Consumption-Based CO₂ Emissions Accounting And Scenario Simulation In Asia And Pacific Region

Mohammad Mazibar Rahman

Hajee Mohammad Danesh Science and Technology University

Nishat Anan

Hajee Mohammad Danesh Science and Technology University

Abu Hashan Md Mashud

University of New South Wales (UNSW)

Mahmudul Hasan

Jahangirnagar University

Ming-Lang Tseng (✉ tsengminglang@gmail.com)

Asia University, Taiwan <https://orcid.org/0000-0002-2702-3590>

Research Article

Keywords: consumption-based CO₂ emissions, consumption-based accounting approach, input-output analysis, carbon Intensity, embodied emissions, carbon emission peak, Monte Carlo simulation

Posted Date: September 7th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-687049/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on January 18th, 2022. See the published version at <https://doi.org/10.1007/s11356-021-18265-w>.

Abstract

This study uses a consumer-based accounting approach to evaluate CO₂ emission factors of 17 major Asia and Pacific countries that distribute all emissions in the supply chain to the commodity up to the final consumption location due to the influence of a country's consumption patterns. In addition, the number of emissions connected with each country's consumption of products and services, mainly in Asia and the Pacific countries, has received little attention. This study contributes to understand the effects of the country's consumption of products and services on carbon emission peaks and formulate efficient carbon-mitigation plans for governments and decision-makers. The accelerating economic growth and industrialization have posed significant challenges to global carbon-mitigation efforts and climate change response; as a result, each country has been provided a higher emphasis on CO₂ emission. The Monte Carlo simulation technique has been used to create a dynamic scenario simulation model to investigate possible future peaks of Asia and Pacific countries' carbon emissions, considering the uncertainties of factors. The result shows that total consumption-based CO₂ emissions are remarkable in the three Asian countries, including China (387451.95 metric tons (Mt) CO₂), Japan (185259.60 Mt CO₂), and India (100720.46 Mt CO₂). In South Korea, Brunei, and Taiwan, annual consumption emissions are 1.77, 1.62, and 1.49 tons of CO₂ per person. In terms of final consumption, the household sector is the supreme noteworthy donor to consumption-based emissions, accounting for 27–56%. The household sector probably peak at 19.7 Gt CO₂ as per the dynamic scenario simulation. As for three other types of final demand, the government expenditure will possibly reach at highest 44.0 Gt CO₂ by the next 30 years while the capital formation will probably hit its highest emissions at 149.5 Gt CO₂.

1. Introduction

The global warming phenomenon that took place many decades ago began to affect the earth significantly. This factor is most visible in emerging markets of Asia and the Pacific region, where economic growth and industrial development have been accelerated. For example, energy and heat producers released approximately 8.1 billion metric tons of CO₂ emissions between 2017 and 2019 in Asia and the Pacific region (Udemba et al., 2021). In addition, fishing in the Asia and Pacific region emitted 10 million metric tons of CO₂ in 2018 (APAC, 2018)[1]. The Pacific region emits less than 0.03 % of the world's total CO₂ emissions, which is alarming in perspective of climate change's consequences. Suppose the world continues the current trend in CO₂ emissions. In that case, the cost of climate change in the Pacific area is predicted to be between 2.9 and 12.7 % of annual gross domestic product (GDP) approximate by 2100 (ADB, 2020)[2]. Under lower carbon conditions, this cost could be considerably lower. However, it could also outweigh almost all increases in economic growth from 2100 onwards. The long-term rise of emissions leads to the increase of urbanization and GDP per capita and increases in world energy and carbon concentration unexpectedly (Peng et al., 2021 and Pandey et al., 2020). There is no indication to develop carbon-intensive industries in developing countries in reaction to climate change

policy; however, industrial growth in those countries for other purposes indirectly threatens ongoing attempts to control emissions. The regional division of production and consumption perplexes the critical issues of who is accountable for pollution.

Among all environmental pollution, mainly CO₂ emissions, has been treated as a severe problem in present sustainable business. There are two methods for calculating CO₂ emission: production-based and consumption-based accounting (CBA) (Shigeto et al., 2012; Zhang et al., 2016; and Safi et al., 2021). Production-based CO₂ emissions are generated by national output without regard to where goods are used or who uses them in the end, including exports (Peters, 2008). However, the production-based CO₂ emissions cannot calculate the embodied emissions in inter-regional trade. This method is commonly applied in global climate change policy agreements involving the Kyoto Protocol and the United Nations Framework Convention on Climate Change (Senbel et al., 2003). Conversely, CBA allocates entire pollutants in supply chains to the final buyers of goods. Furthermore, CBA has been widely used in the multi-regional input-output model (MRIO) (Liang et al., 2017; Meng et al., 2018). Hence, CBE contain imports and emissions embodied in trading; however, lacking to include exports. In contrast, production-based emissions consider total export but do not contain imports. In this direction, prior study of CBE for environmental aspects are water usages (Feng et al., 2011, 2012; Ewing et al., 2012; Cazcarro et al., 2013), materials processing (Wiedmann et al., 2015), bio-diversity losses (Lenzen et al., 2012) and land use (e.g., Yu et al., 2013a, 2013b; Weinzettel et al., 2013).

Numerous studies have been accompanied on consumption-based carbon emissions (CBCE) worldwide (Peters et al. 2011; Davis and Caldeira, 2010; Knight and Schor, 2014; Liddle, 2018a) and national level (Barrett et al. 2013; Feng et al. 2013; Mi et al. 2018; Jiborn et al. 2018; Zheng et al. 2020;). In addition, some studies have been conducted on cities level (Minx et al., 2013; Mi et al. 2016; Feng et al., 2014). However, no study has been conducted on consumption-based CO₂ emissions (CBE) for Asia and the Pacific region. Due to the perceived threat to carbon emissions peak obligation and climate changes, researchers have begun to focus on the peak of energy use and carbon emission (Huo et al. 2020; Xu and Wang, 2020; Shi et al., 2019). Most of these studies only focus on calculating CBE, identifying the impact factors, and policy recommendations. However, uncertainties of variables when predicting CO₂ emission peaks are missing for all previous studies, which is an essential trajectory for the forthcoming energy habit and carbon emissions of the commercial trade division. To remedy the existing research gap, this study attempts to focus on estimating CBE for Asia and the Pacific region and explore the possible future peaks of carbon emissions in this region.

This study makes a unique contribution to the following three aspects. (1) An econometric Leontief Input-Output model is used, which helps the researcher to evaluate CBE for 17 Asia and Pacific regions. The findings allow us to explore each country's level emissions by final demand category and the total embodied emission by export and import; (2) An enhanced Monte Carlo simulation technique has been utilized to build a dynamic carbon emission simulation model to investigate probable future CO₂ emission peaks while considering the variables' uncertainty; and (3) Total 17 comprehensives up to date

Input-Output table and carbon intensity factor have been used to estimate the total emission of each country level. Based on the study, appropriate carbon mitigation paths are established. The government and policymakers will develop reasonable and focused carbon mitigation objectives and strategies.

Our study is systematized as: Section 2 analyses the existing studies on CBCE and the carbon emission peak forecast. Section 3 outlines the methodology and origins of the dataset, and section 4 portrays the results and analysis. The final section describes the concluding remarks.

[1] Volume of carbon dioxide emissions in Asia Pacific in 2018, by sector (in million metric tons). Link: <https://www.statista.com/statistics/206126/total-carbon-dioxide-emissions-in-asia-by-sector/>

[2] The economics of climate change in the pacific. ADB annual reports 2020.

2. Literature Review

This section synthesizes the whole study in mainly two sub-parts, where the first one focuses on a critical review of CBCE. In other way, the second part scrupulously evaluates the importance of the peak forecast of carbon emissions.

2.1 Review on consumption-based carbon emissions

Numerous studies on CBCE have been carried out globally due to their necessity on human lives in emerging economics. Peters and Hertwich (2008) calculate carbon emissions in global trading for 87 nations for the year 2001. The result shows that almost 5.3 Gt of CO₂ is incorporated in trade globally and Annex B nations are net CO₂ importers. This research focuses on a quantitative assessment of how emissions from international commerce impact a country's environmental character and climate change policy. Hertwich and Peters (2009) estimated CO₂ emissions for 73 countries. In 2001, household consumption accounted for 72% of greenhouse gas emissions, 18% for investment, and 20% for Food. Household operation and maintenance accounted for 19% of GHG emissions, and transportation accounted for 17%. Davis and Caldeira (2010) generated a CBCE for 113 nations using a MRIO model and showed that 23% of worldwide CO₂ emissions, or 6.2 gigatons CO₂ were exchanged worldwide, predominantly as trades from China and former developing countries. Peters et al. (2011) created a trade-linked worldwide record for CO₂ emissions that encompassed 113 nations and 57 major industries and discovered that net emissions exchanges from emerging to advanced nations via international commerce jumped from 0.4 Gt CO₂ in 1990 to 1.6 Gt CO₂ in 2008. Knight and Schor (2014) investigated the link between economic growth and CO₂ emissions of 29 high-income nations and consumption-based emissions are more affected by economic growth than geographical emissions. Liddle (2018b) created a CBE database that calculates emissions based on domestic fossil fuel usage plus emissions embodied in imports minus exports. The study puts a panel of 20 Asian countries to the test to see how important trade is in terms of national emissions. Under a territorial consumption-based alternative paradigm. Banerjee (2021) examined the effects of border carbon adjustment (BCA) implementation on exports from developing countries and showed that the lower the BCA and domestic carbon adjustment (DCA)

rates are the more efficient to minimize the emission intensity and energy usage. Prior studies discovered that trade flows were noteworthy for CBE but not for emissions centered on territory.

There are CBCE studies conducted at the national level. For example, Wood and Dey (2009) calculated Australia's carbon footprint using a consumption-based method. From that study, one can discover that emissions associated with exports were much more significant than those associated with imports. Australia's overall carbon emissions in 2005 were 522 metric tons (Mt). Wiedmann (2009) and Barrett et al. (2013) estimated the United Kingdom's greenhouse gas emissions and revealed that CBCE had been quickly raising, with the distance between production-based and CBE growing. Feng et al. (2013) investigated the CO₂ emissions incorporated in goods in several Chinese regions and discover that products and services utilized outside of the province and production accounted for 57% of total emissions. Mi et al. (2018) utilized the MRIO table to show inter-regional and inter-sectoral economic flows for each of China's 30 regions in 2012. Zheng et al. (2020) used MRIO to assess regional decarbonization disparities and driving forces from 2012 to 2015 and determined that consumption-based emissions in China peaked in 2013, mainly owing to a peak in CBE in emerging regions. He et al. (2021) investigated the influence of financial growth and global CBE in Mexico and suggested that globalization and capital formation increase environmental quality, but energy use and economic expansion degrade it.

2.2 Study on the carbon emission peak forecast

Studies have emphasized the peak of energy usages and CO₂ emissions owing to the potential risk of the global carbon emission agreement and climate change and mostly used the top-down approach (Yuan et al. 2014; Fang et al. 2019; Sun et al. 2019) or the bottom-up model (Zhou et al. 2013; Zhou et al. 2018; McNeil et al. 2016) to predict building energy use and CO₂ emissions. The top-down approach's key objective is to examine the relationship between carbon and demographic aspects to create future forecasts. The conventional model primarily includes the IPAT model (Zhang and Zhao, 2019), STochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model (Huo et al. 2020; Xu and Wang, 2020), and computable general equilibrium model (Shi et al., 2019), and so on. For example, Zhang and Zhao (2019) utilized the STIRPAT model to assess the impact of carbon emissions in China at the national level and find that R&D investment and energy intensity have a binding effect in sinking carbon emissions in the convenience sector. Xu and Wang (2020) applied the STIRPAT method and scenario analysis to forecast Chinese CO₂ emissions in the construction and household sector and predict that energy usage in the construction and household industry will remain high, reaching 1155-1243 Mtce by 2050 and declining to 942-1116 Mtce by 2100. Using the STIRPAT model, Huo et al. (2020) provided a complete framework for urbanization and comprehensively investigate the numerous impacts of development on urban building CO₂ emission from in cooperation quantities and structural dimensions and revealed that the urban population and urban building floor size deleteriously impact carbon emissions in the construction industries. The carbon tax in the construction sector was

investigated using the computable general equilibrium model by Shi et al. (2019) and discovered that a 60 RMB per ton carbon tax is suitable and that the building industry will peak in 2025.

In addition, the bottom-up methodology breaks down the energy usages of a household into several points. This technique combines the bottom up to obtain the overall energy usage. It then uses scenario analysis to anticipate carbon emissions (Khanna et al., 2016). For example, Zhou et al. (2013) used the bottom-up modeling framework to assess the effects of various forecasts of several causes on Chinese commercial household energy demand and discovered that energy efficiency increases were insufficient to overcome the energy intensity of commercial households. Zhou et al. (2018) also developed the bottom-up paradigm of construction carbon emissions and discovered that if things continue as they are, Chinese construction energy usage will peak near 2040.

In conclusion, past research has provided us with data and methodologies for predicting future energy demand and carbon emissions based on consumption. However, there are still some significant research gaps: (1) Existing researches have predominantly focused on the effect of carbon emissions on global, national, and local levels. No previous readings emphasis on the effects of the numerous consequences of carbon emission on the future of the Asia and Pacific region. (2) In terms of the prediction model, prior research relied on steady scenario calculations to forecast future CO₂ emissions trends. However, this analysis fails to account for the uncertainties associated with future changes in the variables. The possibility of achieving carbon emission peaks is no longer possible. (3) The regional division between Asia and Pacific countries of production and consumption makes it the critical issue of who is accountable for pollution. The climate change mitigation responsibility that can be distributed under uncertainty has remained unclear till now. This situation may make it difficult for the policymaker to implement efficient carbon emissions reduction strategies.

This study proposes a complete input-output model to estimate CBCE to address the drawbacks in the existing studies. Then, considering the uncertainty of the parameters, a dynamic simulation model implemented using the Monte Carlo simulation method to investigate the probable peaks of carbon emissions in households, government expenses, capital development, and variation in inventory sectors.

3. Method

3.1 Data

This study uses the Leontief input-output model to estimate CBCE for 17 countries in Asia and the Pacific. Data on trade, input-output by sector, and CO₂ emissions based on final demand, export, and import are all taken from OECD 2015 Input-Output table dataset 2018 edition. Input-Output table dataset covers 35 socio-economic sectors and ten primary industry products. In addition, GDP, population, country area, energy consumption data are received from the World Development Indicators database. This study updates regional energy consumption and CO₂ emissions to incorporate all key "commercial" energy

sources. Finally, carbon intensity from each economic sector is calculated using the guidelines referred by the IPCC territorial emissions accounting method.

3.2 Input-output model

The input-output model is one of the most extensively applied methodologies for assessing CBE. This technique has been used in various research, including environmental challenges (Liddle, 2018a).

The I-O calculation is focused on financial flows among industries and countries/regions.,

$$X = \begin{pmatrix} x_{11} \\ x_{12} \\ x_{13} \\ \vdots \\ x_m \end{pmatrix}; Y = \begin{pmatrix} y_{11}y_{21}y_{31}\dots y_{1m} \\ y_{12}y_{22}y_{32}\dots y_{2m} \\ y_{13}y_{23}y_{33}\dots y_{3m} \\ \vdots \vdots \vdots \ddots \vdots \\ y_{m1}y_{m2}y_{m3}y_{mm} \end{pmatrix}; A = \begin{pmatrix} A_{11}A_{21}A_{31}\dots A_{1m} \\ A_{12}A_{22}A_{32}\dots A_{2m} \\ A_{13}A_{23}A_{33}\dots A_{3m} \\ \vdots \vdots \vdots \ddots \vdots \\ A_{m1}A_{m2}A_{m3}A_{mm} \end{pmatrix}$$

As a result, the I-O structure can be expressed as:

$$X = Ax + y \quad (1)$$

After calculating x, one can find

$$X = (I - A)^{-1}y \quad (2)$$

where $(I - A)^{-1}$ is the inverse Leontief matrix that incorporates the direct economic inputs to fulfill one unit of final monetary demand; I denotes the identity matrix.

We need the carbon intensity for all sectors of the economy to compute CBE. For example, suppose k_i is the carbon intensity of sector i. In that case, the CBCE are computed as:

$$CO_2 = k (I - A)^{-1}y \quad (3)$$

where CO_2 is a vector of the total CO_2 emissions embodied in goods and services used for the final demand of all regions, and k indicates a vector of CO_2 emissions per unit of economic output in all regions.

To estimate the embodied emissions from imports, we modify Eq. (3) to:

$$CO_2^{im} = \tilde{k}(I - A)^{-1}y^p \quad (4)$$

where CO_2^{im} is the total emissions embodied in import of regions; $\tilde{k}$ denotes a vector of coefficients for sectoral CO_2 emissions; and y^p indicates the final demand vector of region p .

3.3 Monte Carlo simulation technique

The Monte Carlo simulation approach was cast-off to assess the threat of construction projects. It is now a popular method for dynamic prediction. However, it may need recalculations of variables until it is completed, depending on the figure of uncertainties and the ranges provided for them (Meinshausen et al., 2009; and Vithayasrichareon and MacGill, 2012). Even though the technique may reasonably estimate the index of carbon emissions, it overlooks the impact of energy efficiency and carbon mitigation across policy and socio-economic considerations. The Monte Carlo simulation approach is used in this study to estimate CBCE probable emission peaks dynamically. There are three phases involved in using Monte Carlo simulation: (1) Specify the variables' level of uncertainty. Variables can have various odds of distinct outcomes occurring by employing probability distributions. Each variable satisfies the normal distribution and may be characterized using the mean value (μ) and standard deviation (σ) to assure simulation accuracy. The value must be within the probability ranges to encompass the variable's height and lowest value interval (95%) represented by $\pm 2\sigma$. (2) Run 50,000 stochastic simulations based on predetermined probabilities and distributions to precisely determine the probability distribution of each variable. (3) Use probability distribution diagrams to present the simulation findings.

4. Result And Discussion

4.1 Domestic and Imported Emissions

CBE consist of imported emissions and domestic emissions. For most countries, imported emissions exceeded domestic emissions in 2015 (see Fig. 1). Approximately 60% of consumption-based emissions in nations such as Australia, New Zealand, Malaysia, Singapore, and Thailand are imported from other countries. In terms of overall consumption-based emissions, Hong Kong has the most significant percentage of imported emissions. Its imports are around nine times higher than its ultimate consumption. Therefore, Hong Kong is reliant on commodities and services produced elsewhere in the world. More than 50% of CBCE arise within national areas in various countries, including Brunei, China, India, Indonesia, Japan, South Korea, and Russia. For two reasons, approximately 24% of Russia's emissions are imported from neighboring areas. First, Russia imports less than the other countries. Second, Russia's exports have a far greater carbon intensity than its imports.

4.2 Emissions in Final Demand

In the viewpoint of CO_2 emissions in final consumption, final demand includes four categories, including capital formation, government expenditure, changes in inventories, and household consumption. In Fig. 2, the highest contributor to consumer-based emissions is household consumption. Vietnam has the largest proportion of emissions attributable to household consumption. Household consumption accounts for a variety of emissions percentages, such as 54% (Australia), 49% (India), 60% (Japan), 60% (Russia), 65%

(South Korea), 70% (Taiwan) and 75% (Vietnam). Consumption-based emissions are substantially influenced by urbanization, major economic development, and government controls. In five nations, capital formation accounts for more than 40% of emissions, i.e., Brunei (56%), China (52%), Indonesia (46%), Thailand (46%), and India (45%). Brunei has the largest percentage of capital formation-related emissions, which are determined by the consumption behavior of this country. In 2015, capital formation represented approximately 56% of the total final demand in the country.

4.3 Carbon Intensity of Trade

Figure 3 shows the mean carbon concentration of trade in terms of kg CO₂ per US\$ of exports or imports of each country. Carbon intensity is premeditated by the quantity of CO₂ emissions per unit energy (ft) divided by the amount of energy consumption per US\$ of trade of an individual country. Brunei, Japan, South Korea, and China have the highest total carbon intensity in exports due to the scarcity of carbon-intensive fuels like coal in these regions and the low volume of energy-intensive exports. On the other hand, New Zealand, the Philippines, and Indonesia require a higher value per unit of energy for their exports. In addition, a more significant percentage of that energy was produced using the low-carbon innovation technique. Central Pacific export markets have a much lower carbon intensity than Asian economies.

Goods imported into Cambodia and Indonesia contain significantly higher CO₂ per US \$ than their exports, representing imports of energy-intensive commodities abroad. On the other hand, the carbon intensity of imports to Brunei, Japan, South Korea, China, and India is significantly lower than their exports. For example, imports to South Korea, India, and China entail 0.37, 0.27, and 0.24 (MJ) per US\$, respectively. Imports have the same carbon intensity as exports in New Zealand, indicating a tighter balance of manufacturing and service sectors in the New Zealand economy.

4.4 Embodied Emission in Exports and Imports

Figure 3 displays the carbon emissions in personified imports and exports, which differ significantly in the 17 Asia and Pacific countries. Emissions exemplified in imports in the three Asian nations of Japan, China, and India are significantly higher than in other pacific nations. For instance, Japan emits 3.16 Gt CO₂ emissions embodied in imports, which is 99 times greater than Brunei. The sectors of mining support; electricity, gas, water supply; and construction contribute the most significant emissions embodied in imports. Mining support imports in China emit 52.08 Gt CO₂, accounting for 2.4% of total embodied emissions of imports. However, in India, the imports of Mining support produce 35.19 Gt CO₂, which is the highest embodied imported emission in this country. Electricity, gas, and water contribute the highest CO₂ emission in imports in China (93.83 Gt CO₂) and South Korea (25.52 Gt CO₂). Furthermore, the building industry contributes significantly higher carbon emissions to Australia (13.19 Gt CO₂), Japan (11.67 Gt CO₂), and India (5.51 Gt CO₂). Additionally, emissions imported to China exceed far that of any other country, mainly embodied in agriculture, forestry and fishing (3.09 Gt); textiles, wearing apparel, leather (3.58 Gt); coke and refined petroleum (4.92 Gt); manufacture of basic metals (3.82 Gt); fabricated metal products (3.92 Gt); telecommunications (4.51 Gt); and financial and insurance activities (8.25 Gt).

Figure 4 indicated that the embodied emissions in most countries' exports are higher than the embodied emissions in their imports. Such as, the emissions embodied in China's trades have 166.14 Gt CO₂, but those of its imports are just 2.82 Gt CO₂. Furthermore, China's manufacturing has a lower carbon intensity than its exports. One unit of imports emits more CO₂ than a comparable unit of exports. Nevertheless, in New Zealand and the Philippines, the embodied emissions in exports are lower than those in imports. In many areas, consumer duty outweighs producer accountability. For example, the following exports are responsible for China's massive emissions imbalance: real estate activities (317.12 Gt CO₂), mining support (233.56 Gt), arts, entertainment (166.14 Gt), electricity, gas, water supply (69.52 Gt), agriculture, forestry and fishing (26.93 Gt), and financial and insurance activities (358 Gt).

In Fig. 5, row 1, this study illustrates the CBCE for the top 10 countries in Asia and the Pacific region. The four Asian countries have the highest overall consumption-based emissions, such as China (387451.95 Mt CO₂), Japan (185259.60 Mt CO₂), India (100720.46 Mt CO₂), and S. Korea (90223.37 Mt CO₂). China and India ranked top two countries for emitting the highest CO₂ emissions, 59604.16 and 57499.86 kg per \$GDP, respectively. Figure 5, row 1 shows that in South Korea, Brunei, and Taiwan, annual consumption-based emissions are 1.77, 1.62, and 1.49 tons of CO₂ per person, respectively.

Consumption-based emissions per capita in China are extremely low, at 0.28 tones CO₂ per person. However, the overall consumption-based emissions in this country are very high. A significant difference between per capita emissions and consumption-based emissions has been illustrated based on total carbon emissions and per capita consumption. Therefore, the methods of computing emissions have a substantial impact on determining who is responsible for climate change mitigation. This study is in line with Peters and Hertwich (2008); Peters et al. (2011); and Knight and Schor (2014), who estimate similar findings. Therefore, when determining equitable mitigation measures, consumption-based carbon accounting methodologies must be thoroughly evaluated (Caney, 2009).

In Fig. 5 indicated the total emissions embodied in imports are presented. Emerging economies are more likely to import CO₂ emissions. Being the most developing nations in Asia and the Pacific, China and Japan have the highest emissions embodied in imports. In contrast, in two less advanced countries, the least number of emissions are embodied in imports in Brunei and Cambodia. It indicates that manufacturing-based nations continue to grow consumption-based nations as these nations progress socioeconomically. Overall imported emissions are most significant in, i.e., China (243863.34 Mt CO₂), Japan (116816.47 Mt CO₂), India (86680.84 Mt CO₂), and S. Korea (66022.48 Mt CO₂). India is the highest CO₂ emitter in imported per \$GDP. Hongkong and Singapore ranked first and second positions for per capita imported emissions, 2.94 and 2.89 tones per capita. The conclusions of this study support Feng et al. 2013; and Mi et al. 2018 who calculate country-level CBE. In the circumstance of exports (Fig. 5, row 4, Left), emissions embodied in exports are most significant in Taiwan and Korea, which is a primary reason for these countries' high production-based CO₂ emissions. Korea and Japan ranked first and the second position for per capita exported emissions such as 85.5 and 24.35 tones per person.

Using 50,000 Monte Carlo simulations, we show the likely CO₂ emission peaks in four final demand categories (Fig. 6). This study uses 95 percent confidence intervals to choose probable simulation results that follow a normal distribution to reduce the effects of extreme values. The mean value of expected carbon emissions changes in inventory is 0.43 Gt, with a standard deviation of 0.86 Gt (Fig. 6d). The most likely peaking range is between - 1.0 and 1.2 Gt CO₂. Therefore, compared to 2015, inventory carbon emissions will grow by 35% - 70% during the next 30 years. As a result, there will be continued pressure on inventory modifications to decrease energy use and carbon emissions.

Figures 6a-6c showed the probable emissions peak of prospective CO₂ emissions in the household, government expenditure, and capital formation. The household sector is expected to peak at 19.7 Gt CO₂. The estimated emission peaks are probably between - 2.6 and 25.7 Gt CO₂ (Fig. 6a). In contrast, the maximum emission peak ranges for the government expenditure will be between - 16.0 and 20.0 Gt CO₂ (Fig. 6b). However, the highest probable emission peak is 8.0 Gt CO₂. Future CO₂ emissions from the capital formation will be like those from the household division. The maximum emission peak of the capital formation ranges between - 25.4 Gt and 44.5 Gt CO₂, with an average value of 17.85 Gt CO₂. Therefore, the household sector and capital formation will continue to be the key contributors to the Asia and Pacific region's carbon emission peaks in the near prospect.

To summarize the Monte Carlo simulation findings, we find that dynamic scenario simulation of CO₂ emissions peak is achievable. Therefore, the overall household consumption will exceed a peak of 131.64 Gt CO₂ very soon. As for three other types of final demand, the government expenditure will possibly reach at highest 44.0 Gt CO₂ by the next 30 years, while the capital formation will probably hit its highest emissions at 149.5 Gt CO₂ at the exact times. Also, the change in inventory is likely to achieve its highest emissions at 3.6 Gt CO₂. Thus, based on the initial findings, the household and capital formation sectors would be the primary contributors to the emission peaks. Despite several studies demonstrating the use of consumer-based accounting methods in investigating the causes of carbon emissions rise (Brizga et al., 2014; Wiedmann et al., 2015), few countries incorporate consumption-based indexes in their policy programs (Yu et al., 2010; Barrett et al., 2013).

5. Concluding Remarks

Asia and Pacific countries are experiencing the most extensive industrialization practice, which is precisely adopting high energy demand and carbon emissions. The collaborations between consumption and production areas are essential for climate change mitigation. An increasing number of academics and policymakers are accepting CBE accounting for climate change policies. This study estimates consumption-based carbon emissions for 17 major Asia and Pacific countries. Also, the dynamic scenario simulation has been executed to reconnoiter the possessions of the future carbon emissions peaks in the household, government expenses, capital development, and change in inventory sectors. The following are the key findings:

1. Australia, New Zealand, Malaysia, Singapore, and Thailand are imported other than 65% of CBCE from other countries in 2015. In standings of overall CBCE, Hong Kong produces the greatest percentage of import emissions. Total imports of Hong Kong exceed its ultimate consumption by roughly nine times. Household consumption is the most significant source which contributes to maximum consumer-based emissions among 17 countries. The percentage of emission generated by household consumption range from 54% (Australia), 49% (India), 60% (Japan), 60% (Russia), 65% (South Korea), 70% (Taiwan), and 75% (Vietnam). As Asia and the Pacific countries continue to urbanize, more people will shift from rural to urban lifestyles, resulting in higher CO₂ emissions from household consumption. The capital formation seems to be the second-highest source of emissions. Rapid urbanization, extensive economic expansion, and government strategies contribute to significantly high capital-intensive funding to consumer-based emissions.
2. Emissions embodied in imports for the four Asian countries such as Japan, China, India, and South Korea are significantly higher than other pacific countries. For instance, Japan has 3.16 Gt CO₂ embodied emissions in imports, which is 99 times higher than Brunei. The sectors of Mining support; Electricity, gas, water supply; and construction contribute the most significant emissions embodied in imports. E.g., in China, the imports of Mining support produce 52.08 Gt CO₂, accounting for 2.4% of total import emissions. Most countries' export emissions exceed their import emissions. However, export embodied emissions in New Zealand, and the Philippines are lower than import embodied emissions. Exports of real estate activities (317.12 Gt CO₂), Mining support (233.56 Gt), and Arts, entertainment (166.14 Gt) are responsible for China's massive emissions imbalance. Total consumption-based emissions indicate most remarkable for the three Asian countries, such as China (387451.95 Mt CO₂), Japan (185259.60 Mt), and India (100720.46 Mt). In South Korea, Brunei, and Taiwan, annual consumption-based emissions are 1.77, 1.62, and 1.49 tons of CO₂ per person.
3. The household sector would be most likely to achieve a high peak at 19.7 Gt CO₂, according to the dynamic scenario simulation. The household range's highest probable emission peak will be between – 2.6 and 25.7 Gt CO₂ (Fig. 6a). As for three other types of final demand, the government expenditure's possible emission peak will range from – 16.0 to 20.0 Gt CO₂. The highest emission peak will be 8.0 Gt (Fig. 6b). Future CO₂ emissions in the capital formation sector will resemble those in the household sector. Capital formation contributes most likely emission peak range between – 25.4 Gt and 44.5 Gt, with an average value of 17.85 Gt CO₂. Thus, the household and capital formation sectors will account for the majority of the emission peaks.

The following suggestions are made. The industrial arrangement and the exposure of these industries to compete in international markets must be adjusted to segregate the connection among CO₂ emissions and industrial production. The low-carbon development of the primary industry must be promoted. Carbon pricing policies can be implemented by a tax to give a direct financial incentive to reduce emissions (Toptal et al., 2014). For example, existing markets can include the cost of cutting emissions into the prices of all goods and services in a seamless manner. Moreover, carbon taxes or trading give the industry a persistent price signal to cut emissions where it is most cost-effective (Shi et al., 2019). A vital

component of climate mitigation policy is investing in breakthrough clean energy and emissions reduction technologies (Mashud et al., 2021a; Mishra et al., 2021). The federal government might enhance financing for this effort. Finally, to regulate the energy intensity, more rigorous energy efficiency requirements and energy consumption goal systems should be implemented as a strategy for combating climate change and developing new technologies. More sustainable and greener energy sources (Mashud et al., 2021b) should be created to reduce carbon emissions.

Declarations

Author Contributions

Mohammad Mazibar Rahman- Conceptualize, original version and finalized the final version; Nishat Anan- Conceptualize, original version and finalized the final version; Abu Hashan Md Mashud- Conceptualize, original version and finalized the final version; Mahmudul Hasan- Conceptualize, original version and finalized the final version; Ming-Lang Tseng- original version and finalized the final version

Availability of data and materials

No authorized

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Competing Interests

Not applicable

Ethical Approval

Not applicable

Funding

Not applicable

References

1. Banerjee S (2021) Carbon adjustment in a consumption-based emission inventory accounting: a CGE analysis and implications for a developing country. *Envi Sci Pollut Res* 28(16):19984–20001

2. Barrett J, Peters G, Wiedmann T, Scott K, Lenzen M, Roelich K, Le (2013) Quéré, C. Consumption-Based GHG Emission Accounting: A UK Case Study. *Clim Policy* 13(4):451–470
3. Brizga J, Feng K, Hubacek K (2014) Drivers of greenhouse gas emissions in the Baltic States: a structural decomposition analysis. *Ecol Econ* 98:22–28
4. Caney S (2009) Climate change and the duties of the advantaged. *Crit Rev Int Soc Polit Philos* 12:693–717
5. Cazcarro I, Duarte R, Sanchez-Choliz J Water Footprints for Spanish Regions Based on a Multi-Regional Input-Output (MRIO) Model. *Sustain. Pract. Guide Multi-Regional Input-Output Anal.* Murray J, Lenzen M Eds 2013, 119–132
6. Davis SJ, Caldeira K Consumption-Based Accounting of CO₂ Emissions. *Proc. Natl. Acad. Sci.* 2010, 107 (12), 5687–5692
7. Ewing BR, Hawkins TR, Wiedmann TO, Galli A, Ercin AE, Weinzettel J, Steen-Olsen K (2012) Integrating Ecological and Water Footprint Accounting in a Multi-Regional Input–Output Framework. *Ecol Indic* 23:1–8
8. Fang K, Tang Y, Zhang Q, Song J, Wen Q, Sun H, Ji C, Xu A (2019) Will China Peak Its Energy-Related Carbon Emissions by 2030? Lessons from 30 Chinese Provinces. *Appl Energy* 255:113852
9. Feng K, Chapagain A, Suh S, Pfister S, Hubacek K (2011) Comparison of Bottom-up and Top-down Approaches to Calculating the Water Footprints of Nations. *Econ Syst Res* 23(4):371–385
10. Feng K, Davis SJ, Sun L, Li X, Guan D, Liu W, Liu Z, Hubacek K Outsourcing CO₂ within China. *Proc. Natl. Acad. Sci.* 2013, 110 (28), 11654–11659
11. Feng K, Hubacek K, Sun L, Liu Z, Consumption-Based CO₂ Accounting of China's Megacities: The Case of Beijing, Tianjin, Shanghai and Chongqing. *Ecol Indic* 47:26–31
12. Feng K, Siu YL, Guan D, Hubacek K (2012) Assessing Regional Virtual Water Flows and Water Footprints in the Yellow River Basin, China: A Consumption Based Approach. *Appl Geogr* 32(2):691–701
13. He X, Adebayo TS, Kirikkaleli D, Umar M (2021) Consumption-based carbon emissions in Mexico: An analysis using the dual adjustment approach. *Sustain. Prod. and Con.* 2021, 27, 947–957
14. Hertwich EG, Peters GP (2009) Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environ Sci Technol* 43(16):6414–6420
15. Huo T, Li X, Cai W, Zuo J, Jia F, Wei H (2020) Exploring the Impact of Urbanization on Urban Building Carbon Emissions in China: Evidence from a Provincial Panel Data Model. *Sustain Cities Soc* 56:102068
16. Jiborn M, Kander A, Kulionis V, Nielsen H, Moran DD (2018) Decoupling or Delusion? Measuring Emissions Displacement in Foreign Trade. *Glob Environ Change* 49:27–34
17. Khanna NZ, Zhou N, Fridley D, Ke J (2016) Quantifying the Potential Impacts of China's Power-Sector Policies on Coal Input and CO₂ Emissions through 2050: A Bottom-up Perspective. *Util Policy* 41:128–138

18. Knight KW, Schor JB (2014) Economic Growth and Climate Change: A Cross-National Analysis of Territorial and Consumption-Based Carbon Emissions in High-Income Countries. *Sustainability* 6(6):3722–3731
19. Lenzen M, Moran D, Kanemoto K, Foran B, Lobefaro L, Geschke A (2012) International Trade Drives Biodiversity Threats in Developing Nations. *Nature* 486(7401):109–112
20. Liang S, Feng T, Qu S, Chiu AS, Jia X, Xu M (2017) Developing the Chinese Environmentally Extended Input-Output (CEEIO) Database. *J Ind Ecol* 21(4):953–965
21. Liddle B (2018a) Consumption-Based Accounting and the Trade-Carbon Emissions Nexus. *Energy Econ* 69:71–78
22. Liddle B Consumption-Based Accounting and the Trade-Carbon Emissions Nexus in Asia: A Heterogeneous, Common Factor Panel Analysis. *Sustainability* 2018b, 10 (10), 3627
23. Mashud AHM, Roy D, Daryanto Y, Chakraborty RK, Tseng ML (2021a) A sustainable inventory model with controllable carbon emissions, deterioration and advance payments. *J Cleaner Prod* 296:126608
24. Mashud AHM, Pervin M, Mishra U, Daryanto Y, Tseng ML, Lim MK (2021b) Supply Chain Inventory Model for Controllable Deterioration and Emission Rates in a Greenhouse Farm. *Math* 9(5):1–23
25. McNeil MA, Feng W, du Can S, de la R; Khanna, Ke NZ, Zhou J (2016) N. Energy Efficiency Outlook in China's Urban Buildings Sector through 2030. *Energy Policy* 97:532–539
26. Meinshausen M, Meinshausen N, Hare W, Raper SC, Frieler K, Knutti R, Frame DJ, Allen MR (2009) Greenhouse-Gas Emission Targets for Limiting Global Warming to 2 C. *Nature* 458(7242):1158–1162
27. Meng J, Mi Z, Guan D, Li J, Tao S, Li Y, Feng K, Liu J, Liu Z, Wang X (2018) The Rise of South–South Trade and Its Effect on Global CO₂ Emissions. *Nat Commun* 9(1):1–7
28. Mi Z, Meng J, Zheng H, Shan Y, Wei Y-M, Guan DA (2018) Multi-Regional Input-Output Table Mapping China's Economic Outputs and Interdependencies in 2012. *Sci Data* 5(1):1–12
29. Mi Z, Zhang Y, Guan D, Shan Y, Liu Z, Cong R, Yuan X-C, Wei Y-M (2016) Consumption-Based Emission Accounting for Chinese Cities. *Appl Energy* 184:1073–1081
30. Minx J, Baiocchi G, Wiedmann T, Barrett J, Creutzig F, Feng K, Förster M, Pichler P-P, Weisz H, Hubacek K (2013) Carbon Footprints of Cities and Other Human Settlements in the UK. *Environ Res Lett* 8(3):035039
31. Mishra U, Mashud AHM, Tseng ML, Wu JZ, Optimizing a Sustainable sustainable inventory model with controllable carbon emissions in green-warehouse farms. *J. of Cleaner Production*, 2021, 126777
32. Pandey S, Dogan E, Taskin D (2020) Production-based and consumption-based approaches for the energy-growth-environment nexus: Evidence from Asian countries. *Sustain Prod Con* 23:274–281
33. Peng H, Qi S, Cui J (2021) The environmental and economic effects of the carbon emissions trading scheme in China: The role of alternative allowance allocation. *Sustain Prod Con* 28:105–115

34. Peters GP (2008) From Production-Based to Consumption-Based National Emission Inventories. *Ecol Econ* 65(1):13–23
35. Peters GP, Hertwich EG (2008) CO₂ Embodied in International Trade with Implications. for Global Climate Policy; ACS Publications
36. Peters GP, Minx JC, Weber CL, Edenhofer O Growth in Emission Transfers via International Trade from 1990 to 2008. *Proc. Natl. Acad. Sci.* 2011, 108 (21), 8903–8908
37. Safi A, Chen Y, Wahab S, Ali S, Yi X, Imran M (2021) Financial Instability and Consumption-based Carbon Emission in E-7 Countries: The Role of Trade and Economic Growth. *Sustain Prod Con* 27:383–391
38. Senbel M, McDaniels T, Dowlatabadi H (2003) The Ecological Footprint: A Non-Monetary Metric of Human Consumption Applied to North America. *Glob Environ Change* 13(2):83–100
39. Shi Y, Zhang Z, Chen SC, Cárdenas-Barrón LE, Skouri K (2019) Optimal replenishment decisions for perishable products under cash, advance, and credit payments considering carbon tax regulation. *Int J Prod Econ* 223:107514
40. Shigeto S, Yamagata Y, Ii R, Hidaka M, Horio M (2012) An Easily Traceable Scenario for 80% CO₂ Emission Reduction in Japan through the Final Consumption-Based CO₂ Emission Approach: A Case Study of Kyoto-City. *Appl Energy* 90(1):201–205
41. Sun Z, Liu Y, Yu Y (2019) China's Carbon Emission Peak Pre-2030: Exploring Multi-Scenario Optimal Low-Carbon Behaviors for China's Regions. *J Clean Prod* 231:963–979
42. Toptal A, Ozlu H, Konur D (2014) Joint decisions on inventory replenishment and emission reduction investment under different emission regulations. *Int J Prod Res* 52(1):243–269
43. Udemba EN, Güngör H, Bekun FV, Kirikkaleli D (2021) Economic performance of India amidst high CO₂ emissions. *Sustain Prod Con* 27:52–60
44. Vithayasrichareon P, MacGill IF (2012) A Monte Carlo Based Decision-Support Tool for Assessing Generation Portfolios in Future Carbon Constrained Electricity Industries. *Energy Policy* 41:374–392
45. Weinzettel J, Hertwich EG, Peters GP, Steen-Olsen K, Galli A (2013) Affluence Drives the Global Displacement of Land Use. *Glob Environ Change* 23(2):433–438
46. Wiedmann TA (2009) Review of Recent Multi-Region Input–Output Models Used for Consumption-Based Emission and Resource Accounting. *Ecol Econ* 69(2):211–222
47. Wiedmann TO, Schandl H, Lenzen M, Moran D, Suh S, West J, Kanemoto K The Material Footprint of Nations. *Proc. Natl. Acad. Sci.* 2015, 112 (20), 6271–6276
48. Wood R, Dey CJ (2009) Australia's Carbon Footprint. *Econ Syst Res* 21(3):243–266
49. Xu G, Wang W (2020) China's Energy Consumption in Construction and Building Sectors: An Outlook to 2100. *Energy* 195:117045
50. Yavari M, Ajalli P Suppliers' coalition strategy for green-Resilient supply chain network design, *J. of Indus. and Prod. Eng.* 2021, 38(3), 197–212

51. Yu Y, Feng K, Hubacek K Consumption-Based Inventory of Global Land Use. *Enough Forever Handb. Learn. Sustain.* 2013a
52. Yu Y, Feng K, Hubacek K (2013b) Tele-Connecting Local Consumption to Global Land Use. *Glob Environ Change* 23(5):1178–1186
53. Yu Y, Hubacek K, Feng K, Guan D (2010) Assessing Regional and Global Water Footprints for the UK. *Ecol Econ* 69(5):1140–1147
54. Yuan J, Xu Y, Hu Z, Zhao C, Xiong M, Guo J (2014) Peak Energy Consumption and CO₂ Emissions in China. *Energy Policy* 68:508–523
55. Zhang B, Qiao H, Chen ZM, Chen B (2016) Growth in Embodied Energy Transfers via China's Domestic Trade: Evidence from Multi-Regional Input–Output Analysis. *Appl Energy* 184:1093–1105
56. Zhang S, Zhao T (2019) Identifying Major Influencing Factors of CO₂ Emissions in China: Regional Disparities Analysis Based on STIRPAT Model from 1996 to 2015. *Atmos Environ* 207:136–147
57. Zheng H, Zhang Z, Wei W, Song M, Dietzenbacher E, Wang X, Meng J, Shan Y, Ou J, Guan D (2020) Regional Determinants of China's Consumption-Based Emissions in the Economic Transition. *Environ Res Lett* 15(7):074001
58. Zhou N, Fridley D, Khanna NZ, Ke J, McNeil M, Levine M (2013) China's Energy and Emissions Outlook to 2050: Perspectives from Bottom-up Energy End-Use Model. *Energy Policy* 53:51–62
59. Zhou N, Khanna N, Feng W, Ke J, Levine M (2018) Scenarios of Energy Efficiency and CO₂ Emissions Reduction Potential in the Buildings Sector in China to Year 2050. *Nat Energy* 3(11):978–984

Figures

Figure 1

Domestic and imported emissions from overall consumption-based carbon emissions.

Figure 2

Embodied CBCE of the final demand categories

Figure 3

Mean value of carbon intensity of imports and exports countries

Figure 4

CO2 emissions embodied in imports and exports for Asia and Pacific regions

Top 10 Consumption-based Emissions

Top 10 Net Export of Emissions

Top 10 Net Import of Emissions

Figure 5

Top 10 countries/regions by consumption emissions, net imports, and net exports.

Figure 6

Possible emission peaks of CBCE.