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China's production, consumption and final import based industrial temporal emissions

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Abstract
Industries are one of the major sources of carbon emissions. Conventional production and consumption based accounting approaches are based on the concept of emission responsibility founded on place of production and final place of consumption. But there is another dimension that regional final demand basically comes from two sources i.e. final demand for domestic and imported goods. China's industrial Production and consumption based emissions are on rise since 2002 onwards while emissions from final-imports have actually decreased over the years. Owing to China's emergence as an industrial giant and more and more foreign brands shifting production operation to China resulted in decreased dependence on finished foreign goods. Construction sector with a total of 16580.26 million tons and 16655.78 million tons respectively from 1995-2009 was the highest contributor under both CBA and PBA while Machinery, Nec, with total of 5311.86 million tons was the major contributor towards final imported emissions. Emission intensities from all three are on decline with Electricity, Gas and Water-Supply being most carbon intensive. This further classification of will assist policy makers to further understand China's industrial emissions, plus temporal presentation of industrial emissions will allow policy makers to analyze historical pattern to device future mitigation policies.

Keywords: China, industrial emissions, consumption-based, Production-based, final imports, temporal emissions

1. Introduction

CO_2 Emission extenuation is a mutual universal prosperity issue, which must be paid keen consideration to by one and all [1, 2]. About 60% of global GHG emissions are CO_2 emissions [3]. Ever since 'industrial revolution' CO_2 intensity in 'atmosphere' has greatly increased [4]. Current rate of global GHG emissions can affect the worldwide environment [5]. Sources of GHG emissions advantage people by feeding them with consumable goods and services [6]. But pose biggest health difficulties of current century [7].

The chief reason of global warming are the emissions released during burning of fossil fuel [8]. Pursuing many nations to impose mechanisms for decrease in consumption of fossil fuels [9]. As a matter of fact many nations have achieved reductions in CO_2 emissions and some have fulfilled their Kyoto protocol [10]. 36 developed Annex A countries achieved 36% decrease in their GHG emission between 1990 & 2008-2012 as compared to their commitment of 4% decrease. On other hand Annex B countries achieved a 10% reduction in their emissions while increasing their GDP by 47% [11, 12].

Industrial sector is one of the main culprit for global carbon emissions. In 2005 industrial sector accounted for 14.7% of world total GHG emissions excluding Agriculture 13.8% and electricity and heat 24.9% [13], if we consider agriculture plus electricity & heat as an industry it gives us an astonishing high total of 53.4% of world total GHG emissions. During 2016 in United States more than 22% of total GHG emissions came alone from industrial sources [14]. Due to the immense importance of industrial sector there is wide variety of literature on industrial emissions including: Structural impact, where the impact of improvement in technology on carbon emissions is investigated [15, 16, 17, 18], driving factors for industrial GHG emissions [19, 20, 21], different aspects of energy use and carbon emissions [22, 23, 24], Industrial emission intensity [25], Policy [26], International trade [27] and industrial agglomeration [28] etc.

Sajid, *et al.* [29] further decomposed China emissions from final demand of domestic and imported goods. In to emissions from final demand of domestic goods (including emissions from final domestic demand of domestic goods plus emissions from foreign demand of domestic goods (exports)) production-based emissions. Emissions form final use consumption-based emissions and emissions form final demand of imported goods. They measured production and consumption-based emission based on basic idea of competitive imports assumption which embeds emissions from intermediate imports to final Household, Capital, Government and exports (except for consumption-based).

In this study we have adopted Sajid, *et al.* [29] model and presented China's temporal industrial emissions under consumption, production and final imports emissions. This will help us to not only further understand China's industrial emissions but temporal presentation will help policy makers to learn from the past and design more informed and strategically planned mitigation policies. The remainder of the article is distributed in following manner: section 2 contains methodology, section 3 is about data sources and in section 4 results have been presented and in section 5 we have concluded our work and gave suggestions.

2. Methodology

Wassily W. Leontief [30] introduced the basic input-output model

$$X = AX + F \tag{1}$$

BY solving for X we have,

$$X = (I - A)^{-1} F \tag{2}$$

Where, total yield of a given economy is represented by column vector X, an $n \times n$ dimensional matrix of identity is symbolized as I, A is direct requirement matrix whose element $a_{ij} = \frac{x_{ij}}{x_j}$ characterizes the quantity of total yield prerequisite from sector i to yield one unit at sector j, $(I - A)^{-1}$ symbolizes Leontief inverse matrix denoted as L matrix, F is the vector of final demand or external demand.

National input out tables provided by WIOD database uses non-competitive imports assumption meaning intermediate imports are treated separately from intermediate domestic goods. We have to add intermediate imports to the original domestic technology matrix so;

$$X = (I - A)^{-1} F = X + IM = (I - (A^D + A^M))^{-1} F^{DD} + E \tag{3}$$

Where, A^D is a technology matrix of intermediate demand for domestic goods, A^M is a technology matrix of domestic intermediate demand for imported goods, IM is intermediate imports, F^D domestic final demand for domestic goods, here

$$A = A^D + A^M \tag{4}$$

If $\varphi = [\varphi_1, \varphi_2, \varphi_3 \ldots, \varphi_n]$ is a vector of sectoral intensities representing emission intensities of sector one to n then

By multiplying φ with X we can get the total carbon emissions embodied in final demand for domestic goods and services including from domestic final demand and form exports.

$$C^D = \varphi (I - A)^{-1} \hat{F}^{DD} + \hat{E} \tag{5}$$

Where C^D is the vector for total embodied emissions from total demand of domestic goods, $\wedge$ sign represents that the vectors of $\hat{F}^{DD}$, $\hat{E}$ have been diagonalized.

Correspondingly, the embodied carbon emission intensity of the final demand of domestic consumer products and services in Sector i is

$$T_i^D = \frac{C_i^D}{\hat{F}_i^D}, \quad (i = 1,2,\cdots,n) \tag{6}$$

Where:

$$\hat{F}_i^D = \hat{F}_i^{DD} + \hat{E}_i$$

By multiplying φ with F^M we can get emissions from final demand for imported goods.

$$C^M = \varphi \hat{F}^M = \sum_{i=1}^{n} \varphi_i \sum_{i=1}^{n} \hat{F}_i^M \tag{7}$$

Carbon emission intensity of the final demand of imported consumer products and services in Sector i is

$$T_i^M = \frac{C_i^M}{\hat{F}_i^M}, \quad (i = 1,2,\cdots,n) \tag{8}$$

Consumption-based emissions are equal to emissions embodied in final demand for domestic goods (production-based emissions) minus emissions from exports (external demand for domestic goods) plus emissions from imports [31] which in our case will be emissions from final imports [1].

$$C^{cn} = C^D - C^E + C^M \tag{9}$$

Here C^{cn} is total consumption based emissions and C^D, C^E, C^M represent domestic emissions from domestic demand, emissions from exports and imports respectively.

Correspondingly consumption-based industrial intensities can be presented by:

$$T_i^{cn} = \frac{C_i^{cn}}{\hat{F}_i^{cn}}, \quad (i = 1,2,\cdots,n) \tag{10}$$

3. Data

The central home of our data including IO tables and environmental information is from world input-output database [32]. There are two releases 2013 and 2016 [2], we have utilized 2013 releases' environmental accounts [33] and

[1] Following Sajid, *et al.* [29] to avoid double counting when calculating consumption-based emissions we have just added emissions from final domestic demand of imported goods instead of emissions from total imports. Because of the fact that embodied emissions from intermediate imports are already been embedded in to final demand categories for domestic goods.

[2] Owing to the fact that 2016 release lacks environmental accounts we have selected 2013 release with latest available environmental data of the year 2009. Although 2013 release provides IO tables for 2010 & 2011 but lacks environmental accounts for the respective years.

national IO tables [34]; [35] for the years1995-2009, Under release 2013 following sub-categories are available: 'World, national & regional IO tables', 'environmental accounts' and 'Socio- economic information'. Many scholars have considered WIOD as a reliable source of information for environmental problems [36, 37, 38, 9, 39, 40]. And for socio-economic indicators data is collected from [41].

4 Results

4.1 Sector wise emissions

WIOD input-output tables catalogues Chinas' industries in to 35 sectors its worth mentioning that out of these 35 two sectors namely: sector of sector of Private Households with Employed Persons plus Sale, Maintenance and Repair of Motor Vehicles and Motorcycles have almost negligible emissions hence not included in the subsequent analysis. As can be seen from fig 1 Chinas production and consumption based emissions rocketed after 2002. This might be owing to the fact that Chinese economy boosted from 2002 onwards with more than 4 time increased GDP from 1.471 trillion US$ in 2002 to 5.11 trillion US$ in 2009 [41]. Construction sector was the highest contributor with constantly increasing consumption and production-based emissions over the years with a total of 16580.262 million tons and 16655.78 million tons respectively from 1995-2009. The results are also supported by various other studies conducted over the years also showing construction sector to be the highest contributor to Chinas' CO_2 emissions [42] at country [43] and at city [44] level. A recent study conducted by [45] for 1995-2009 also showed construction sector to be the largest emitter under consumption-based approach in China. Other major sectoral consumption based emissions were from Electricity, Gas and Water Supply with a total of 2909.35 million tons followed by Food, Beverages and Tobacco; Agriculture, Hunting, Forestry and Fishing; Machinery, Nec; Public Admin and Defence, Compulsory Social Security with totals of 2626.94 million tons, 2555.07 million tons, 2371.45 million tons and 2021.39 million tons. All the sectors with exception for few show increase in their emissions. Contrary to this Agriculture, Hunting, Forestry and Fishing has shown gradual decrease in its emissions from 1995-2009. Besides Construction other five major sectors for production-based emissions were Electrical and Optical Equipment; Machinery, Nec; Electricity, Gas and Water Supply; Food, Beverages and Tobacco and Basic Metals and Fabricated Metal with total of 5311.86 million tons, 3195.03 million tons, 3077.18 million tons, 2914.68 million tons and 2811.14 million tons respectively. Opposite to sectoral consumption and production-based emissions sector wise emissions from final imports actually shirked over time. This might be due to the rapid development of domestic industry and local brands as an alternative to final imports for example smart phone industry and Chinas' computer sector. Also might be due to the fact that famous foreign brands moved their production operations to mainland China [3].

[3] Only one hundred foreign owned companies were working in China in 1979 coming to 1998 this number increased to 280,000. In 1998 major foreign brands made huge investments in China, including: Proctor and Gamble,Amoco and United Technologies, General Motors, Hewlett-Packard, Motorola, General Electric, Arco and Coca Cola [51].

Following were the five major sectors for emissions from final imports: Machinery, Nec, Chemicals and Chemical Products, Electricity, Gas and Water Supply, Basic Metals and Fabricated Metal, Electrical and Optical Equipment with total emissions of 60.54 million tons, 50.01 million ton, 33.07 million tons, 26.50 million ton and 17.36 million tons respectively. While final imported emission from most of the industries are decreasing over time emissions from Air Transport and Electricity, Gas and Water Supply generally have increased over time. This might be owing to the fact that passenger traffic increased form 51.2 million person to 138.3 million person, freight traffic increased from 1010 thousand tons to 3070 thousand tons and number of airports increased from 116 to 142 from 1995 to 2005 [46]. Electricity, Gas and Water Supply increased emissions could be linked with the need for additional resources to sustain mainland China rapid economic growth during these years.

4.2 Sector-wise emission intensities

Intensities from consumption, production and final demand of imported goods are consistently declining from 1995-2009. Electricity, Gas and Water Supply sector has highest average intensity of 20.28 Kt/10^6, 20.31 per ton and 16.79 Kt/10^6 for consumption, production and final demand of imported goods from 1995-2009. Followed by Other Non-Metallic Mineral, Basic Metals and Fabricated Metal, Water Transport, Chemicals and Chemical Products and Coke, Refined Petroleum and Nuclear Fuel with average emission intensities of 5.84, 3.93, 3.21, 3.165 and 2.97 respectively for consumption-based intensities. And five highest averaged carbon intensive sectors from 1995-2009 under production-based emissions were Other Non-Metallic Mineral, Basic Metals and Fabricated Metal, Chemicals and Chemical Products, Air Transport and Water Transport with emission intensities of 5.99, 4.33, 3.64, 3.31 and 3.28 respectively. And final imports' top carbon intensive sectors were Non-Metallic Mineral, Air Transport, Water Transport, Basic Metals and Fabricated Metal and Chemicals and Chemical Products sectors with average intensities of 2.89, 1.96, 1.75, 1.16 and 1.15 respectively. Overall final imports are not as much emission intensive as other two approaches. Our results are in line with the findings of [47] which showed constant decline in china's industrial CO_2 emissions intensities from 1991-2005. Li, *et al*. [48] also predicted future trajectories of Chinas CO_2 emission intensities as constantly declining from 2005-2030. Although this decrease in emission intensities indicate efficiency gains, but these efficiency gains will not be enough for future mitigation of China's CO_2 emissions [49].

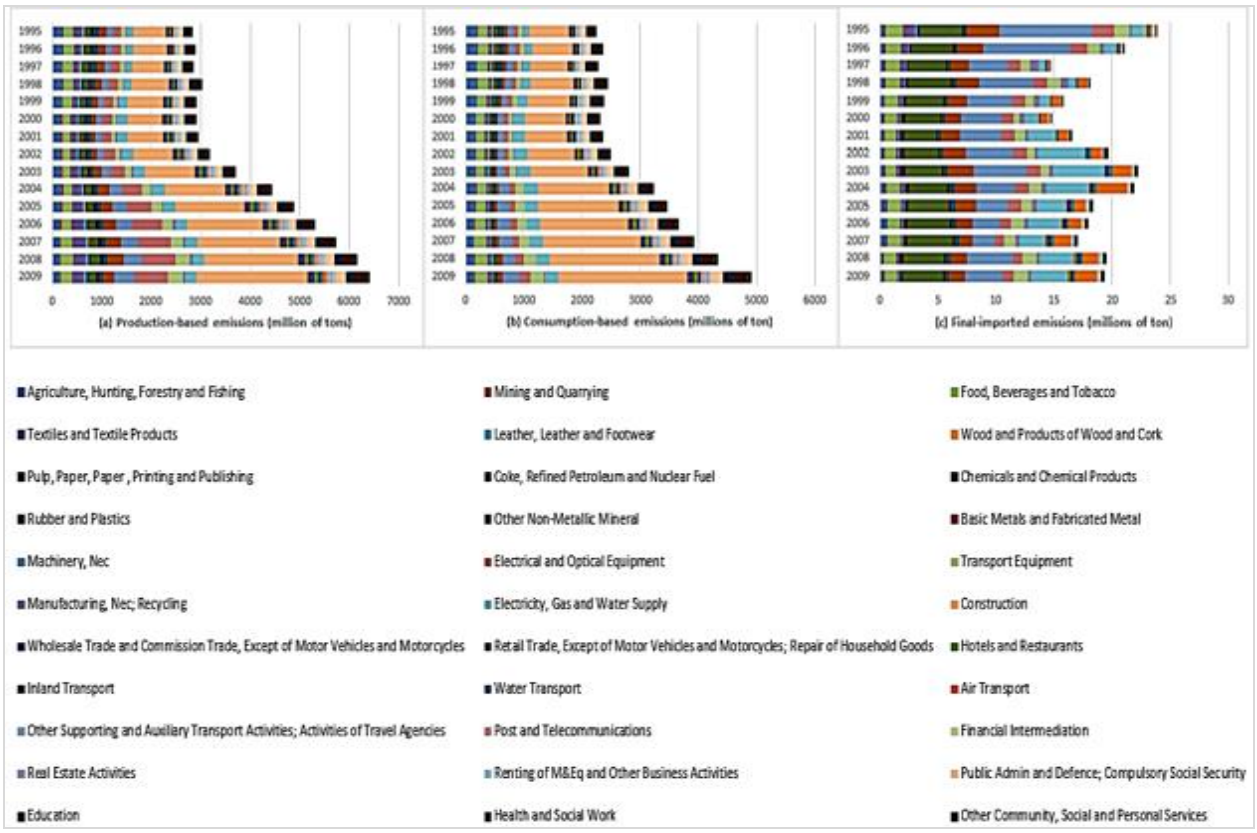

Fig 1: Sectoral emissions where: (a) = Production-based, (b) = Consumption-based and (c) = Final imported emissions.

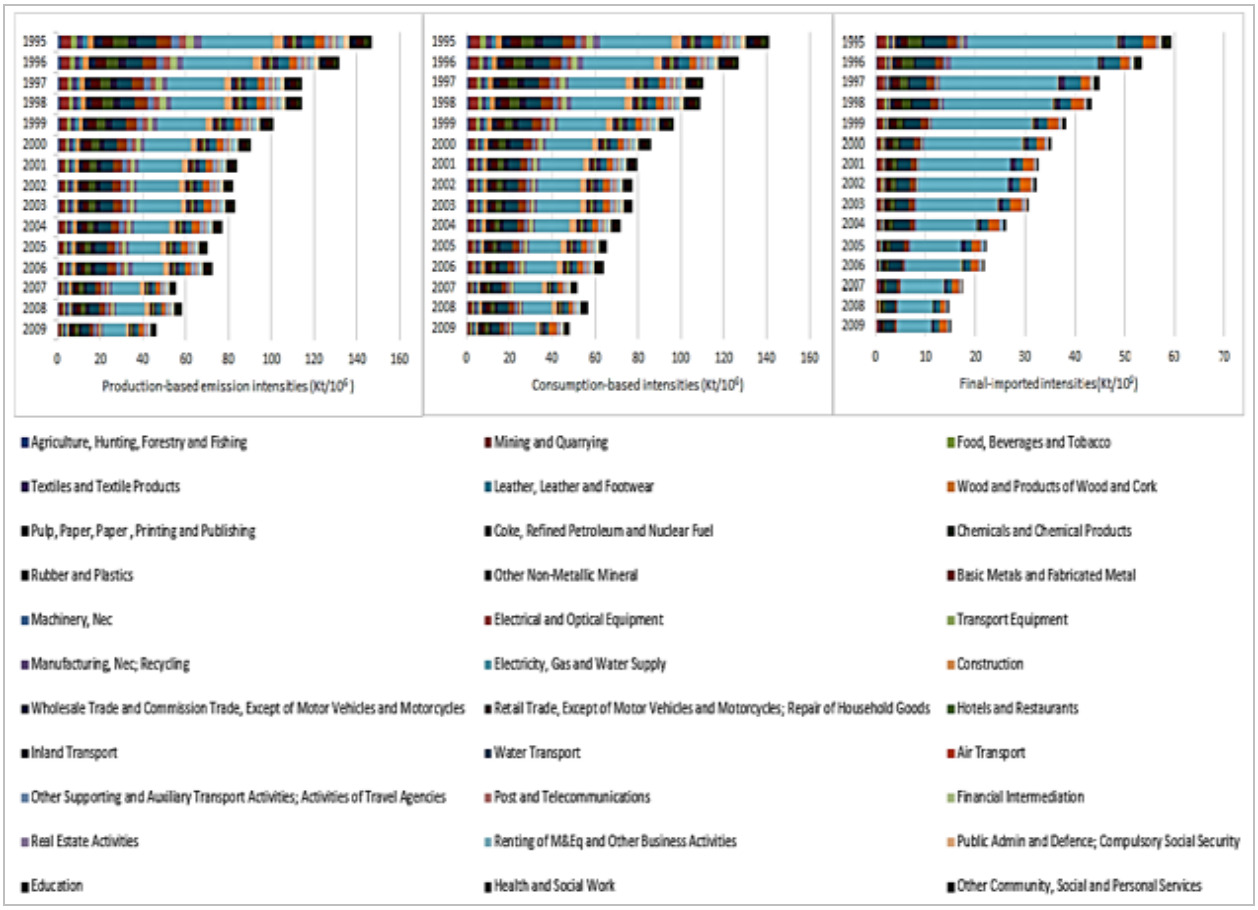

Fig 2: Sectoral emission intensities

5. Conclusion

China is the world's top emitter of greenhouse gases and industries are one of the main causes of these emissions hence it's extremely important for China to curb its industrial CO_2 emissions. For that it has to first fully understand the causes and sources of its industrial CO_2 emissions and then advise mitigation policies accordingly.

Form 2000 onwards China has experienced a rapid increase in Its production and consumption-based emissions while emissions from final imports are generally in decline. This decline in embodied emissions from final demand for imported goods may be partially caused by the rapid development of alternative industries and brands in domestic markets and FDI. Construction sector is the main contributor towards Chinas' PBA and CBA emissions. With a total of 16580.26 million tons and 16655.78 million tons of CO_2 emissions under CBA & PBA respectively from 1995-2009. While the sector of Machinery, Nec, with 60542.89 million tons of embodied emissions was the greatest contributor from final imports. While over the years emissions from final imports are decreasing but emissions from Air Transport and Electricity, Gas and Water Supply more or less increased over the years.

China industrial emission intensities are constantly declining over the years. This might be owing to the initiatives taken by China to move form fossil fuel to alternative sources of energy. Particularly China's policies towards use of coal and sources of energy [50]. Electricity, Gas and Water Supply sector was the most carbon intensive sector from 1995-2009 with average intensity of 20.28 per ton, 20.31 per ton and 16.79 per ton for consumption, production-based and final demand of imports.

Although china has successfully declined its industrial emission intensities over time but the effect of these reductions is not much impacting the overall emissions of China as evident by rapid increase in China's production and consumption-based emissions from 2000 onwards. Which is mainly caused by increased production triggered by rapid increase in final demand. Despite this China's emissions from final imports demand have decreased over time. Which is basically due to availability of alternatives and FDI.

In order to reduce its emissions it's necessary that beside alternative energy sources. On one hand China should focus on consumption behavior by encouraging sustainable consumption, carbon labelling, green consumption etc. And on other hand implement tougher regulations on cleaner production by utilizing tools like carbon taxation, carbon capping etc.

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