Embodied GHG Emissions in ASEAN: A Multi-Regional Input-Output Analysis

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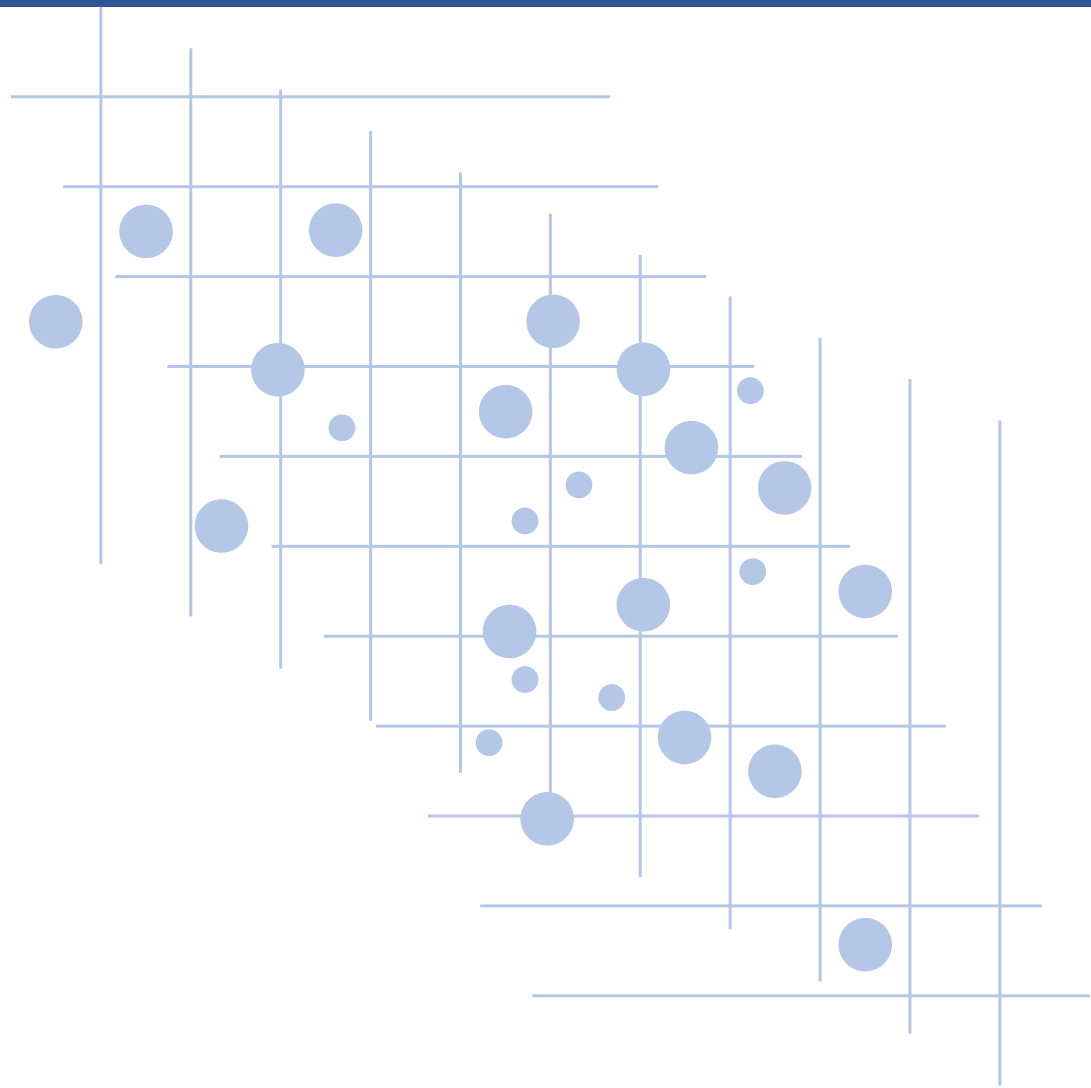


1. Introduction

- ✓ The Association of Southeast Asian Nations (ASEAN), consisting of ten Southeast Asian countries, is often referred to as "a global growth center" due to its increasingly significant role in the world economy.
- ✓ The population of ASEAN has increased nearly fourfold over the past 70 years, and it is projected to reach 790 million by 2050 (International Energy Agency (IEA), 2024).
- ✓ This demographic growth is expected to double the region's energy demand compared to 2020 levels (International Energy Agency (IEA), 2024).
- ✓ There are growing concerns over the stability of future energy supply and the accompanying increase in greenhouse gas (GHG) emissions.

(Association of southeast Asian nations, Asean main portal)

1. Introduction

- ✓ In response, ASEAN countries are aiming for carbon neutrality between 2050 and 2065 in line with the Paris Agreement and are actively promoting measures to reduce CO_2 emissions (United Nations Framework Convention on Climate Change, 2015).
- ➢ However, the region remains heavily dependent on inexpensive and abundant fossil fuels, while the share of renewable energy in its energy mix remains relatively low (ASEAN Centre for Energy, 2024).
- ✓ Fossil fuels are extensively used directly and indirectly across a wide range of industries through regional supply chains. This results in substantial CO_2 emissions across the ASEAN industrial sector.
- ✓ Due to its relatively low labor costs, ASEAN serves as a vital supplier of intermediate goods and a production and market base for multinational corporations. Consequently, CO_2 emissions in ASEAN are not only driven by domestic demand but are also significantly influenced by global demand through international trade.
- ➢ It is essential to quantitatively assess CO_2 emissions from the ASEAN region while accounting for its embedded role in international supply chains.

1. Introduction

Literature review

- In many cases, prior studies on environmental burdens in the ASEAN region have focused on the relationship between ongoing economic growth and greenhouse gas (GHG) or CO_2 emissions within the region (Yoo, 2006; Lean and Smyth, 2010). These studies commonly employ regression analysis techniques to investigate these relationships and do not consider the complex structure of supply chains.
- To address CO_2 emissions associated with complex inter-industry transactions, the environmentally extended input–output (EEIO) model provides a comprehensive framework for quantifying emissions associated with commodity supply chains (Liang *et al*., 2017).
- Multi-regional input-output (MRIO) models are particularly useful for capturing inter-industry transactions embedded in global supply chain (Wiedman, 2009) which is important considering ASEAN's role in international trade.
- So far, A few studies regarding GHG emissions using IO models have not conducted a comprehensive analysis covering all ten ASEAN countries (Amheka *et al*., 2022).

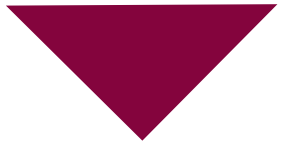
1. Introduction

Objective of this study

- To quantitatively estimate both the direct and indirect CO_2 emissions from all ten ASEAN member countries using a MRIO model, considering global supply chains.

Given the diverse levels of economic development, industrial structures, policy approaches, and historical contexts among ASEAN countries, achieving a coordinated effort toward decarbonization across the region remains a significant challenge.

Taking this into consideration, this study analyzes the embodied CO_2 emissions of each country in relation to its specific characteristics and background.

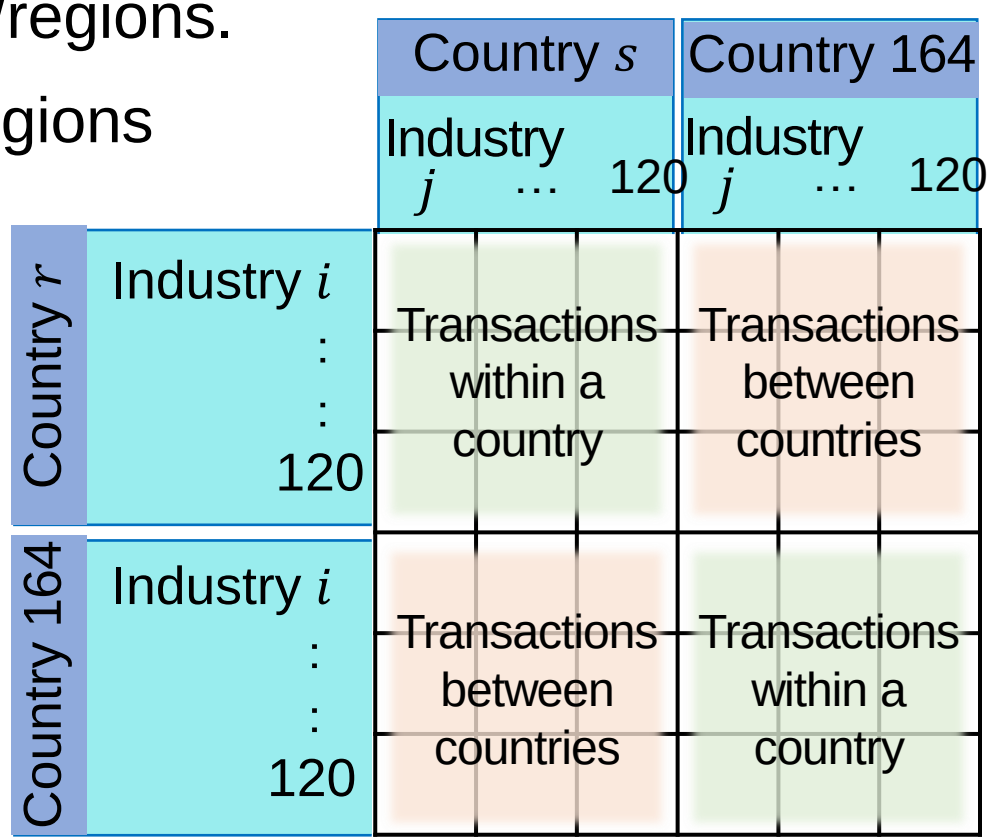


- Based on these insights, we further discuss potential strategies for promoting effective decarbonization within the ASEAN region.

2. Methodology and data

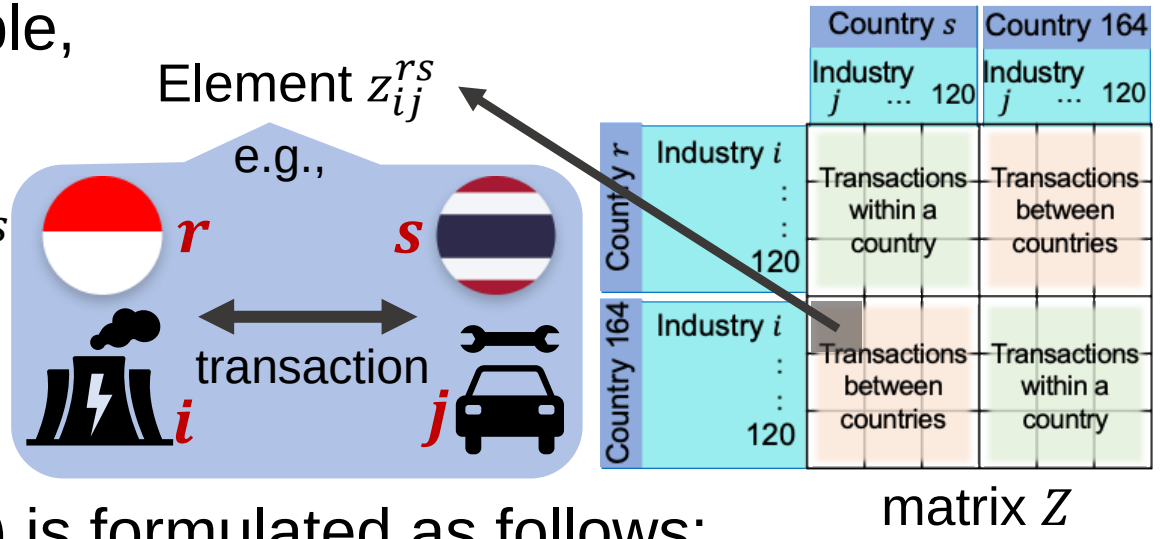
Data used in this study

- This study uses the Release 059 of the GLORIA global environmentally-extended multi-regional input-output (MRIO) database (Lenzen *et al*., 2021), constructed in the Global MRIO Lab (Lenzen et *al*. 2017).
- The MRIO table constructed from this database represents inter-industry transactions in 2019 among 120 industries across 164 countries/regions.
- Direct CO_2 emission data for these 164 countries/regions are also provided by the GLORIA database.
- All 10 ASEAN countries are included in the dataset.



MRIO table

- Using a multi-regional input-output (MRIO) table, inter-industry transactions among *N* countries and *M* industries are represented by the intermediate input matrix $Z = (z_{ij}^{rs})$, where z_{ij}^{rs} denotes the intermediate input from industry i in country r to industry j in country s.



- The traditional Leontief model (Leontief, 1953) is formulated as follows:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{L}\mathbf{f} \qquad (1)$$

$\mathbf{x} = (x_i^r)$: Output vector of industry i in country r

$\mathbf{I}$: Identity matrix

$\mathbf{A} = (a_{ij}^{rs})$: Intermediate input coefficient matrix, indicating the inputs from industry i in country r required to produce one unit of output in industry j in country s.

$\mathbf{L} = (l_{ij}^{rs})$: Leontief inverse matrix , which represents the output of industry i in country r irectly and indirectly required per unit of final demand in industry j in country s

$\mathbf{f} = (f_i^r)$: Final demand vector for industry i in country r

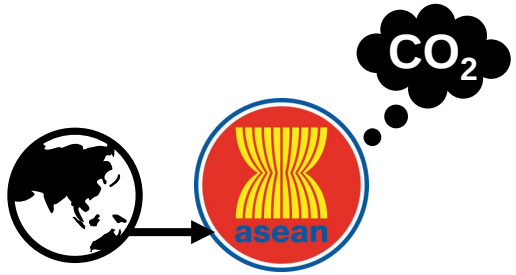
- CO_2 emissions from industry i in country r induced by global final demand can be calculated as follows:

$$\mathbf{q} = \mathrm{diag}(\mathbf{e})(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathrm{diag}(\mathbf{e})\mathbf{L}\mathbf{f} \quad (2)$$

$\mathbf{q} = (q_i^r)$: Vector of the direct and indirect CO_2 emissions associated with global final demand

$\mathrm{diag}(\mathbf{e})$: a diagonal matrix of direct CO_2 emission coefficients, representing the direct CO_2 emissions per unit of output in industry i in country r

- We focus on the direct and indirect CO_2 emissions $\mathbf{q}^{ASEAN}$ generated within ASEAN countries to meet the global final demand.



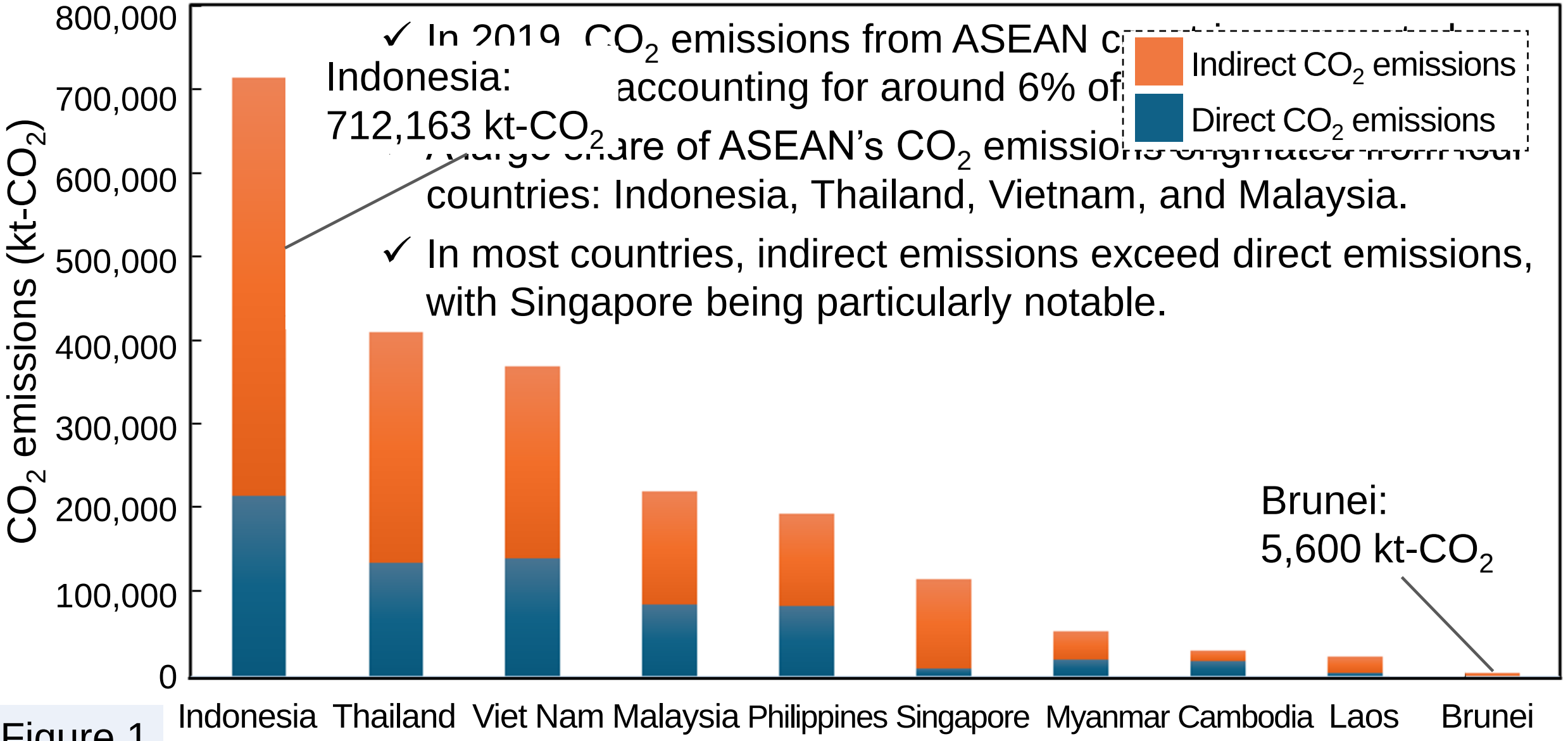
$$\mathbf{q}^{ASEAN} = \mathrm{diag}(\mathbf{e}^{ASEAN})\mathbf{L}\,\mathbf{f} \quad (3)$$

Direct CO_2 emission coefficients, in industry i in ASEAN country r

The global final demand vector for industry i in country r

3. Results and Discussion

- Total CO_2 emissions from ASEAN countries induced by global final demand in 2019



✓ In 2019, CO_2 emissions from ASEAN c… accounting for around 6% of …

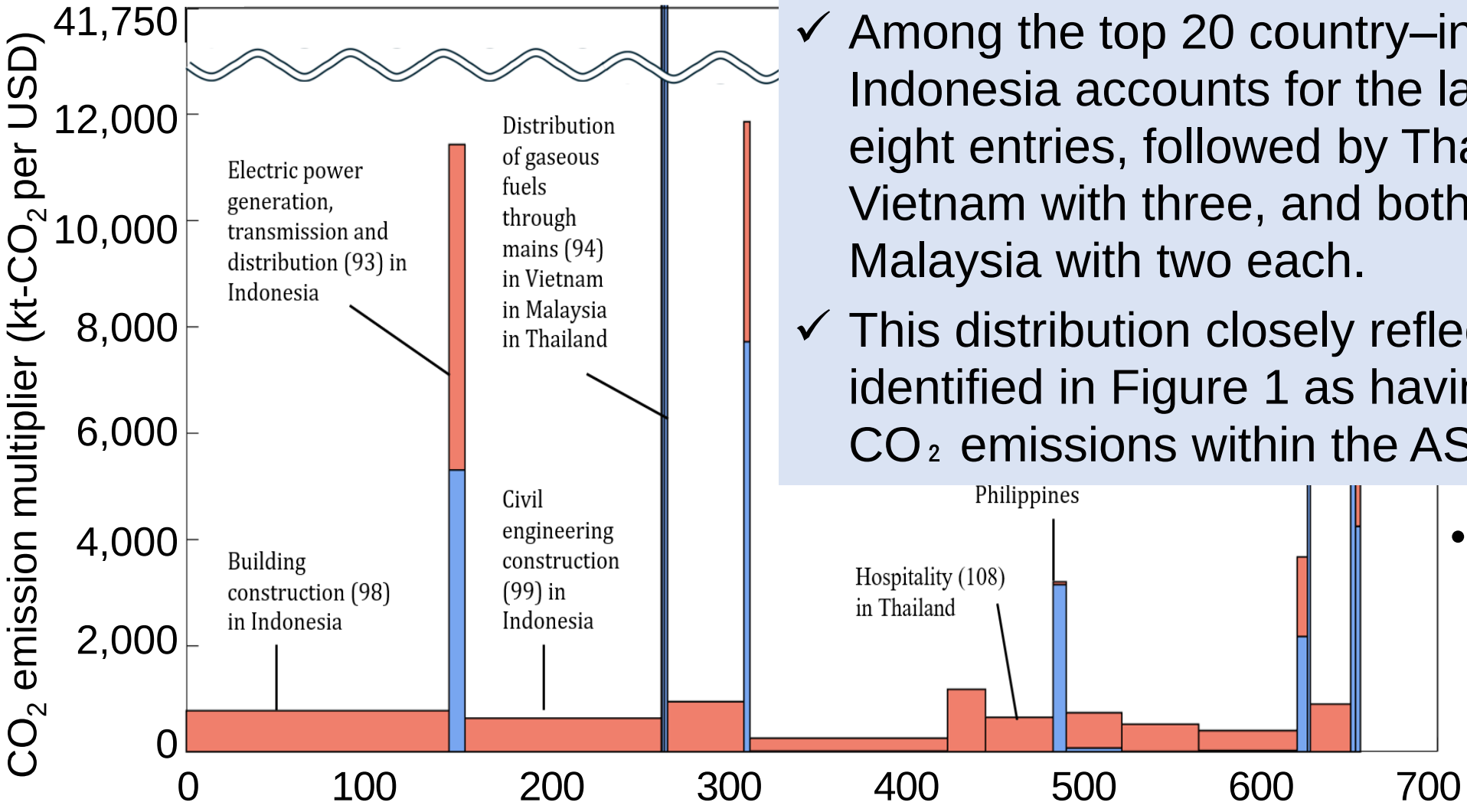
… large share of ASEAN's CO_2 emissions originated from four countries: Indonesia, Thailand, Vietnam, and Malaysia.

✓ In most countries, indirect emissions exceed direct emissions, with Singapore being particularly notable.

Figure 1

3. Results and Discussion

- A skyline chart of the top 20 country–industry combinations with the highest direct and indirect CO_2 emissions in ASEAN, induced by global final demand



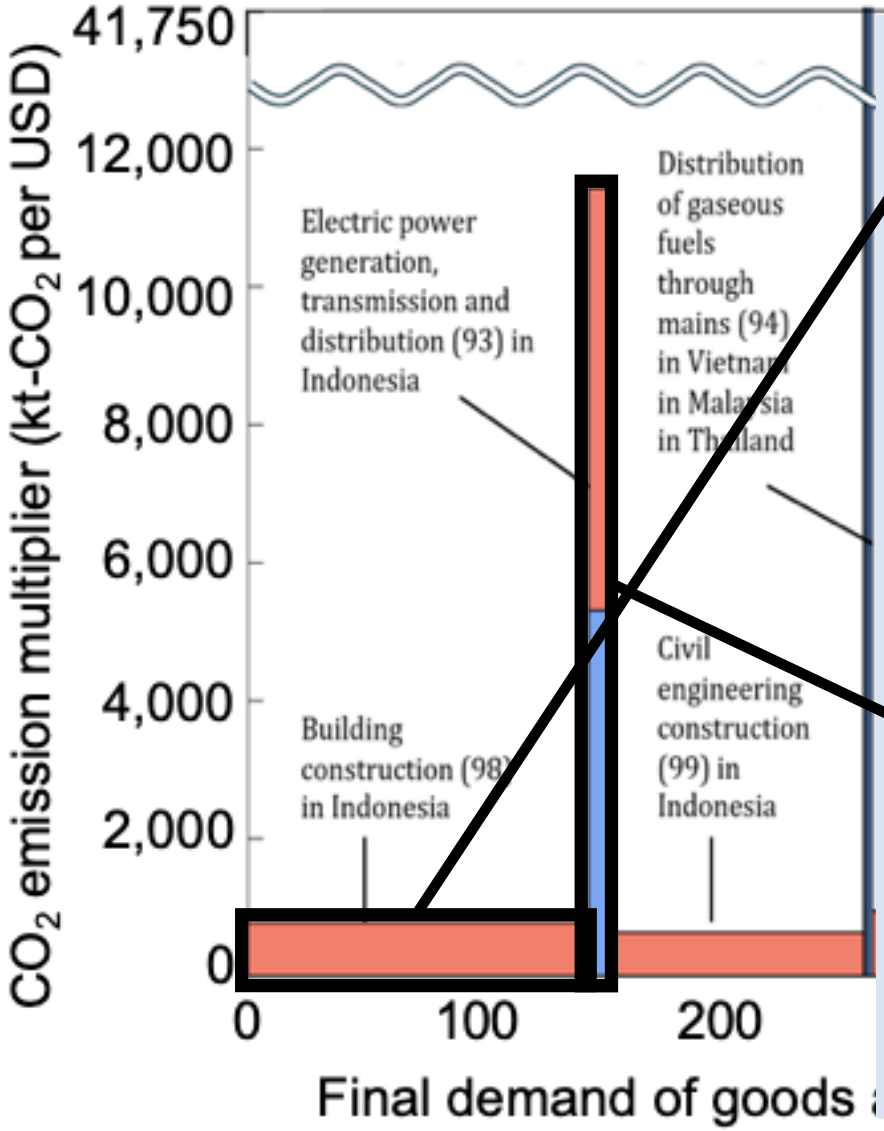
✓ Among the top 20 country–industry combinations, Indonesia accounts for the largest share with eight entries, followed by Thailand with five, Vietnam with three, and both the Philippines and Malaysia with two each.

✓ This distribution closely reflects the countries identified in Figure 1 as having the highest total CO_2 emissions within the ASEAN region.

- The bars are sorted in descending order from left to right, based on total emissions.

Figure 2 Final demand of goods and services for ASEAN (billion USD)

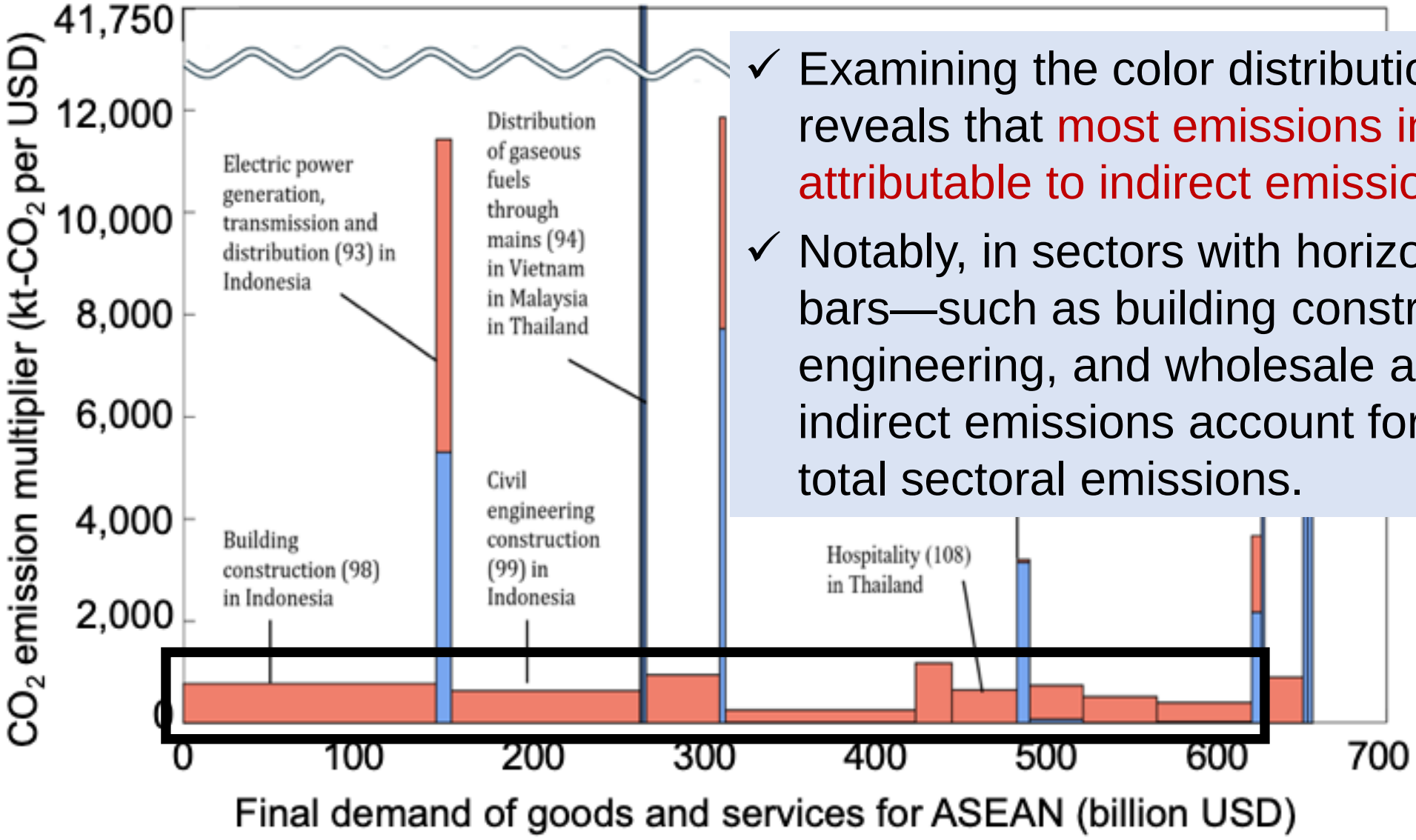
3. Results and Discussion



- ✓ The sector with the highest CO_2 emissions (113 Mt-CO_2) was the building construction sector in Indonesia.
- ✓ In the figure, the associated bar appears horizontally extended, indicating that the high CO_2 emissions are primarily driven by the large volume of global final demand rather than by high emission intensity.
- ✓ Electric power generation sector in Indonesia follows that sector and recorded high CO_2 emissions.
- ✓ In contrast, the bars for electric power generation are vertically extended, showing that their high emissions are mainly due to high emission coefficients rather than large demand volumes.

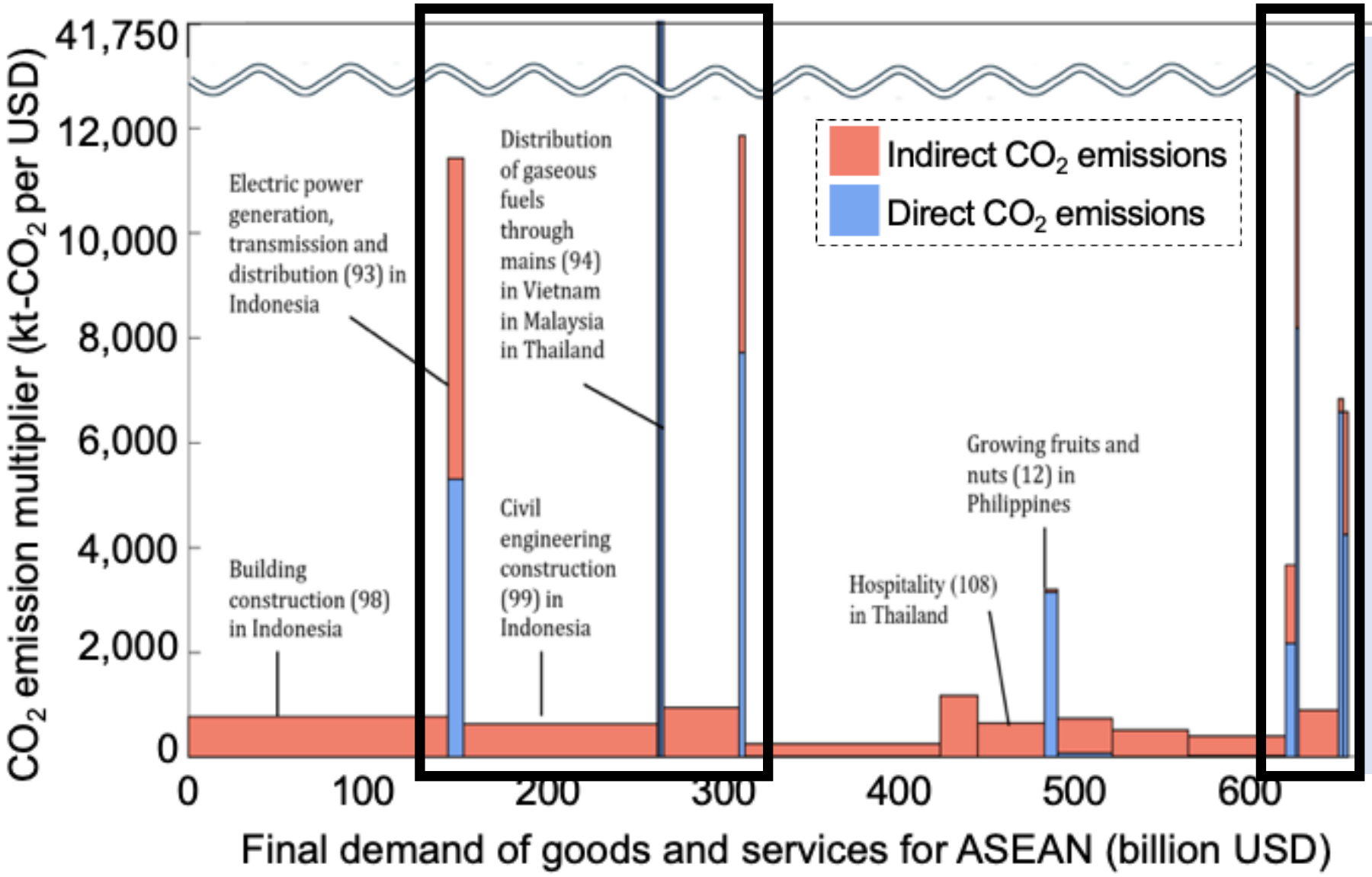
➢ The highest CO_2 emissions were generated by the top three sectors in Indonesia. The driving factors behind those emissions vary by sectors.

3. Results and Discussion



- ✓ Examining the color distribution in the chart reveals that most emissions in ASEAN are attributable to indirect emissions (the red segments).
- ✓ Notably, in sectors with horizontally extended bars—such as building construction, civil engineering, and wholesale and retail trade—indirect emissions account for a large proportion of total sectoral emissions.

3. Results and Discussion

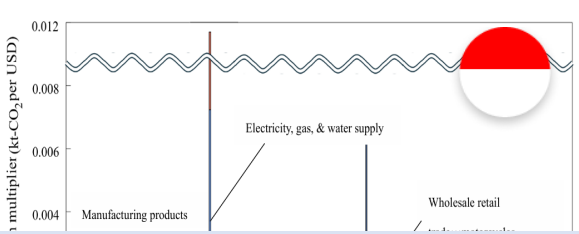


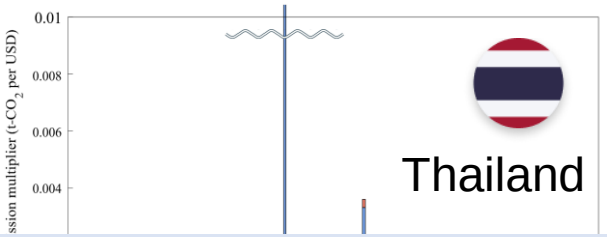
✓ In contrast, vertically extended bars —such as electric power generation, transmission, and distribution — show especially large contributions from both direct and indirect emission coefficients.

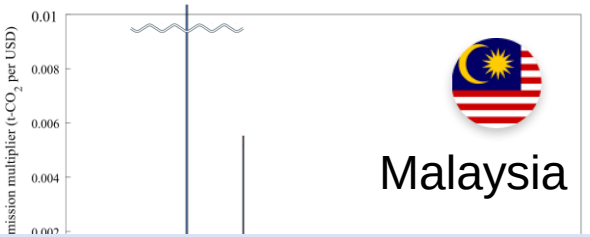
➢ These sectors have economic structures heavily dependent on fossil fuels. Reducing emission intensity is an immediate and effective strategy for cutting CO_2 emissions.

3. Results and Discussion

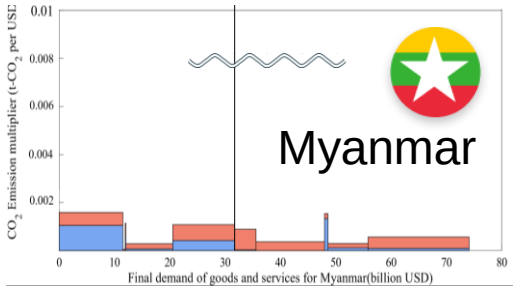
- We estimated skyline chart of direct and indirect CO_2 emissions by each ASEAN country to examine the sectoral composition of CO_2 emissions in each country, highlighting country-specific characteristics.

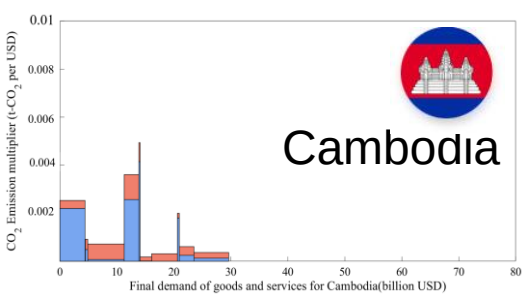


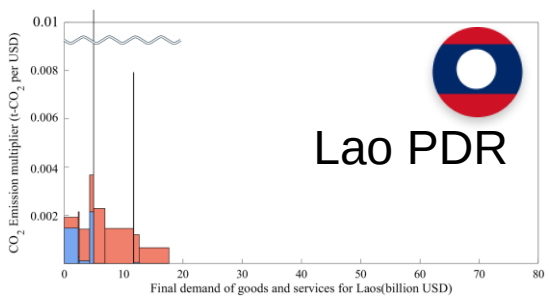


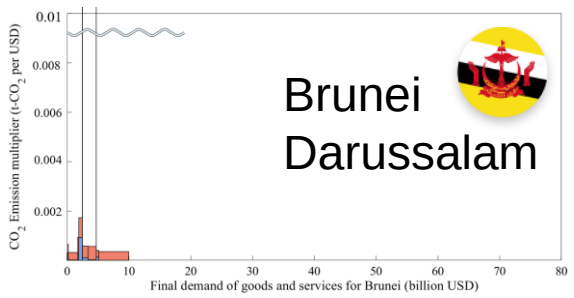


- ✓ In Among the ten ASEAN countries, substantial differences in demand levels made it difficult to directly compare emission volumes using a common scale.
- ✓ Therefore, in this study, we categorized the ASEAN countries into three groups based on the magnitude of their final demand (horizontal axis), and constructed skyline charts for each group using a unified scale within the group.









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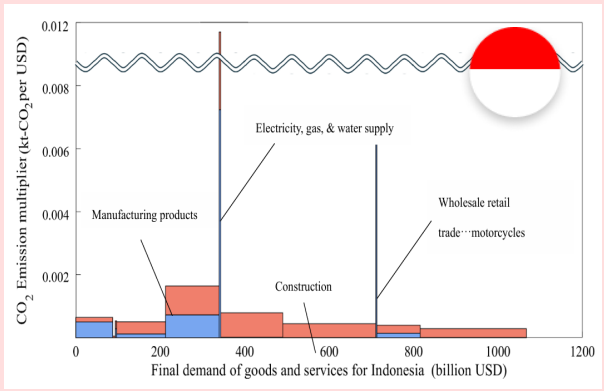
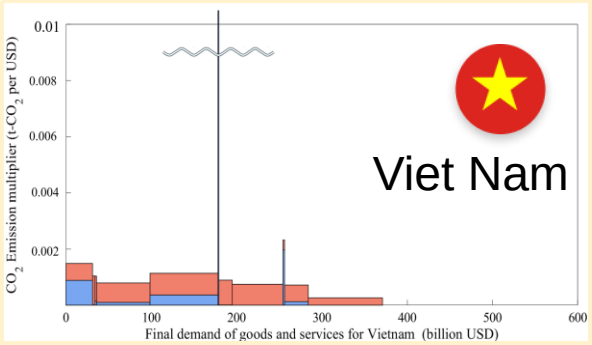
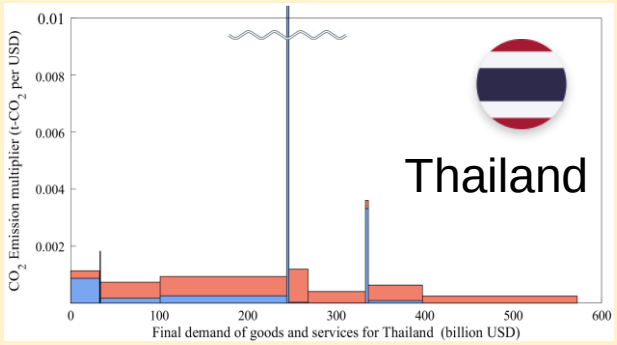


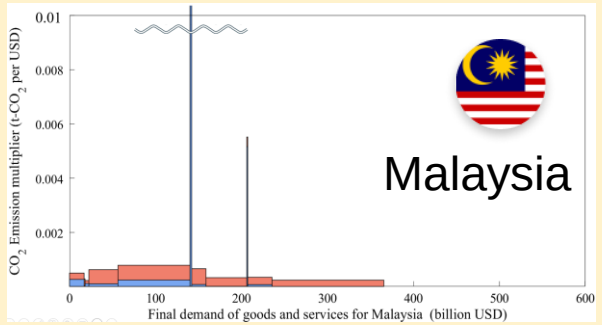
Maximum: 1200 billion USD

Group 1:

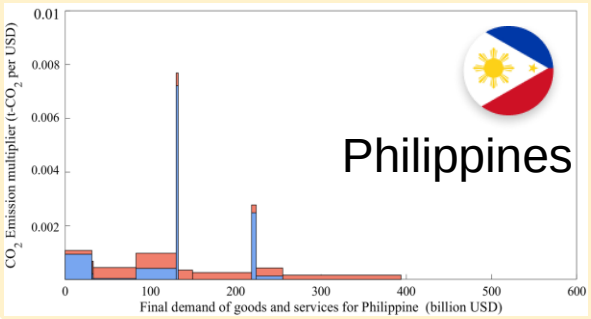
High final demand

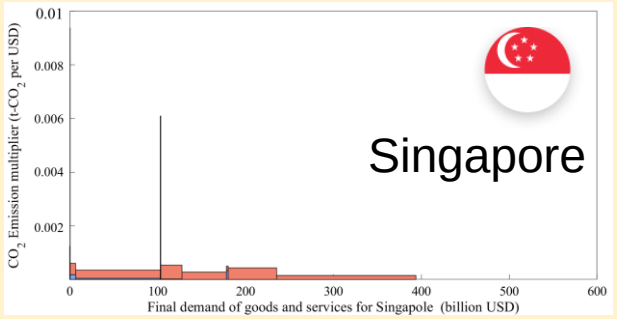






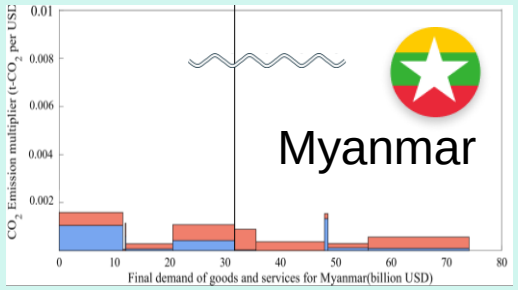
Maximum: 600 billion USD



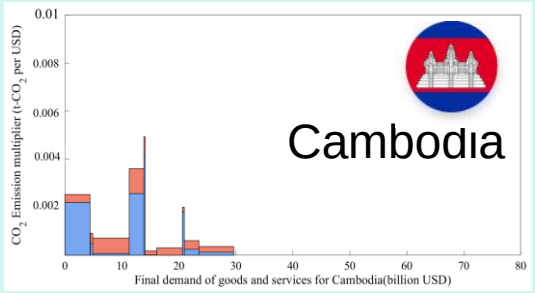


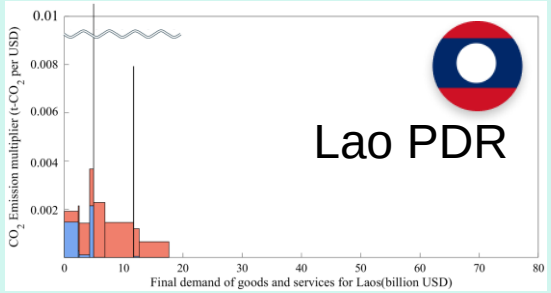
Group 2:

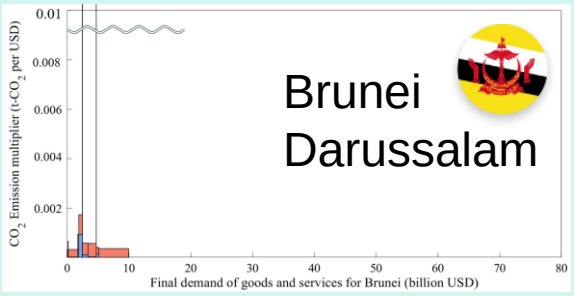
Medium final demand



Maximum: 80 billion USD



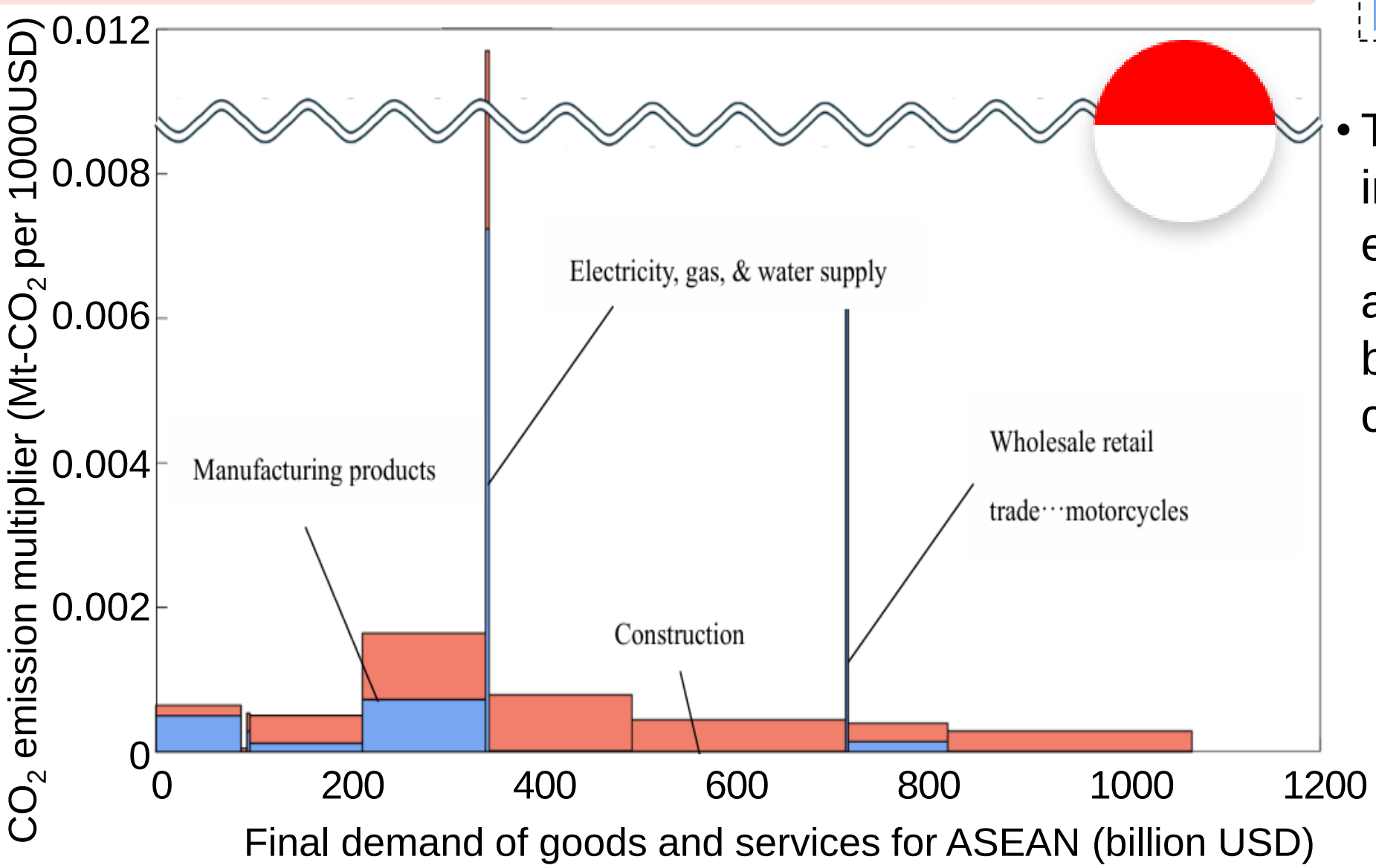




Group 3: Low final demand

3. Results and Discussion

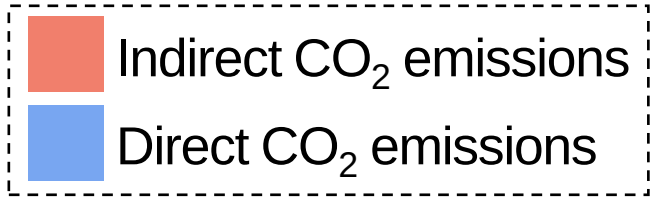
- A skyline chart of direct and indirect CO_2 emissions by eleven aggregated industries in Indonesia



- The original 120 industrial sectors in each country have been aggregated into 11 broader sector categories.

3. Results and Discussion

- A skyline chart of direct and indirect CO_2 emissions by eleven aggregated industries in Indonesia

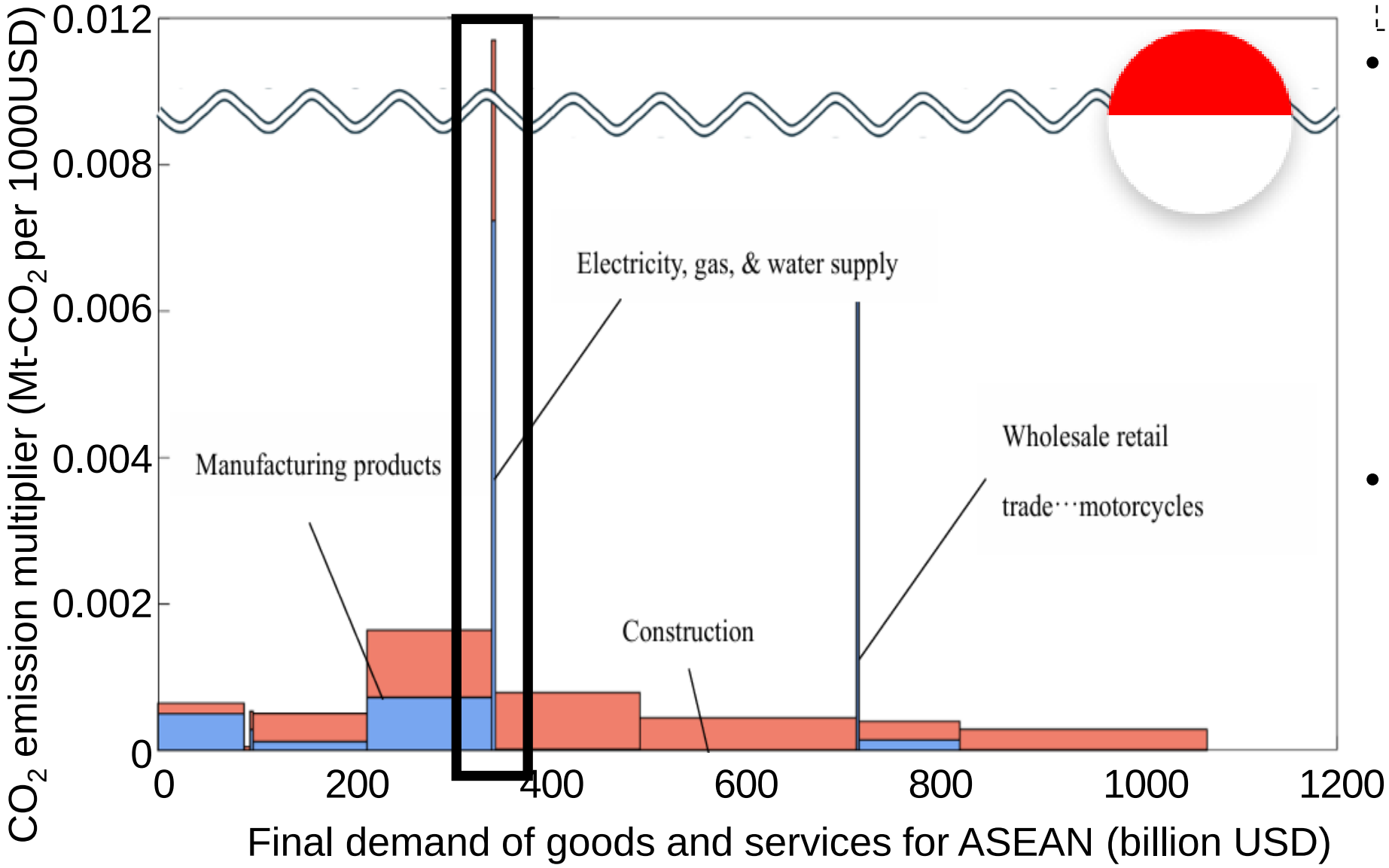


Aggregated industry code	Industry
1	Agriculture
2	Fishing
3	Mining
4	Food products
5	Manufacturing products
6	Electricity, gas, & water supply
7	Waste collection & materials recovery
8	Construction
9	Wholesale and retail trade; repair of motor vehicles and motorcycles
10	Transport
11	Other services

- The original 120 industrial sectors in each country have been aggregated into 11 broader sector categories.

3. Results and Discussion

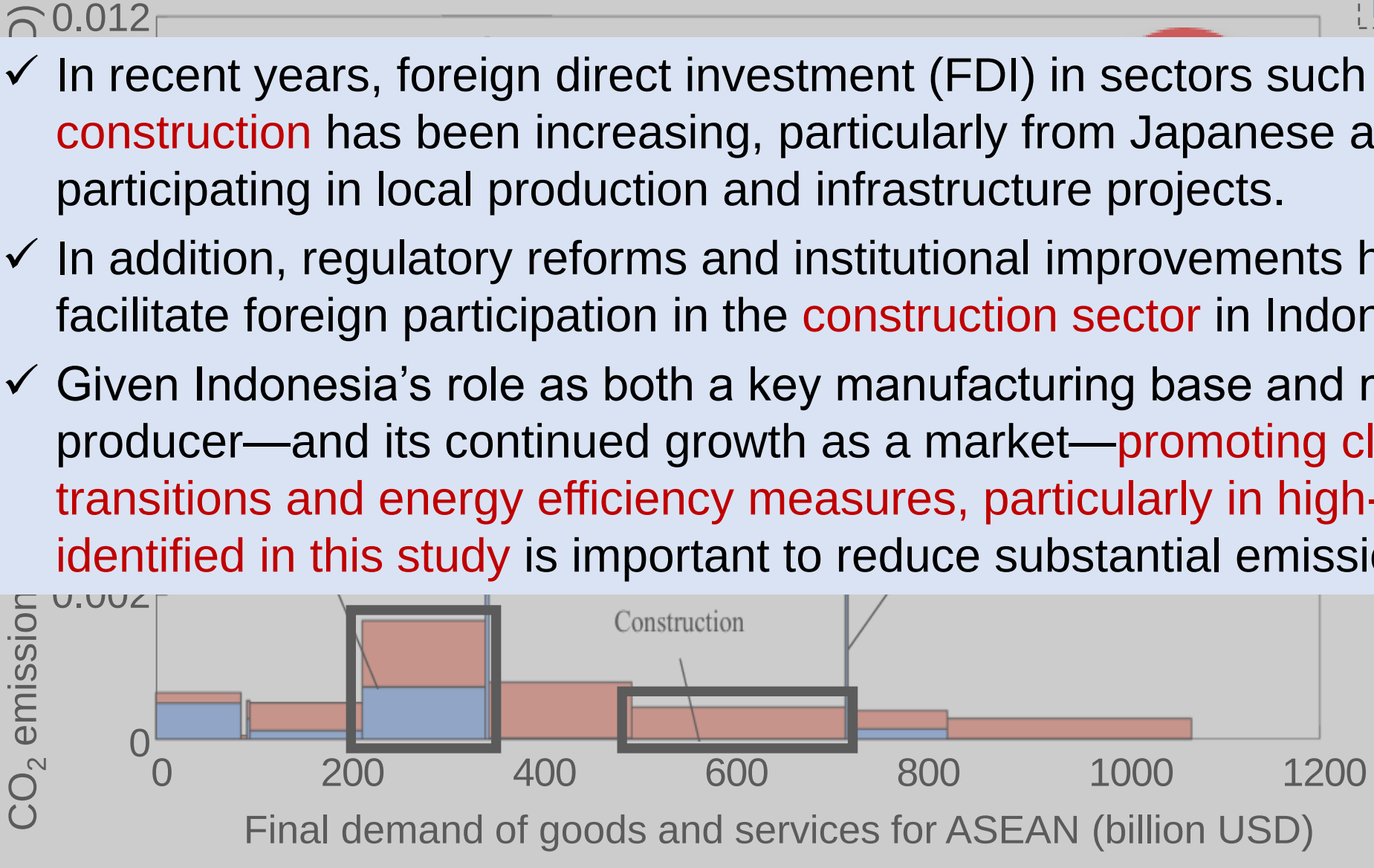
- A skyline chart of direct and indirect CO_2 emissions by eleven aggregated industries in Indonesia



- The bar representing "Electricity, gas, steam, and air conditioning supply" is vertically elongated, indicating an extremely high emission intensity.
- One major reason for this high emission intensity is that more than 60% of Indonesia's electricity is generated from coal-fired power plants.

3. Results and Discussion

- A skyline chart of direct and indirect CO_2 emissions by eleven aggregated industries in Indonesia

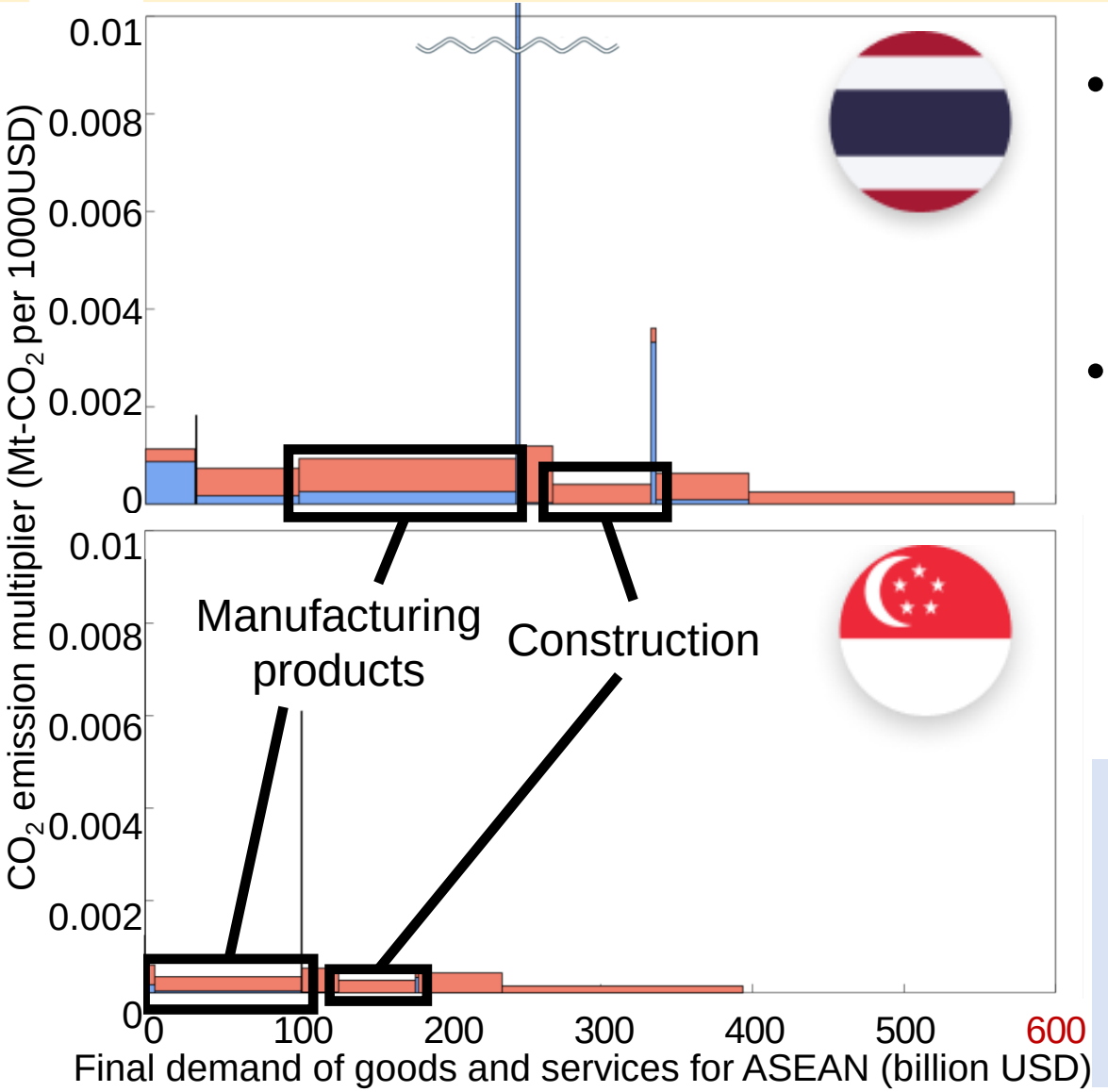


- ✓ In recent years, foreign direct investment (FDI) in sectors such as manufacturing and construction has been increasing, particularly from Japanese and South Korean firms participating in local production and infrastructure projects.
- ✓ In addition, regulatory reforms and institutional improvements have been introduced to facilitate foreign participation in the construction sector in Indonesia.
- ✓ Given Indonesia's role as both a key manufacturing base and major energy producer—and its continued growth as a market—promoting cleaner energy transitions and energy efficiency measures, particularly in high-emission sectors identified in this study is important to reduce substantial emissions.

production systems, the use of cleaner energy sources, or the inherently lower carbon intensity.

3. Results and Discussion

- Skyline charts of direct and indirect CO_2 emissions by eleven aggregated industries in Thailand and Singapore



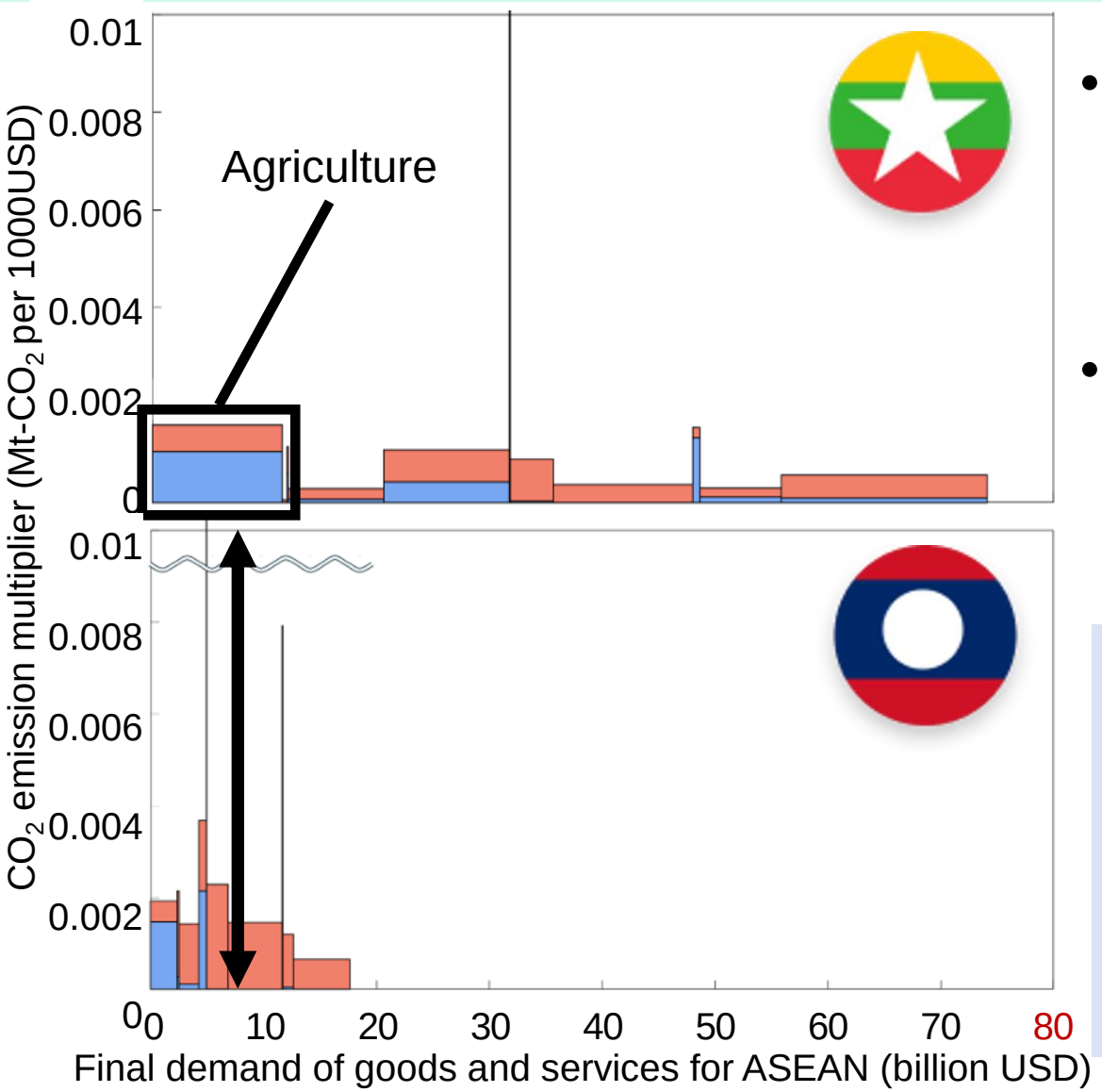
- Similar to Indonesia, Thailand and Singapore also show prominent "Manufacturing" and "Construction" sectors, each with particularly long horizontal bars.
- In Singapore, the dominance of indirect emissions is visually evident (red portion), reflecting an industrial structure heavily concentrated in tertiary sectors such as services—unlike countries with strong primary industries like agriculture.

✓ As is common in upper-middle-income economies, emissions from manufacturing and construction are significant.

✓ The characteristics vary by countries.

3. Results and Discussion

- Skyline charts of direct and indirect CO_2 emissions by eleven aggregated industries in Myanmar and Laos



- Myanmar's "Agriculture" sector stands out, reflecting its role as the backbone of the economy—employing 50–60% of the labor force and contributing significantly to GDP.
- In Laos, the electricity supply sector shows notably high emission coefficients. Known as "the battery of Southeast Asia," Laos exports substantial electricity to neighboring countries.

✓ Although final demand is small, several sectors have higher emission coefficients compared to other countries.

✓ Introducing low-carbon technologies and improving energy efficiency in these sectors is essential.

4. Conclusion

- This study estimated both the direct and indirect CO_2 emissions from industries across all ten ASEAN countries using a Multi-Regional Input–Output (MRIO) model.
- The results revealed that the causes of CO_2 emissions varied significantly among ASEAN countries, suggesting that flexible, country-specific decarbonization policies were necessary considering regional characteristics as follows.

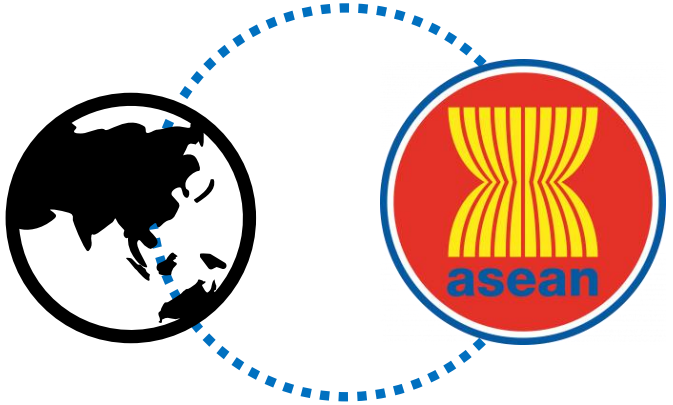
Group 1: Its overall CO_2 emissions were largely driven by substantial final demand in electricity, manufacturing, and other market-driven sectors.

Group 2: Despite structural differences among the countries, emissions were primarily driven by the manufacturing and construction sectors—industries typically prominent in economies at moderate levels of industrial development.

Group 3: It showed notably high direct and indirect emission coefficients, particularly in the agriculture sector, which is a key industry in several countries of this group.

4. Conclusion

- Considering these regional characteristics, it is important to strengthen intra-ASEAN cooperation to reduce CO_2 emissions across the region-wide supply chain.
- Efforts to reduce emission coefficients needed to be prioritized—particularly in the manufacturing sectors of more industrialized countries and in agriculture in less developed member states.
- The adoption of advanced emission-reducing technologies from developed countries, along with collaboration with non-ASEAN countries that relied on imports from the region, appeared essential to achieving shared climate goals.



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Thank you for your kind attention!

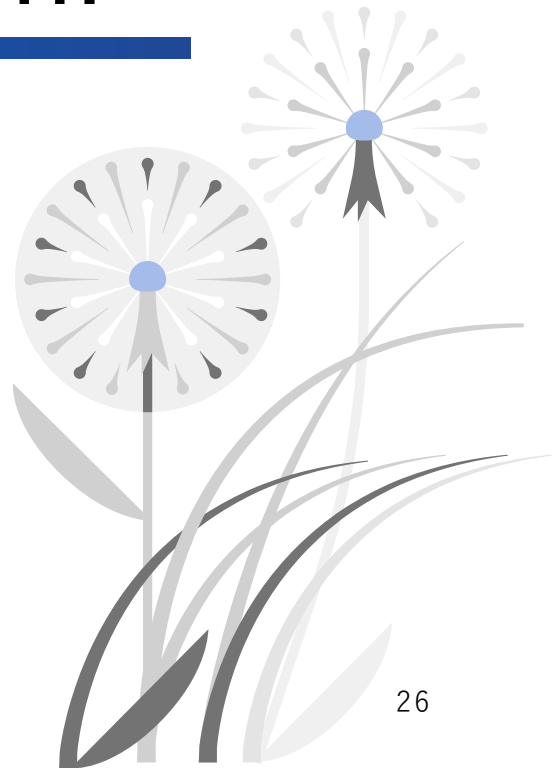

Table 1. Countries and industries corresponding to the top 20 CO_2 emissions

Rank	Country	Industry code	Industry
1	Indonesia	98	Building construction
2	Indonesia	93	Electric power generation, transmission and distribution
3	Indonesia	99	Civil engineering construction
4	Vietnam	94	Distribution of gaseous fuels through mains
5	Malaysia	94	Distribution of gaseous fuels through mains
6	Thailand	94	Distribution of gaseous fuels through mains
7	Vietnam	99	Civil engineering construction
8	Indonesia	94	Distribution of gaseous fuels through mains
9	Indonesia	100	Wholesale and retail trade; repair of motor vehicles and motorcycles
10	Thailand	98	Building construction
11	Thailand	108	Hospitality
12	Philippines	12	Growing fruits and nuts
13	Thailand	87	Motor vehicles, trailers and semi-trailers
14	Indonesia	56	Tobacco products
15	Indonesia	116	Government; social security; defense; public order
16	Philippines	93	Electric power generation, transmission and distribution
17	Vietnam	93	Electric power generation, transmission and distribution
18	Thailand	99	Civil engineering construction
19	Indonesia	101	Road transport
20	Malaysia	93	Electric power generation, transmission and distribution