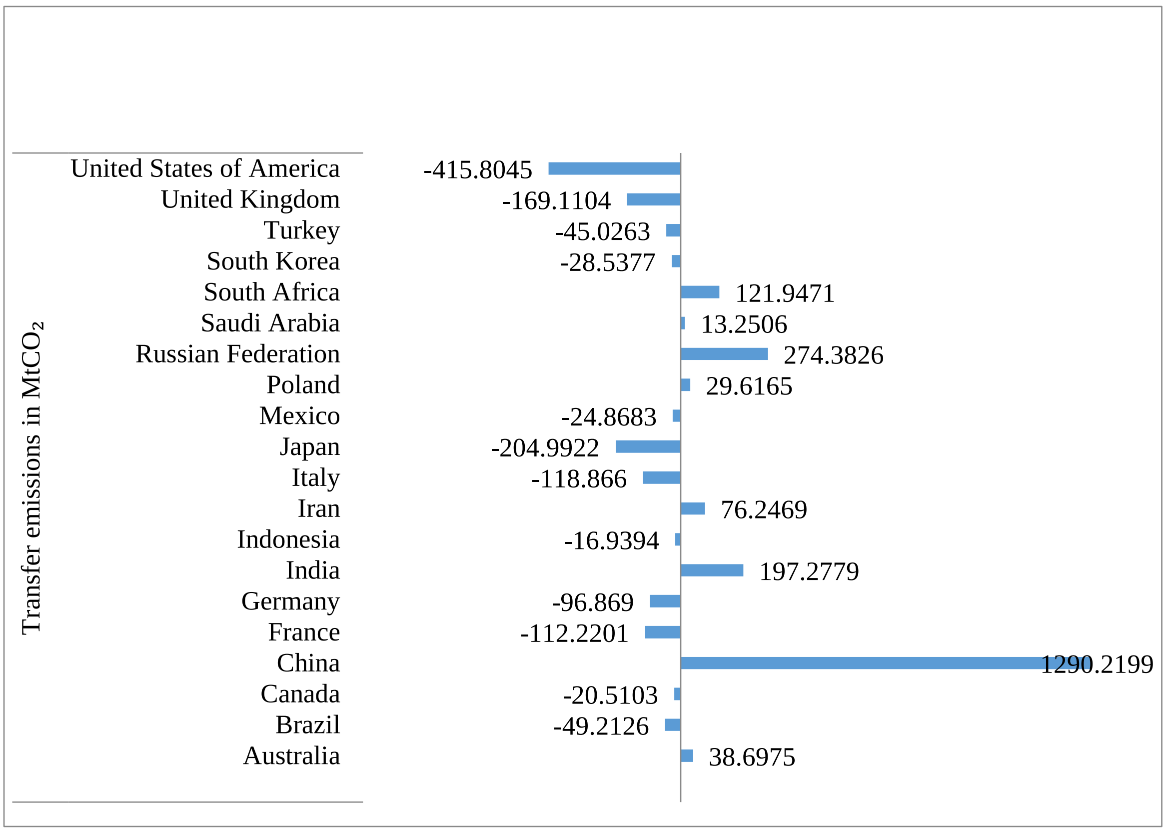
[2]https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_emissions#:~:text=Carbon%20dioxide%20emissions%20or%20CO,as%20well%20as%20gas%20flaring.

[3] Causes of Climate Change, accessed from: https://www.canada.ca/en/environment-climate-change/services/climate-change/causes.html

[4]Ritchie Hannah, 2019. Who has contributed most to global CO2 emissions? Available at: https://ourworldindata.org/contributed-most-global-co2

same. Whereas the emissions produced by say China, India (two of top three largest carbon emitting nations) are not meeting only their domestic needs and demands, but a larger part of their produce and carbon emissions are attributed to their trading partners as well. Hence, international trade is considered as an important determinant of carbon emissions (greenhouse gases in general) produced and consumed globally, and an important factor of adopting the consumption based carbon accounting approach. Figure 1 below indicates the Transfer emissions in MtCO2, i.e., it shows the net emissions transferred after taking into account the component of international trade. It clearly shows that out of all the top 20 carbon emitting and consuming countries, China has maximum transfer of emissions out of its territory which are followed by Russian Federation and India, whereas the United States, United Kingdom, Japan, etc. being net importer of carbon emissions.

Figure 1. Carbon emissions transfers in MtCO2 (2017)



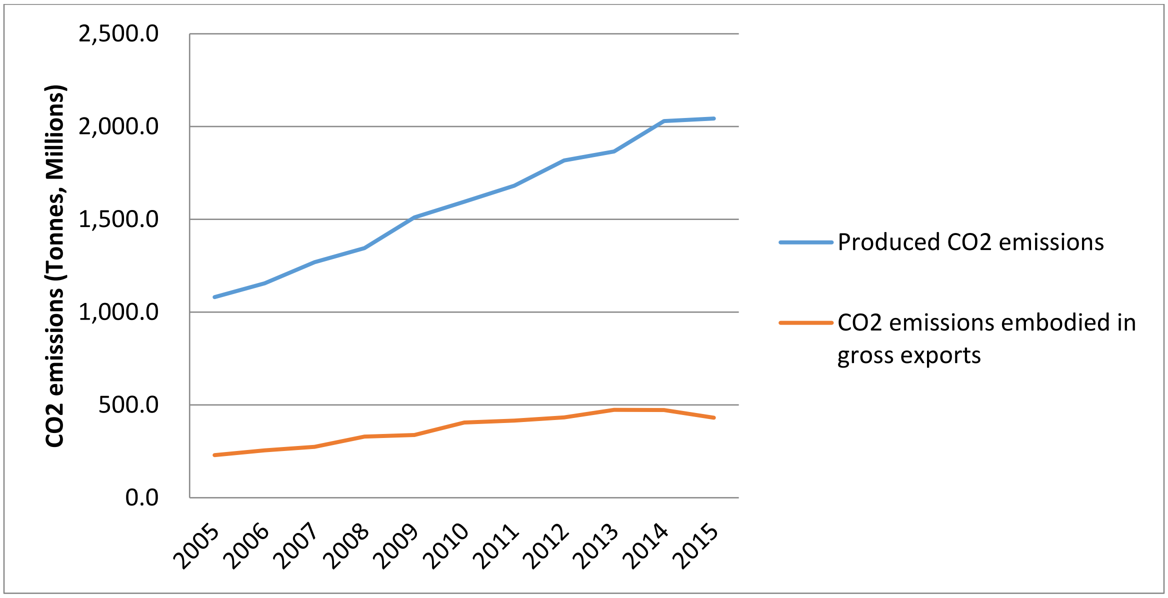
Source: Global Carbon Atlas

India too has witnessed a dramatic rise in carbon emissions since past few decades, and carbon emitted by India has increased massively, as is evident from share of India's emissions of global carbon emissions which has increased sharply from 2.6% to 6.3% from 1990 to 2015[5], and subsequently India has turned out as the third largest carbon emitting country after China and the USA. India is not consuming all the carbon emissions that it produces, as a part of emissions produced by India are transferred to countries abroad and India is a net carbon exporting country. It was especially during liberalization that net export of emissions from India took place, as carbon emissions transfer as a share of carbon emissions produced in India

[5] Author's own calculations on the basis of data retrieved from International Energy Agency (IEA) https://www.iea.org/data-and-statistics?country=INDIA&fuel=Energy%20supply&indicator=TPESbySource

increased from 0.177% in 1990 to 8.34% in 2015[6], which highlights that carbon emissions exported from India to rest of the world. In addition to this, as per recent data collected from OECD stats, India's production of carbon emissionsincreased continuously and in 2015 reached almost double the level as in 2005, and so is the case of carbon emissions embodied in its gross exports to world. Figure 2 below shows the trends in carbon dioxide emitted within India's domestic territory and the emissions which are embodied in its gross exports. As per data, 21-26% of emissions produced have been exported by India to the world outside, which highlights the important role international trade plays within a nation's environment.

Figure 2: India's total Carbon emissions based on production and Carbon emissions embodied in its gross exports.



Source: OECD. Stat

Over the past few years, there have been numerous studies which have been examining how international trade impacts the carbon emissions produced by the countries, carbon emissions embodied in their international trade, etc. Since India has emerged as an important trading partner globally and also holds an important place when it comes to carbon emissions production, consumption and trade, and since demand for Indian produce keeps on rising in international markets, hence it becomes important to understand and analyze how this demand of Indian products affect the carbon emissions in India, i.e. how India's international trade with its trading partners impacts the carbon emissions embodied in India's exports. This study intends to answer the presentquestion by analyzing and estimating the carbon emissions which are embodied in India's exported merchandise goods to its major export destination countries. For this purpose we will be estimating carbon emissions embodied in India's exports to its 5 major export destinations, which are USA, UAE, China, Hong Kong, and Bangladesh[7]. This will help us analyze and estimate the part of carbon emissions produced in India, but are not consumed here and exported to trading partners in the form of carbon emission embodied in India's exports to some of its major trading partners. So in order to better estimate the emissions embodied in India's exports, this paper is divided among various sections, where Section 2 of the paper discusses about available literature on trade and environment nexus, Section 3 sheds light upon the model used to estimate the trade embodied emissions, followed by Section 4 on the

[6] Author's own calculations on the basis of data retrieved from Global Carbon project.

[7]These are India's 5 major export destinations as per India trade portal 2018-19

data sources used in this study to collect the relevant data and theMethodology used. The Results so obtained by from the analysis are discussed in Section 5. In the Section 6 conclusions are drawn and on the basis of results policy recommendations are given.

2. Literature Review

2.1. Theoretical Review:

Since decades, a large strand of literature discusses environmental impacts of certain economic activities, including international trade. Levinson A. (1996) have argued that the debate and hence literature on relationship between trade and environment was sparked in 1970s with the adoption of environmental regulations in developed countries which was further developed in 1990s with the debate of environmental impacts of trade agreements like NAFTA. Many scholars have worked extensively, in order to explain the relationship between various aspects of environment and different strands of economics, including international trade and environment.

One such remarkable paper in the area of international trade and development is (Grossman & Krueger, 1991) which found the presence of inverted U shaped relationship between air quality and economic growth for two pollutants i.e. smoke and sulphur dioxide. This was analyzed using a cross-sectional study of three comparable pollutants in urban areas of 42 countries. While estimating the likely environmental impacts of NAFTA, duo decomposed the environmental impact of Trade among three effects: scale effect, composition effect and technique effect. Scale effect reflects an increase in pollution created by trade as it increases economic activity. Composition effect reflects the change in pollution due to change in composition of goods produced in a country (which may be environmentally bad if produces more energy intensive goods and has lax or no environmental regulations). Trade may benefit environment, as free and liberalize trade increases the availability of cleaner technology, then technique effect as per which output need not be produced in a manner similar to pre liberalization/free trade, may improve energy efficiency and can help fight rising emissions of GHGs(Grossman and Krueger, 1991; Copeland and Taylor, 1994; Antweiler et al. 2001). Hence, stresses the fact that emission embodiment in trade is not determined entirely by the quantum of goods traded, but also by various other effects, i.e. scale, composition and technique effects too.

Three major theories in environment and trade/economic growth available in literature are Environmental Kuznets curve, pollution haven hypothesis and carbon leakage. Environmental Kuznets curve explains the relationship between environmental degradation and economic growth, propounded by Grossman and Krueger (1991), where they found the existence of bell shaped relationship between per capita income and environmental degradation, similar relationship was also found by Shafik and Bandyopadhyay (1992), Panayotou (1993). Since then it has been studied widely, though no conclusive consensus yet, has been achieved.Another remarkable hypothesis in literature is Pollution haven hypothesis, which posits that industrialized countries with relatively higher environmental standards as compared to low environmental standards in developing countries and LDCs, may lead to shift of dirty or pollution intensive industries to low environmental standards countries, also known as the industrial flight hypothesis, which has been discussed in literature since 1970s, withno conclusive result yet (Dean, 1992).

Another important theory which highlights the Environmental debate in context of North-South trade is Carbon leakage. As per Kyoto protocol (December 1997) carbon emissions reduction targets among developed and developing countries were allocated unevenly as the Annex 1[8](developed) countries were

[8] Annex I or Annex B countries include those industrialized countries which were members of the OECD in 1992, and also the countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

legally obliged to limit their GHG emissions, however Non-Annex 1 (or developing) countries were exempted from such legally binding targets, and instead they were allowed to adopt voluntarily a national GHG emissions mitigation policy. However, it created concerns and debates over how effective binding GHG emissions targets for developed countries will be in lowering the global emissions, and also raised concerns and possibility of carbon leakage (Kuik and Gerlagh, 2003; Aichele and Felbermayr, 2011).

Grossman and Krueger (1991) studied the environmental impacts of NAFTA and decomposed theminto: scale , composition and technique effect. .

Many researchers have stressed upon the need of putting attention towards trade embodied carbon emissions. The term embodied carbon refers to those carbon emissions which are emitted at all the stages of a product's production right from the mining of raw materials through its distribution to the end consumer, i.e. carbon emissions which are emitted during a good's entire production and distribution process is called 'embodied carbon' (Wyckoff and Roop, 1994). Trade embodied carbon emissions can be put as: when one country imports goods/services it not only imports that very product, but it also imports those carbon emissions which are embodied in that product, as the exporting country also emits the carbon while producing the goods and/or services meant for exports.

In the literature, most common approach to estimate trade embodied emissions has been Input-Output analysis, which was first introduced by Wassily Leontief in 1930s. Since then, it has been extensively studied and extended to various strands like energy economics, trade and environmental aspects, etc. Estimation of embodied carbon emissions has been done using the Environmentally extended Input-Output analysis, under which there are three approaches that are widely used across literature to calculate the carbon emissions embodied in international trade, which are: Single Region Input-Output (SRIO) Model, Bilateral Trade Input-Output Model (BTIO) or Emissions Embodied in Bilateral Trade (EEBT) Model and Multi Regional input-Output Model (MRIO), (Sato, M. (2012)).

2.2. Empirical Review

Some of the studies which have been cited in literature review have also been tested empirically. . Some of the most useful empirical studies which have helped in drawing the objective and framework of study are discussed here.

Shunsuke et al. (2008) found trade to be beneficial for environment for the OECD countries, while it detriments the environment in non-OECD countries. Sun et al. (2019) examined the trade and environment nexus for 49 high-emission countries (further divided on the basis of income level and region) in Belt and Road region using panel analysis for time period 1991-2014 and found trade significantly increases the carbon emissions in majority of developing Asian and African economies, whereas for East Asian and European economies found an inverse and significant relationship b/w trade and carbon emissions. Shahbaz et al. (2017) to analyze relationship between trade, environment and economic growth, used a panel of 105 countries and found trade openness impedes the quality of environment. Peters and Hertwich (2008) analyzed trade embodied emissions for 2001 and found Annex B countries to be net importers of carbon emissions, while non-Annex B countries be netexporter. Peters et al. (2011) developed a global database of trade linking the carbon emissions for 113 countries covering years 1990-2008. They have found that consumption of emissions in most developed countries have increased faster than their production of emissions, and opposite is the case in developing countries, and found net emission transfer from developing to developed countries have increased significantly over the time. Pie et al. (2018) have found that it is the import and export of goods, which are found to be related to the CO2 equivalent levels and not the international trade of services. Yanmei et al. (2014) studied the sources and flows of carbon emissions embodied in imports and exports of China. To calculate carbon emissions embodied in international trade of China with respect to other 112 countries, methodology used is I-O methods, for which authors used GTAP (version 7) database. The study revealed carbon embodied in China's exports than those embodied in imports are much larger, making China a net exporter of carbon emissions. They argued if international negotiations for dividing carbon emissions responsibility are to be implemented, then major importers of China's carbon emissions also need to be held accountable of the same.Liu et al. (2009) analyzed the trade embodied carbon emission of Japan-China trade. This study estimated embodied emissions using input-output model and using scenario analysis also estimated how bilateral trade b/w the two nations impacts the carbon emissions. Using I-O framework, they found Chinese industries to be much more carbon-intensive than those in Japan, and as per hypothetical scenario bilateral trade was found to be beneficial in lowering the carbon emissions. Wang et al. (2019) examined the carbon emissions embodied in China and Australia trade. Using the input output analysis, they calculated the trade embodied emissions for years 2000-2014, and found net outflow of embodied emissions from China to Australia during the same period has increased. They also found trade b/w China and Australia is highly concentrated, where net emissions outflow from China to Australia are largely concentrated in heavy manufacturing sectors and textile, while China's inflow of emissions are mainly attributed to primary sectors. For 2015-2022, the authors proposed a procedure in order to forecast the bilateral trade embodied emissions b/w the two.

India has emerged as the third largest carbon emitting and carbon consuming country in the world. At the same time, India is also the third largest net carbon exporter in the world, i.e. it produces more carbon than that it consumes, and exports the excess to other countries. However not many have discussed the Trade and Environment Nexus (from the perspective of trade embodied carbon emissions, carbon leakage, etc.) for India, however there exists some studies which discuss this relationship and environmental impact of trade for India.

Wang et al. (2018) examined the India's production and consumption of carbon emissions for 2000-2014 using MRIO model and found constantly increasing production and consumption of carbon emissions over the period. Mainly its developing countries from which India imports its carbon emissions, whereas India exports emissions to developed countries. They also found intermediate products contributed the most to India's import and export of carbon emissions which are largely embodied in manufacturing products, hence to mitigate emissions India need to improve its energy efficiency.

Banerjee, Suvajit (2020) examined the India's bilateral trade embodied carbon emissions with one of its trading partner United Kingdom (UK) using the EEBT (Emissions Embodied in Bilateral Trade Approach). This study found Indian manufacturing to be highly dependent over more emission intensive energy sources and also argued in favour of possibility of carbon leakage as UK is able to lower its emissions wheras opposite be case in India, and also argued that with more India-UK trade in future, it will result more carbon emissions in the environment.

Wang and Yang (2020) studied the carbon emissions which are embodied in China-India trade (the two major carbon emitting countries in the world) using MRIO for 2000-2015. They found China to be net exporter of both trade and embodied carbon emissions in China-India trade.

(Wang & Zhou, 2020) examined the carbon emissions of China and India for years 2000-14 and found them to be two major source of global emissions over the period, however tendency of the same varies across the two countries.Using Structural decomposition analysis (SDA) they found growth of emissions in China slowed down post 2008 financial crisis largely because of slowdown in Chinese economic growth and the efficiency gains there, however structure effects there lead to rising emissions. However in India, emissions were slightly reduced by structural effects, but scale effect and low emission efficiency promoted emission growth there.

Banerjee, Suvajit (2021) quantified the carbon emissions embodied in India's trade with UK and the US for 2011-14 to examine presence of carbon leakage and also used decomposition analysis. This study found highly carbon intensive consumption pattern of India as compared to US and UK, highlighlighting presence of carbon leakage and decomposition analysis highlighted that emission imbalance is mainly due to emission intensity of output in the three nations.

Though estimation and analysis of carbon emissions embodied in international trade is now being studied widely, however at least in India, it is still at a very preliminary stage. Very few and limited efforts so far have been made in order to estimate the emissions embodied in India's biltateral trade. This study tries to fill this gap as it will contribute to limited but rising literature on carbon emissions embodied in India's bilateral trade with its various trading partners, as so far this study has been done mainly for India and its bilateral trading partners like UK, US, China.

3. **Model**:

In literature, to calculate the carbon emissions embodied in international trade (or embodied in exports in particular) the most commonly used approach has been Input-Output analysis, as this has been considered as the best method to calculate the energy consumption and carbon emissions embodied in imports and exports of a nation. This technique of Input-Output analysis was first introduced by Wassily Leontief in 1930s in order to verify the Heckscher-Ohlin model of International trade. Since then, this method has been extensively studied and extended to various strands like energy economics, trade and environmental aspects, etc. In the Environmentally extended Input-Output analysis, there are three approaches that are widely used across literature to calculate the carbon emissions embodied in international trade, which are: Single Region Input-Output (SRIO) Model, Bilateral Trade Input-Output Model (BTIO) or Emissions Embodied in Bilateral Trade (EEBT) Model and Multi Regional input-Output Model (MRIO). All the three models have been used widely in the literature but this study uses Emissions Embodied in Bilateral Trade (EEBT) Approach in order to measure the carbon emissions embodied in India's exports to its various leading trading partners.Since as compared to SRIO and BTIO, MRIO model extends this I-O analysis at multi-regional levels, andconsider imports of final consumption goods as different from imports of intermediate consumption, hence at least theoretically MRIO approach has been considered as the best among three in order to quantify the emissions embodied in trade (Peters and Solli, 2010) but owing to its complex methodological and data requirements this approach is not being used here. SRIO model on the other hand is quite narrow as it takes one single country and while estimating its emissions embodied in trade, aggregates rest of the world as one region and alsoassumes same production technology in both home country and rest of the world. Whereas BTIO model while estimating emissions embodied in trade of a country with its trading partners, decomposes its trade by trading partners and also relaxes the assumption made in SRIO above and is also quite simple to use as compared to MRIO. Since BTIO model is being considered as relatively transparent, analytically simple and requires lesser data than MRIO and more extensive than SRIO, hence considered more superior among three by (Peters and Hertwich, 2008; Jayanthakumaran& Liu, 2016; etc.) Hence this study uses BTIO/EEBT approach while estimating the carbon emissions embodied in India's exports, which is explained below.

This study starts with the basic Input-Output framework, as per which total output of India is as follows:

$$Y= Z + X, \qquad \text{(eqn. 1)}$$

where Y is the total output of the country, Z is theintermediate consumption and X is the volume of final consumable goods (meant for both domestic and overseas consumption), or more extensively it can be denoted as: $Y^I = A^I Y^I + x^I + e^I$, where Y^I is the total output of India, A^I is the coefficient matrix of India's intermediate consumption, $x^I$is the final demand output of India and e^Ibe its export output.

Alternatively the above equation can be written as:

$Y = (I – A)^{-1} .X$, (eqn. 2)

Where $(I – A)^{-1}$ is the Leontief Inverse matrix, which explains the sectoral interdependence in the economy. Banerjee, S. (2020) has stated that, if in above equation X is the volume of final consumable goods and if A is domestic input coefficient matrix of any economy (say India here), in that case Y can be represented as the calculated total manufacturing of commodities in that respective country, so as to make available the amount of X for final consumption.

As final consumable goods in any country are either being consumed domestically or exported, hence it implies carbon emissions produced in any country are either emitted while domestic production of goods and services meant for domestic consumption within the concerned economy, or they are there in the form of carbon emissions embodied in say India's exports to other countries. From the perspective of trade and the carbon emissions, basic I-O framework has been extended and the equation for the same is expressed as:

$EEY = E^I (I – A^I)^{-1} Y$, which represents the emissions embodied in the final product Y, and using the same we can calculate the emissions embodied in production of commodities meant to be exported to some other country, which is expressed as:

$EEX = EC^I (I – A^I)^{-1} EX$ (eqn. 3)

Where EEX represents the carbon emissions embodied in India's exports to some other country or region (i.e. emissions which are embodied in production of commodities which are meant for export to some other economy). EC^Irepresents the direct carbon emission coefficients of 'n' different sectors of Indian economy per unit output of respective sector. EC^I is a row vector of dimension (1*n) which is expressed as $EC^I = (EC^I_1, EC^I_2, EC^I_3, \dots\dots\dots ,EC^I_n)$ and represents the vector of energy coefficient per unit output of each sector. When Emission coefficient matrix is multiplied by the Leontief inverse matrix i.e. $(I – A^I)^{-1}$, the resultant $E^I (I – A^I)^{-1}$ represents the row vector (1*n) of full energy consumption which is nothing but the total energy that is consumed both directly and indirectly while producing each unit of the product. EX in the equation above which is a column vector (n*1) can be defined as the matrix of sector wise volume of export (of the n different sectors) from India (here) to its respective trading partner. And the total Emissions embodied in exports i.e. EEX are thus calculated by multiplying the full energy consumption matrix with the final production of sectoral exportable products. In a similar fashion Emissions embodied in Imports can also be calculated, however since this paper is concerned about emissions embodied in India's exports, hence we will leave the concept of emissions embodied in imports for now.

The sector wise energy coefficients per unit output represented by $EC^I = (EC^I_1, EC^I_2, EC^I_3, \dots\dots\dots, EC^I_n)$ above need to be calculated in order ultimately calculate the emission embodiment. This can be calculated by multiplying the sector wise energy coefficients, i.e.E^I_i for sector I, with the inverse of sector wise total output i.e. $(x^{\sim}*)^{-1}$, in order to calculate the sector wise energy coefficients per unit of output, which can be expressed as:

$EC^I_i= E^I_i*(x^{\sim}*)^{-1}$

where, $(x^{\sim}*)^{-1}$ = inverse of Gx˜G', as discussed in Appendix A, and calculation of EC^{I}_{i} in Appendix B below.

Now, further these energy coefficients, i.e. $E^{I}_{i} = (E^{I}_{1}, E^{I}_{2}, E^{I}_{3}, \ldots\ldots, E^{I}_{n})$ can be calculated by multiplying the sector wise consumption of six different energy inputs (inputs included in this study includes: Primary coal and peat, Coal and Peat products, Oil products, Natural Gas, Bio-fuels and waste, and Electricity[9]) which are used while producing the output in the 'i'th sector along with the calculated carbon emission intensities of the respective energy input. So energy coefficient of sector i will be calculated as:

$$\mathbf{E_i^I} = E_{i1}{}^{I}\, EB_{i1}{}^{I} + E_{i2}{}^{I}\, EB_{i2}{}^{I} + \ldots + E_{iK}{}^{I} EB_{iK}{}^{I}$$

where $EB_{ik}{}^{I}$ represents the energy balance of India of the i-th sector for the k-th type of energy item, i.e. it represents the energy demand of the k-th type of energy item required for manufacturing produce in the i-th sector in India. Here '$E_{ik}{}^{I}$'s are the carbon emission factor of k-th type of energy item involved in producing i-th sector item. Since in case of different countries, each energy class consists of many energy items, which need not to be same in case of each and every country as their respective composition of available energy items might differ across countries, hence these carbon emission factors can't just simply be default carbon emission intensity values of the k-th energy group given in IPCC reports, but need to be calculated for the country studied.

These carbon emission factors (in case of India) of the k-th energy group used as an input while undertaking production in i-th sector can be calculated as the weighted average of the default emission intensities of say j-th energy item involved within the k-th energy group, and is represented as:

$$E_{ik}{}^{I} = w_{1k}{}^{I}\, EI_{1k} + w_{2k}{}^{I}\, EI_{2k} + \ldots\ldots + w_{nk}{}^{I} EI_{nk}$$

Where $w_{nk}{}^{I}$ represents the weights associated with the consumption of j-th energy item within the k-th energy group used as an energy input. These weights might be the reason which ensures different emission factors for different countries as countries may choose to consume different energy groups in different composition of energy, i.e. one country may choose to consume an energy composition involving more of renewable energy items, whereas another may choose the one which involves more pollution and emissions, which is actually the driving force behind different emission factors across countries. Here EI_{nk} represents the carbon emission intensity of the per unit of energy generated of the j-th energy item involved within the k-th energy group. These EI_{nk}i.e. carbon emission intensity value of j-th item in k-th energy group are the default carbon emission intensity values which are taken from 2006 IPCC Guidelines, Ch-2 Stationary Combustion.

4. Data Sources and Methodology:

As this study uses Bilateral trade input-output model, which uses input-output tables to calculate bilateral trade embodied emissions, those tables are taken from OECD input-output database (table used here is Input-Output Table ISIC Rev.4 for year 2015). The sectors in the table can be further aggregated into various sectors (the way it has been done in UNSD Energy Balances reports). Here the sectors are further aggregated into 14 sectors, and this correspondence is done in accordance with the International Recommendations for Energy Statistics (IRES). Further, post following the recommendations of IRES and Energy Balances Reports, the framework with which sectors are aggregated and while using the resultant

[9] These six energy groups here are taken in accordance with India's Energy Balances

I-O matrix, the way calculation of Leontief inverse matrix takes place is discussed in detail in Appendix A below.

India's sector wise export data to its respective trading partner has also been collected from OECD.Stat (STAN Databases). To calculate energy coefficients we need data on the sector wise consumption of various energy groups, which is taken from UNSD Energy Balances 2016 report for the year 2015. Since energy group wise data on carbon emission factor is not available, hence in order to calculate the same using weighted average of consumption of energy items with their respective default emission intensities, data on consumption of various energy items is collected from multiple sources and default emission intensities are collected from Chapter 2- Stationary Combustion of 2006 IPCC Guidelines for National Greenhouse Gas Inventories[10]. However default emission intensities are not available, hence will be calculated. Using the Tier 1 approach of Stationary Combustion, for electricity emissions of carbon from fuel combustion (in kg) can be calculated as the product of the amount of fuel consumption (in TJ) with the respective fuel's default carbon emission factor[11].

India's bilateral export data as collected from OECD.Stat (STAN Databases) need to be aggregated into 14 sectors (aggregation so done is in accordance with Sector classification table Table A1).

Using the above discussed Model and methodology, required matrices and vectors are calculated in order to calculate the emission embodiment in exports[12] and the three desired matrices i.e. calculated emission coefficient per unit of output, calculated Leontief Inverse matrix and the sector wise India's exports data are tabulated in Table 1, 2 and 3 respectively. Using the three tables below and the (eqn. 3) we will calculate the carbon emissions embodied in India's exports to its five major export destinations.

Table1: Calculated emission coefficients per unit of output (kilo-ton/USD Million)

Sector No.	Sector Name	Emission coefficients per unit of sector output
1	PRIM	0.1259
2	FBT	0.0371
3	TnL	0.0857
4	WOOD	0.0226
5	PAPE	0.1601
6	CnP	0.3719
7	NMET	1.0174
8	BMET	1.3741
9	MACH	0.0274
10	TREQ	0.0315
11	INES	7.9829
12	CONS	0.0389
13	HHLD	188.7156
14	CnPS	0.0343

Source: Authors' own calculations.

Table 2: Calculated Leontief Inverse Matrix[13]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14

[10] Detailed explanation is given in Appendix.
[11] Entire explanation is given in Appendix.
[12] Detailed calculation procedure is given in Appendix below.
[13] Row and column heading of (1-14) matrix below, is nothing but the numbers associated to 14 sectors.

1	1.172	0.687	0.148	0.434	0.163	0.068	0.054	0.124	0.037	0.037	0.087	0.062	0.000	0.030
2	0.016	1.059	0.011	0.009	0.009	0.021	0.007	0.007	0.005	0.006	0.012	0.005	0.000	0.013
3	0.003	0.005	1.317	0.010	0.018	0.031	0.011	0.006	0.008	0.024	0.060	0.010	0.000	0.006
4	0.001	0.001	0.002	1.052	0.008	0.002	0.004	0.001	0.002	0.004	0.028	0.018	0.000	0.001
5	0.002	0.012	0.013	0.009	1.230	0.014	0.016	0.005	0.009	0.011	0.019	0.008	0.000	0.012
6	0.023	0.024	0.117	0.035	0.074	1.282	0.054	0.035	0.037	0.050	0.158	0.036	0.000	0.017
7	0.001	0.003	0.005	0.006	0.004	0.007	1.118	0.008	0.011	0.014	0.011	0.109	0.000	0.003
8	0.003	0.006	0.008	0.010	0.026	0.014	0.035	1.274	0.273	0.208	0.118	0.126	0.000	0.008
9	0.003	0.008	0.010	0.012	0.013	0.010	0.019	0.039	1.103	0.082	0.037	0.061	0.000	0.011
10	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	1.156	0.001	0.002	0.000	0.003
11	0.002	0.008	0.017	0.012	0.017	0.015	0.013	0.008	0.021	0.042	1.066	0.027	0.000	0.007
12	0.004	0.006	0.006	0.005	0.008	0.006	0.009	0.006	0.006	0.007	0.007	1.086	0.000	0.015
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
14	0.106	0.319	0.349	0.238	0.343	0.265	0.343	0.353	0.267	0.319	0.309	0.305	0.000	1.319

Source: Authors' own calculations.

Table 3: India's export data (in USD Million)

Sector	U.S.	China	UAE	Hong Kong	Bangladesh
PRIM	775.960	1475.870	1186.919	179.785	1143.487
FBT	2872.769	613.328	1514.505	119.978	435.270
TnL	8400.698	2030.963	4782.159	514.051	1333.070
WOOD	952.487	4.907	20.212	2.791	2.569
PAPE	799.162	3.633	126.399	9.433	29.654
CnP	7548.006	1716.272	983.789	93.891	767.843
NMET	246.179	79.076	184.572	7.145	52.888
BMET	1172.302	1619.573	6176.570	9.708	301.250
MACH	4344.620	845.227	2031.501	245.230	640.665
TREQ	1987.303	184.930	2137.952	48.053	517.800
INES	2917.689	386.732	6389.576	10848.082	172.244
CONS	0	0	0	0	0
HHLD	0	0	0	0	0
CnPS	0	0	0	0	0
Total	32017.175	8960.511	25534.154	12078.147	5396.74

Source: OECD.Stat.

5. Results and Discussions:

Carbon emissions embodied in India's exports to its trading partners can be quantified using the methodological approach as discussed in previous Section and detailed estimation as done in Appendix below. Since study is more focused on estimating the carbon emissions embodied in India's exports to its five major export destinations, i.e. U.S., China, U.A.E., Hong Kong and Bangladesh, using the BTIO model and its methodological framework as discussed in the paper above, embodied CO2 emissions are so estimated and results are aggregated in table below.

Table 4: Carbon emissions embodied in India's exports to its 5 major export destinations (in kiloton).

Country	CO2 emissions embodied in India's exports
US	41319.191
China	9394.413
UAE	73527.651
Hong Kong	95734.936
Bangladesh	4183.435

Source: Authors own calculation.

The table above depicts the extent of carbon emissions embodied in India's exports to its five trading partners for the year 2015. Clearly, of the five countries above emissions embodied in India's exports to Hong Kong is highest i.e. 95734 kiloton or 95.73 million-ton, followed by UAE, US, China and then Bangladesh, which sheds light upon the fact that India emits huge carbon emissions,all of which are not just consumed directly within the country, but a substantial part of which are exported to its trading partners in the form of carbon emissions embodied in its exports.

Grossman and Krueger (1991) have argued that emissions embodied in international trade do not depend on just the volume of traded goods/services (or volume of exports in this study), but also on the composition of goods traded and carbon intensity of traded goods. In this study, of all the 14 sectors, three sectors i.e. Construction, Household, and Commerce and public services are non-traded sectors, and exports of India takes place in rest of the 11 sectors in all five export destinations. This study also gives results consistent to above argument made by Grossman and Krueger (1991), as in this study as well, the extent of trade embodied carbon emissions do not depend entirely on the volume of exports. Table 3 above, shows that out of US, UAE and Hong Kong, value of India's exports to them is highest in case of US, followed by UAE and then Hong Kong. However Table 4 shows that, the emissions embodied in India's exports is found to be highest in case of Hong Kong, followed by UAE and then US. This clearly depicts emission embodiment do not depend just on the quantum or value of exports, but on other factors as well like emission intensity or emission coefficient of the goods exported, goods are exported on what composition (i.e. if more of carbon intensive goods are being exported to some countries, as compared to others). Table 1 and Table B4, which shows per unit carbon emission coefficient, and emission coefficient for entire sector, for all 14 sectors respectively, have found INES (Industries not elsewhere specified) sector to be most emission intensive[14], hence it is implicit that more the goods of INES sector are traded/exported, more will be embodied carbon emissions. This is largely because INES sector not just consumes massive energy (as evident from Table B1), but among all sectors, it is also the largest consumer of Primary coal and Peat, Natural Gas and largest consumer of Biofuels and Waste, and Electricity among 11 traded sectors. Table B2 shows that energy groups- Primary Coal and Peat, Biofuels and Waste, and Electricity are among the most carbon intensive energy groups, which highlights the fact that goods exported under sector INES are

[14] Household sector is ignored here, being a non-traded sector.

among the most carbon intensive products, hence higher exports of the same will increase the carbon emissions embodied in exports.

This has been seen in this study as well, even though India's exports to Hong Kong are much smaller than UAE and US, but of them all India exports highest INES goods (most carbon intensive goods) to Hong Kong, then in UAE, followed by U.S., China and Bangladesh, and emissions embodied in India's exports is found to be highest in similar pattern. Moreover, India's exports to Hong Kong is quite concentrated towards INES, the highest carbon intensive sector (which is about 80% of total exports), hence highest emissions embodied in India's exports to Hong Kong, as compared to its share in total exports to 5 export destinations. It strengthens the fact that carbon emissions embodied in international trade is determined by not just quantum of trade but also on carbon intensity and composition of goods traded. However, since this study merely focuses upon carbon emissions embodied in India's exports to just five nations, hence to substantiate the results, this finding needs more substantial evidence which can be done by further extending the analysis.

6. Conclusion:

This study estimated the carbon emissions embodied in India's exports to five of its major export destination countries using the Bilateral trade Input-Output Model. The results drawn from the above exercise sheds lights upon certain key points, some of which are discussed below.
First, of all five countries discussed in the study, India exports highest trade embodied carbon emissions to Hong Kong, followed by UAE, US, then China and Bangladesh, whereas when it comes to the value of goods exported, in 2015 India had exported most goods to US, followed by UAE, Hong Kong, China and Bangladesh.
Second, it highlights the fact that trade embodied carbon emissions are not determined merely by quantity or value of goods traded, but also depends upon the composition of goods traded, and carbon intensity of the goods traded.
Third, it is found that of all the sectors, INES (i.e. Industries not elsewhere classified, which comprises DOM_22: Rubber and plastics products and DOM_31T33: Other manufacturing; repair and installation of machinery and equipment) is most energy intensive sector of all traded sectors, which further uses energy groups which are among the most carbon intensive energy groups. Hence it is quite implicit that, any increase in exports of INES, increases the carbon emissions embodied in exports the most, when compared with exports of some other sector.

Even though present study is at its preliminary stage, which can be further extended to discuss more important issues; still the study is relevant to understand the detailed procedure of estimating the trade embodied carbon emissions. In addition, this study provides a good understanding of carbon emissions embodied in India's exports, good understanding of sector wise energy consumption and determining sector's carbon intensity, which becomes important while taking say certain policy measures in order to lessen the carbon intensity, etc. This study is relevant from the view point of potential trade impacts of trade embodied carbon emissions. For instance, if an exporting country is aimed at lowering its production of emissions, and when production of a certain product emits emissions the most (say analogous to INES sector in this study), in such a case emission controlling targets may even hamper the exports of such carbon intensive products.

On the basis of results of this study, few recommendations may be drawn. In case of India, energy groups are found to be highly carbon intensive. For instance, energy groups like: Primary coal and Peat, Coal and Peat Products, Biofuels and Waste, and Electricity are found to be highly carbon intensive, hence there is need to reduce the carbon intensity of these sectors. It can be done by adoption of adequate set of policies which stresses upon the need to substitute fossil fuels with cleaner sources of energy, promotes widespread adoption of cleaner technology and green energy sources, and if need arises govt. may even put tight regulations to improve the energy efficiency.

References:

Ahmad, N., & Wyckoff, A. (2003). Carbon dioxide emissions embodied in international trade of goods.

Aichele, R., &Felbermayr, G. (2015). Kyoto and carbon leakage: An empirical analysis of the carbon content of bilateral trade. Review of Economics and Statistics, 97(1), 104-115.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment?. American economic review, 91(4), 877-908.

Banerjee, S. (2019). Addressing the Drivers of Carbon Emissions Embodied in Indian Exports: An Index Decomposition Analysis. Foreign Trade Review, 54(4), 300-333.

Banerjee, S. (2020). Carbon Emissions Embodied in India–United Kingdom Trade: A Case Study on North–South Debate. Foreign Trade Review, 55(2), 199-215.

Banerjee, S. (2021). Addressing the carbon emissions embodied in India's bilateral trade with two eminent Annex-II parties: with input–output and spatial decomposition analysis. Environment, Development and Sustainability, 23(4), 5430-5464.

Dean, J. M. (1992). Trade and the Environment: A Survey of the Literature (No. 966). The World Bank.

Electricity Profiles (2016). Department of Economic and Social Affairs, Statistics Division, United Nations. Accessible at: UNSD — Energy Statistics

Energy Balances (2016). Department of Economic and Social Affairs, Statistics Division, United Nations. Accessible at: UNSD — Energy Statistics

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement.

International Recommendations for Energy Statistics (IRES), Department of Economic and Social Affairs, Statistics Division, United Nations. Accessible at: UNSD — Energy Statistics

IPCC. 2006 ipcc guidelines for national greenhouse gas inventories. IPCC Reports, IPCC - Integovernmental Panel on Climate Change, 2007. URL http://www.ipcc-nggip.iges.or.jp/public/index.html.

Li, Y., Fu, J., Ma, Z., & Yang, B. (2014). Sources and flows of embodied CO 2 emissions in import and export trade of China. Chinese geographical science, 24(2), 220-230.

Liu, X., Ishikawa, M., Wang, C., Dong, Y., & Liu, W. (2010). Analyses of CO2 emissions embodied in Japan–China trade. Energy Policy, 38(3), 1510-1518.

Love, Patrick and Ralph Lattimore (2009), "Trade and Growth", in International Trade: Free, Fair and Open?, Chapter 9. OECD Publishing, Paris.

Managi, S., Hibiki, A., & Tsurumi, T. (2008). Does trade liberalization reduce pollution emissions. Discussion papers, 8013.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development (No. 992927783402676). International Labour Organization.

Peters, G. (2008). Reassessing carbon leakage.

Peters, G. P., &Hertwich, E. G. (2008). CO2 embodied in international trade with implications for global climate policy.

Sato, M. (2014). Embodied carbon in trade: a survey of the empirical literature. Journal of economic surveys, 28(5), 831-861.

Shafik, N., & Bandyopadhyay, S. (1992). Economic growth and environmental quality: time-series and cross-country evidence (Vol. 904). World Bank Publications.

Simola, H. (2020). CO2 emissions embodied in EU-China trade and carbon border tax.

Siriwardana, M. (2015). Australia's new Free Trade Agreements with Japan and South Korea: Potential economic and environmental impacts. Journal of Economic Integration, 616-643.

Su, B., Huang, H. C., Ang, B. W., & Zhou, P. (2010). Input–output analysis of CO2 emissions embodied in trade: the effects of sector aggregation. Energy Economics, 32(1), 166-175.

Sun, H., Attuquaye Clottey, S., Geng, Y., Fang, K., & Clifford Kofi Amissah, J. (2019). Trade openness and carbon emissions: evidence from belt and road countries. Sustainability, 11(9), 2682.

Tan, H., Sun, A., & Lau, H. (2013). CO2 embodiment in China–Australia trade: The drivers and implications. Energy Policy, 61, 1212-1220.

Wang, Z., Meng, J., Zheng, H., Shao, S., Wang, D., Mi, Z., & Guan, D. (2018). Temporal change in India's imbalance of carbon emissions embodied in international trade. Applied Energy, 231, 914-925.

Wyckoff, A. W., &Roop, J. M. (1994). The embodiment of carbon in imports of manufactured products: implications for international agreements on greenhouse gas emissions. Energy policy, 22(3), 187-194.

APPENDIX:

A. **Calculation of Leontief Inverse Matrix:**

Step 1: In order to calculate Leontief Inverse matrix, first step is to extract Input-Output database for India from OECD.Stat for the year 2015.

Step 2: Next is to aggregate the I-O table into 14 sectors, and aggregation of original sectors is done in accordance with the IRES methodology and Energy Balances. Concordance Table is shown below.

Table A1: Sector classification as per ISIC Rev. 4

Sector	Sector classification as per ISIC Rev. 4
PRIM (Primary sector)	DOM_01T03: Agriculture, forestry and fishing
	DOM_07T08: Mining and quarrying of non-energy producing products
	DOM_09: Mining support service activities
FBT (Food, Beverage and Tobacco)	DOM_10T12: Food products, beverages and tobacco
TnL (Textiles and Leather)	DOM_13T15: Textiles, wearing apparel, leather and related products
WOOD (Wood and wood products)	DOM_16: Wood and of products of wood and cork (except furniture)
PAPER (Paper, pulp and print)	DOM_17T18: Paper products and printing
CnP (Chemical and Pharmaceuticals)	DOM_20T21: Chemicals and pharmaceutical products
NMET (Non-metallic minerals)	DOM_23: Other non-metallic mineral products
BMET (Basic Metals)	DOM_24: Manufacture of basic metals
MACH (Machinery)	DOM_25: Fabricated metal products, except machinery and equipment
	DOM_26: Computer, electronic and optical products
	DOM_27: Electrical equipment
	DOM_28: Machinery and equipment n.e.c.
TREQ (Transport equipments)	DOM_29: Motor vehicles, trailers and semi-trailers
	DOM_30: Other transport equipment
INES (Industries not elsewhere specified)	DOM_22: Rubber and plastics products
	DOM_31T33: Other manufacturing; repair and installation of machinery and equipment
CONS (Construction)	DOM_41T43: Construction
HHLD (Household)	DOM_97T98: Private households with employed persons
CnPS (Commerce and public services)	DOM_35T39: Electricity, gas, water supply, sewerage, waste and remediation services
	DOM_45T47: Wholesale and retail trade; repair of motor vehicles
	DOM_49T53: Transportation and storage
	DOM_55T56: Accomodation and food services
	DOM_58T60: Publishing, audiovisual and broadcasting activities

	DOM_61: Telecommunications
	DOM_62T63: IT and other information services
	DOM_64T66: Financial and insurance activities
	DOM_68: Real estate activities
	DOM_69T82: Other business sector services
	DOM_84: Public administration and defence; compulsory social security
	DOM_85: Education
	DOM_86T88: Human health and social work
	DOM_90T96: Arts, entertainment, recreation and other service activities

Step 3: Sectors are aggregated using the Data Treatment Scheme 1 as prescribed by (B. Su et al. (2010)). This is done because, sectors classified as per industrial classification (here ISIC classification Rev. 4) do not entirely match with the sectors classification as per Energy balances, or IRES methodology, which results incompatibility between the two. In our case too, as per ISIC Rev. 4 we have some 34 sectors, whereas energy data is available at more aggregated level. Hence, the methodology adopted here to make the two compatible is to aggregate the I-O data (available at more disaggregated level) to the one which matches to aggregation level of Energy data. This is known as Data Treatment Scheme 1. As per this method, sectors in I-O table will be aggregated as:
We know basic I-O model is:
x= Z + y, or x = Ax + y;
$x = (I-A)^{-1}y$
where, x: n*1 vector of total outputs; Z: n*n matrix of intermediate demand; y: n*1 vector of final demand; A: n*n matrix of domestic production coefficients; $(I-A)^{-1}$: n*n Leontief inverse matrix.
However energy data we have is way more aggregated, say instead of n sectors energy data is available for n_0 sectors, where $n_0 < n$, such that post aggregation of sectors in I-O framework, the matrices and vectors are denoted with asterisk i.e. *.
In addition to above matrices, we will introduce here G- a simple grouping matrix of order n_0*n, whose column sums equal to 1. In our study, n=34, n_0=14, and Grouping matrix G is as follows:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Transpose of above will give us G' of order $n*n_0$, i.e. 34*14.

Now, the above Z matrix can be aggregated to get Z* of order 14*14, using formula: Z*= GZG'.
So, Z* matrix is:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	1	1	1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0

As we know, we need to calculate leontief inverse matrix i.e. $(I-A^*)^{-1}$, but the aggregated production coefficients matrix i.e. A* can be calculated as: $A^* = Z^*(x^{\sim *})^{-1}$. Hence, need is to first calculate $x^{\sim *}$, and then its inverse, from which we can calculate A* and then Leontief inverse matrix.

Since, x is our n*1 vector of total outputs, from which we can extract a n*n diagonal matrix of total outputs, denoted as matrix $x^{\sim}$. Further sectors in $x^{\sim}$ can be aggregated to get $x^{\sim *}$ (m*m matrix) using the formula, $x^{\sim *} = Gx^{\sim}G'$.

Using above framework, $x^{\sim *}$ matrix is:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	491039.8	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	185796.2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	151128.7	0	0	0	0	0	0	0	0	0	0	0

4	0	0	0	14964.9	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	27935.7	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	151967.3	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	53427.7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	149130.2	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	175903.4	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	119210.2	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	93822.5	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	428041.3	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	3498.3	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1739068.8

Now, $(x^{\sim *})^{-1}$ is:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2.03649E-06	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	5.38224E-06	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	6.61688E-06	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	6.6823	0	0	0	0	0	0	0	0	0	0

				E-05										
5	0	0	0	0	3.57965E-05	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	6.58036E-06	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1.87169E-05	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	6.70555E-06	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	5.68494E-06	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	8.38854E-06	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1.06584E-05	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	2.33622E-06	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0.000286	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	5.7502E-07

Now, Production coefficient matrix can be calculated as $A^* = Z^*(x^{\sim*})^{-1}$, as given below:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.136975251	0.553207762	0.084539204	0.345013999	0.099027409	0.029029929	0.02716194	0.075251693	0.001230221	0.000801945	0.032475153	0.022593147	0	0.011638355

2	0.011820427	0.044862597	0.002845919	0.000815241	0.002165688	0.013247587	0.00170698	0.000993092	0.000868659	0.001145036	0.004869834	0.000634985	0	0.008536063
3	0.001350807	0.000701844	0.237413542	0.004657565	0.008777299	0.016929958	0.004851416	0.001561052	0.002961853	0.012035883	0.038862746	0.003843554	0	0.002842441
4	0.000323192	0.000235742	0.000868796	0.048466746	0.005820509	0.000682384	0.002399504	0.000204519	0.001118796	0.001993957	0.024522902	0.014545092	0	0.00033932
5	0.000559629	0.006224562	0.005272327	0.004744435	0.184316126	0.006990978	0.009189989	0.000653791	0.003882244	0.004145618	0.010772469	0.002083444	0	0.006963669
6	0.014000087	0.004608275	0.06417775	0.01546285	0.040228095	0.213844689	0.031414416	0.016350813	0.016331123	0.020924384	0.105401156	0.012995008	0	0.007777898
7	0.000137667	0.00111843	0.001962566	0.004189804	0.001242138	0.004062716	0.10391239	0.004537646	0.006611583	0.008118433	0.006643396	0.08829148	0	0.000753967
8	0.000588343	0.000468255	0.000815199	0.00255264	0.012435701	0.004883287	0.01876929	0.207650094	0.193116222	0.124668023	0.078641051	0.076015328	0	0.00147602
9	0.001692938	0.003067339	0.003865579	0.00737058	0.005899262	0.004725359	0.011791636	0.025628612	0.083847726	0.057177993	0.025733699	0.044705266	0	0.006111029
10	0.000187358	0	2.44824E-05	0	0.00010381	0.000175696	0	0	0.001778249	0.134016217	0.000100189	0.000593634	0	0.001999748
11	0.001168948	0.004342931	0.009474044	0.008827323	0.010692412	0.009498096	0.008544257	0.003694087	0.015619368	0.030422732	0.057380692	0.019665859	0	0.004201444
12	0.002050343	0.000334237	0.001220814	0.001369872	0.002176427	0.001848424	0.004018515	0.001341781	0.00214379	0.00178676	0.002287298	0.075306518	0	0.010706994
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.061585232	0.181852481	0.17606186	0.132957788	0.184337604	0.140151862	0.209859305	0.194096166	0.121733861	0.145501811	0.149528098	0.148026137	0	0.228980245

Using above matrix, we can calculate (I-A*), from which $(I-A^*)^{-1}$, i.e. Leontief inverse matrix can be easily calculated, which is:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**1.172319013**	**0.687013992**	**0.148466429**	**0.434274324**	**0.162564051**	**0.067752318**	**0.054116194**	**0.123563798**	**0.037288821**	**0.036504916**	**0.087444045**	**0.061727732**	**0**	**0.030205458**
2	**0.01580966**	**1.058763036**	**0.010658013**	**0.009032885**	**0.009101199**	**0.021236062**	**0.006685195**	**0.006621023**	**0.004820927**	**0.006005364**	**0.011896799**	**0.005294042**	**0**	**0.012511386**

3	0.003201235	0.004562943	1.316656417	0.009743396	0.018498938	0.030696031	0.010787095	0.005657799	0.008071729	0.023758248	0.060070777	0.010327307	0	0.006051572
4	0.000603335	0.001013096	0.002102491	1.051698884	0.008367961	0.001673891	0.003627085	0.000879601	0.002234287	0.004037362	0.028121576	0.017899768	0	0.001018603
5	0.002121876	0.011712606	0.013043575	0.009196627	1.230255535	0.014029367	0.016489912	0.004916284	0.00862056	0.010553587	0.01919334	0.007927592	0	0.011802651
6	0.022970518	0.02415163	0.117300459	0.034576206	0.074394909	1.282159371	0.053947048	0.035316612	0.036552109	0.049506818	0.157913132	0.035658286	0	0.016562025
7	0.000853444	0.002555331	0.004659894	0.006164468	0.0035559	0.007021077	1.117911039	0.007954045	0.010769865	0.013707994	0.010793072	0.10887326	0	0.00296405
8	0.002819783	0.005541037	0.00804542	0.009512	0.026375041	0.013561298	0.03478154	1.274438523	0.273077239	0.208191759	0.118156172	0.125735561	0	0.008080816
9	0.003456592	0.007917891	0.010032582	0.012169581	0.012771224	0.010058477	0.019112132	0.039202055	1.10255376	0.082314104	0.037489631	0.061376014	0	0.010501564
10	0.000512783	0.000913173	0.000928502	0.000683253	0.001023889	0.000916537	0.000864836	0.000934826	0.00290356	1.155690418	0.000972975	0.001600133	0	0.003090685
11	0.002465256	0.007909479	0.016778746	0.012473992	0.017279419	0.015205017	0.013308214	0.008113082	0.021488752	0.04213457	1.066452273	0.027389311	0	0.007001385
12	0.00390794	0.005743674	0.006483643	0.005490196	0.007545366	0.005981938	0.00925139	0.006447111	0.006338228	0.006824193	0.007198834	1.086109907	0	0.01548853
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0
14	0.105698731	0.319151396	0.349385209	0.238482115	0.343071595	0.265320053	0.343307985	0.352638622	0.26673592	0.318689326	0.308640552	0.305111095	0	1.319150877

This way we will get the calculated Leontief Inverse matrix (with aggregated sectors, of order 14*14).

B: (a) Calculation of emission coefficients, i.e. E^I:

$E^I = (E^I_1, E^I_2, E^I_3, \ldots, E^I_n)$ represents the vector of energy coefficient of each sector, which is calculated in following way:

Step 1: First step is to extract data on Sector wise energy consumption in India, i.e. India's Energy Balances for the respective sectors, which is given below:

Table B1: Sector wise energy consumption in India in Terajoules (2015)

Sector	Primary Coal and Peat	Coal and Peat Products	Oil Products	Natural Gas	Biofuels and Waste	Electricity
PRIM	0	0	35097	6753	0	624240
FBT	0	0	0	0	0	73238
TnL	4932	0	2120	0	0	130705
WOOD	0	0	0	0	0	3596
PAPE	22,102	0	0	0	0	24854
CnP	48326	0	511293	0	0	141739
NMET	0	0	627153	0	0	75560
BMET	1181749	556847	21720	0	0	315886
MACH	0	0	20631	0	0	34654
TREQ	0	0	0	0	0	39870
INES	4536229	0	313328	195257	2034285	784206
CONS	165682	0	8772	0	0	0
HHLD	0	14300	1103935	28911	4935115	859954
CnPS	0	0	0	31088	287450	309733

Source: 2016 Energy Balances, UNSD.

Step 2: Next is to calculate carbon emission factor for energy sectors of India. This is done in the following way:

Table B2: Calculation of Co2 emission factors for different energy groups:

Energy Groups	Energy Items	Consumption in million tonnes	Default Co2 emission factor (kg of greenhouse gas per TJ on a Net Calorific Basis)	Calculated Co2 emissions factor (Kg/Tj)
Primary Coal and Peat	Anthracite and Other Bit.	663.51	96450	96421.6
	Coking coal	102.39	94600	

	Sub-bituminous coal	79.44	96100	
	Lignite	42.21	101000	
Coal and Peat Products	Coke (Proxy item)		107000	107000
Oil Products	LPG	19.62	63100	
	Naptha	13.27	73300	
	Aviation Gasoline (or Aviation Turbine Fuel)	6.26	70000	
	Other kerosene (or Kerosene)	6.83	71900	
	Gas oil/diesel oil	75.05	74100	
	Fuel oil	6.63	77400	75325.3
	Lubricants	3.57	73300	
	Refinery Fuel and Losses	18.77	73300	
	Petroleum coke	19.29	97500	
	Bitumen	5.94	80700	
	Other oil products n.e.c.	6.35	73300	
Natural Gas	Natural gas		56100	56100
Biofuels and Waste				99872.1*
Electricity	Electricity			94187.6**

Note: Energy groups taken are as per India's energy balances, Energy items are in accordance with Standard International Energy Product Classification (SIEC) and of all them only those energy products used within respective energy groups in India.

Source:

i. Default CO2 emission factor: from 2006 IPCC Guidelines, Ch-2 Stationary Combustion.
ii. Consumption data collected from multiple sources: Office of Coal Controller, Ministry of Coal; Ministry of Petroleum & Natural Gas; Central Electricity Authority.
iii. * Collected from Banerjee S. (2020).
iv. ** For electricity, calculation is shown below.

So, our calculated carbon emission factors for energy sectors are:

Table B3: Calculated carbon emission factor (in Kg/Tj)

Energy group	**Calculated Co2 emissions factor (Kg/Tj)**
Primary coal and Peat	96421.65003
Coal and Peat Products	107000
Oil Producrs	75325.33614
Natural Gas	56100
Biofuels and Waste	99872.12
Electricity	94187.5769

Step 3: Emission coefficients are calculated using matrix multiplication of Sector wise energy consumption and calculated emission factors. The calculated emission coefficient (in kilo-ton) vector is as follows:

Table B4: Calculated emission coefficient of 14 sectors (in kiloton)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
61818.19	6898.11	12946.03	338.70	4472.05	56523.04	54357.32	204917.42	4818.01	3755.26	748976.96	16636.09	660183.66	59625.28

Step 4: Next is: Emission coefficients per unit of output, which is calculated as:
$EC^I_i = E^I_i * (x^{\sim *})^{-1}$, i.e. by multiplying sector wise emission coefficients with the respective sector's output. The resultant vector is tabled below:

Table B5: Calculated emission coefficient per unit output of 14 sectors (in kiloton/USD million)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.1259	0.0371	0.0857	0.0226	0.1601	0.3719	1.0174	1.3741	0.0274	0.0315	7.9829	0.0389	188.7156	0.0343

(b) **Calculated Co2 emissions factor (Kg/Tj) for Electricity:**

For calculating emission factor of electricity we need default emission factor and consumption of various energy items of electricity.

Inputs	**Fuel Combustion (In Terajoules)***	**Default carbon emission factor**	**Emissions of carbon from fuel combustion (in kg)**
Hard coal	9353251	96203	899810805953.00
Brown coal	360925	97800	35298465000.00
Gas-diesel oil	9632	74100	713731200.00
Fuel oil	19432	77400	1504036800.00
LPG	142	63100	8960200.00
Naphtha	2225	73300	163092500.00
Natural gas	634158	56100	35576263800.00
Coke-oven gas	29689	44400	1318191600.00
Fuelwood (Proxy: Wood / Wood Waste in solid biofuels)	225409	112000	25245808000.00
Vegetable waste (Proxy: Municipal Wastes (biomass fraction))	349703	100000	34970300000.00

Total fuel combustion	10984566		
Total Carbon emission from fuel combustion			1034609655053.00
So, carbon emission factor (=total carbon emission from fuel combustion/total fuel combustion)		94187.58	

Source: * Fuel combustion data is collected from 2015 Electricity Profiles, UNSD- Energy Statistics. Default carbon emission factor data collected from 2006 IPCC Guidelines, Ch-2 Stationary Combustion. Emissions of carbon from fuel combustion are calculated using Tier 1 approach of emission estimate of Stationary Combustion. Further calculation of carbon emission factor is also done using same approach.

IIFT Working Paper series:

SKatyaayun, U., Shapovalova, O., & Nag, B. (2016). State of Ukraine's Educational Services. How attractive is it for Indian Students? Indian Institute of Foreign Trade (No. EC-16-30).

Chowdhury, S. R., & Sinha, D. (2017). Enhancement of Port's Brand Equity through BPR Implementation in Indian Context. Indian Institute of Foreign Trade. (No. MA-17-31)

Sinha, D., & Chowdhury, S. R. (2018). Optimizing private and public mode of operation in major ports of India for better customer service. Indian Institute of Foreign Trade. (No. LD-17-32)

Nayyar, R., & Mukherjee, J. (2018). Outward FDI from India: A macro level examination in the presence of structural breaks. Indian Institute of Foreign Trade. (No. EC-18-33).

Nag, B., & Khurana, S. (2018). India's Trade Sensitive Employment-Analysis at the Sectoral Level. Indian Institute of Foreign Trade. (No. EC-18-34).

Sikdar, C., & Nag, B. (2018). Foreign Trade and Employment Growth in Manufacturing Sector–Implication of Indian ASEAN FTA. Indian Institute of Foreign Trade. (No. EC-18-35).

Marjit, S., Pant, M., & Huria, S. (2020). Unskilled immigration, technical progress, and wages—Role of the household sector. Indian Institute of Foreign Trade. (No. EC-19-36).

Kapil, S., & Mishra, R. K. (2019). Corporate Governance structure and firm performance in Indian context: A Structural Equation Modelling Approach. Indian Institute of Foreign Trade. (No. FI-19-37).

Raju, S., & Saradhi, V. R. (2019). Imports from China: Threat or Opportunity Analysis of Indian Manufacturing Sector. Indian Institute of Foreign Trade. (No. EC-19-38).

Chaudhuri, B. R., Bhattacharyya, S., & Chatterjee, S. (2019). Pharmaceutical exports and patents in India–an empirical investigation. Indian Institute of Foreign Trade. (No. EC-19-39).

Pant, M., & Huria, S. (2019). Quantification of Services Trade Restrictions-A new Approach, Indian Institute of Foreign Trade. (No. EC-19-40).

Nag, B., & Van der Geest, W. (2020). Economic Impact Analysis of Covid-19 Implication on India's GDP, Employment and Inequality, Indian Institute of Foreign Trade. (No. EC-20-41).

Dey, O., & Chakravarty, D. (2020). Electric Street Car as a Clean Public Transport Alternative: A Choice Experiment Approach. Indian Institute of Foreign Trade. (No. EC-20-42)

Pant, M., & Huria, S. (2020). Labour, Trade, and Wage Inequality Some New Results. Indian Institute of Foreign Trade. (No.EC- 20-43).

Aggarwal, S., & Chakraborty, D. (2020). Is there any relationship between Marginal Intra-Industry Trade and Employment Change? Evidence from Indian Industries. Indian Institute of Foreign Trade. (No. EC-20-44).

Arora, K., Siddiqui, A. A., & Nag, B. (2020). Developing Linkages between Export Guarantees And Technical Efficiency Of Indian Firms. Indian Institute of Foreign Trade. (No. EC-20-45).

Marjit, S., & Yang, L. (2020). An Elementary Theorem on Gains from Virtual Trade. Indian Institute of Foreign Trade. (No. EC-20-46)

Marjit, S., & Oladi, R. (2020). Internal Migration, Minimum Rural Wage and Employment Guarantee: Recasting Harris Todaro. Indian Institute of Foreign Trade. (No. EC-20-47)

Marjit, S. (2020). A New Ricardian Model of Trade, Growth and Inequality. Indian Institute of Foreign Trade. (No. EC-20-48)

Marjit, S., Mukhopadhyay, A. K., & Chatterjee, M. (2020). Combatting Covid-19-On Relative Performance of the Indian States. Indian Institute of Foreign Trade. (No. EC-20-49)

Nag, B., Chakraborty, D., & Aggarwal, S. (2021). India's Act East Policy: RCEP Negotiations and Beyond (No. 2101). Indian Institute of Foreign Trade. (No. EC-21-50)

Chakraborty, D., Nag, B., & Bhardwaj, R. S. (2021). The Proposed India-EU Trade Agreement and UNECE 1958 Provisions: Empirical Results for Indian Automobile Sector. Indian Institute of Foreign Trade. (No. EC-21-51)

Arora, K., & Siddiqui, A. A. (2021). Asian Global Value Chain Upgradation: Comparing Technology & Trade Performance. Indian Institute of Foreign Trade. (No. EC-21-52)

Bhattacharyya, R., Das, G., & Marjit, S. (2021). Effect of Contract Farming in a Small Open Less-Developed Economy: A General Equilibrium Analysis. Indian Institute of Foreign Trade. (No. EC-21-53)

Aggarwal, S., & Chakraborty, D. (2021). Which Factors Influence Vertical Intra-industry Trade in India?: Empirical Results from Panel Data Analysis. Indian Institute of Foreign Trade. (No. EC-21-54)

Mullick, N & Siddiqui, A. A. (2021). Economic Integration Agreements and Extensive Margin of Export: An Empirical Study of India. Indian Institute of Foreign Trade. (No. EC-21-55)