UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

TRADE, INVESTMENT AND INNOVATION DIVISION

Greenhouse Gas Emissions embedded in agricultural trade: implications and potential opportunities for Asia-Pacific

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Trade, Investment and Innovation

Working Paper Series

NO. 01 | January 2023

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Please cite this paper as: Alexey Kravchenko, Yann Duval and Maria Semenova (2023). "Greenhouse Gas Emissions embedded in agricultural trade: implications and potential opportunities for Asia-Pacific", TIID Working Paper Series No. 1, January 2023, Bangkok, ESCAP.

Available at https://www.unescap.org/knowledge-products-series

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Abstract

Greenhouse Gas (GHG) emissions are the main driving force of climate change, and all economic sectors need to internalize their costs. Food systems (including land use, production, refrigeration, food processing) account for a quarter of global GHG emissions. Agricultural exports in Asia-Pacific account for 18% of total exports, twice as much as in the rest of the world. Pacific Island Developing States (PIDS) and New Zealand, are particularly reliant on trade in agriculture. Agricultural export shares of many PIDS significantly exceed the global average of 9%, while New Zealand agricultural exports account for 31% of its total exports. This study sought to estimate the CO2-equivalent content of agricultural trade in Asia and the Pacific, and examine the ramifications of potential carbon tariffs, such as the European Union's Carbon Border Adjustment Mechanism as well as global carbon tariffs, using partial equilibrium analysis. We find that half of emissions embedded in agricultural trade in the region are due to farming (such as methane emissions from ruminant stock), and a quarter is due to land use change (deforestation), while only 4% of emissions in agricultural trade in the region is due to transport. The findings imply that carbon taxing transport alone may be counterproductive to climate action as lower cost/bulkier food products would be taxed at a relatively higher price due to their lower carbon content to weight ratio. Asia-Pacific is a net importer of GHG emissions embedded in the agricultural products considered. The emissions intensity is lower for exports than for imports (3.3 CO2 kg per $1 for exports vs 3.5 CO2 kg per $1 for imports), indicating that regional demand is more CO2 intensive than foreign demand. Economies that rely on carbon intensive agricultural products, such as beef, are found to be at the greatest risk from potential carbon tariffs: the meat sector would bear the brunt of global charges, followed by animal oils given the high amount of CO2 embedded in these products. Even relatively small surcharges may have a large effect on mean exports for such products. However, in the scenario of European Union's Carbon Border Adjustment Mechanism (due to data limitations, applied externally only), if it were to include agricultural products in the future, overall Asia-Pacific agricultural exports would only be reduced by 3%, though decreases would be significantly more pronounced for the Pacific subregion. Interestingly, the Asia-Pacific region as a whole is a net importer of CO2 equivalent emissions embedded in agricultural products. As such, for most of the economies in the region, implementing some form of carbon tariffs on foods with high emission-to-calorie ratios, such as beef, may be worth considering as part of trade-related climate action, subject to further detailed studies of socio-economic impacts.

JEL: F14; F18; Q17

Keywords: agricultural trade; GHG emissions; climate change; carbon tariffs; carbon pricing; Asia-Pacific

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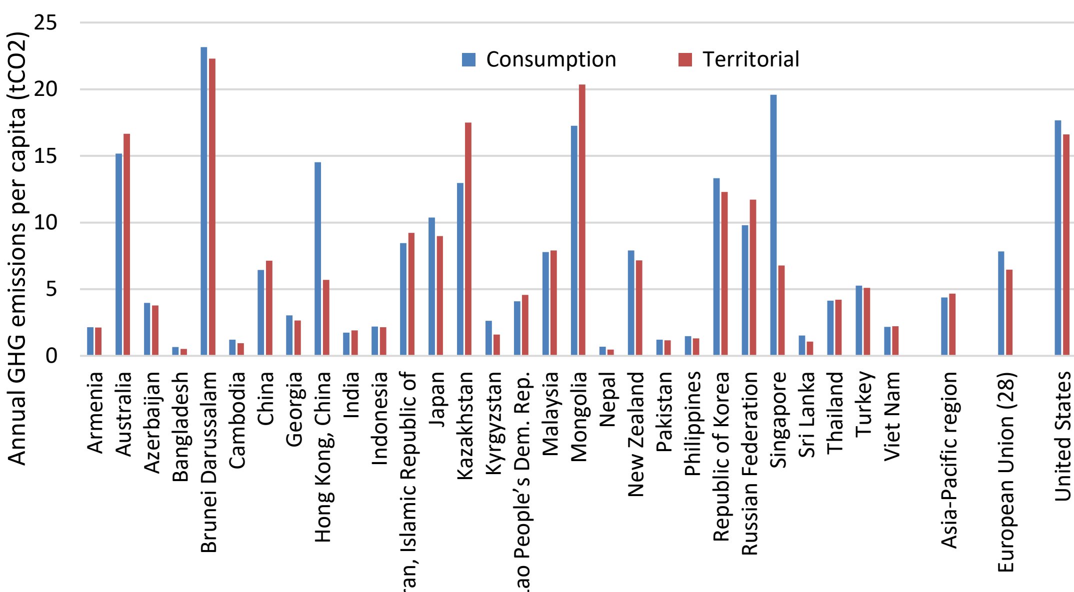
1. Introduction

Economic development has lifted hundreds of millions of people out of poverty in the Asia-Pacific region, despite continued population growth. Yet, this has come at significant environmental costs, including an acceleration in climate change. The consequences of climate change include raising sea levels, increased frequency and severity of extreme weather events, decreased agricultural productivity, water shortages, loss of biodiversity, among many others negative effects (IPCC, 2021). According to ESCAP (2021) among the Sustainable Development Goals (SDGs) for which sufficient monitoring data is available, progress towards climate action (Goal 13) has been most lacking in the region: indeed, there has been a notable decline in achieving this goal.

Anthropogenic greenhouse gas (GHG) emissions are widely considered to be the main driving force of climate change. While this issue can be addressed in part through regulations imposed on domestic industries, increasingly more consideration is given to the potential benefits of regulating GHG emissions associated with imported goods. Indeed, many developed countries with relatively more stringent environmental laws typically have higher consumptive emissions because they import emissions embedded in production of goods produced elsewhere (figure 1).

Figure 1 Per capita territorial and consumption emissions in the Asia-Pacific region and selected trade partners



Source: ESCAP, UNEP and UNCTAD (2021).

As some developed economies, in particular the European Union, are ratcheting up climate action through increased carbon pricing to internalize GHG emissions, carbon leakage increasingly becomes an issue. Carbon leakage occurs when relatively more stringent environmental polices incentivize polluting industries to relocate to locations with relatively less stringent environmental regulations. Not only does it reduce the competitiveness of domestic production against imports from jurisdictions with lower environmental standards, it can also even potentially lead to the opposite of what domestic or regional carbon pricing schemes were designed to do: increase net global GHG emissions. As such, European Union (as well as potentially other economies) are considering implementing “carbon tariffs” (carbon border adjustment mechanism, or CBAM) to account for discrepancies in carbon pricing policies to level the playing field between imports and domestic production.

While much attention has been given to the potential impact of the EU’s proposed CBAM on the currently targeted industries,[4] relatively little consideration has been given to implications of potential carbon pricing and carbon border taxes for trade in agricultural products. Food production contributes up to 26 per cent of global carbon emissions (Poore and Nemecek, 2018), predominately through methane emissions, and arguably provides some of the most low-hanging fruit to address emissions. Socio-economic impacts of new policies in this sector need to be carefully considered given the industry’s importance, particularly for the rural poor in developing countries.

New Zealand is the first country in the world planning to price agricultural emissions from as early as 2025 (Cooke, 2021). Even without carbon pricing and carbon tariffs, it may well be that consumer behaviour nudged by voluntary or compulsory labelling may swing demand from carbon-intensive agricultural products. Indeed, a survey of 10,000 consumers in Europe revealed that two thirds of the respondents support carbon labelling of products (Carbon Trust, 2020). As such, this study aims to estimate exposure of economies in the region to potential climate-related trade policies and/or changes in consumer behaviour in that sector.

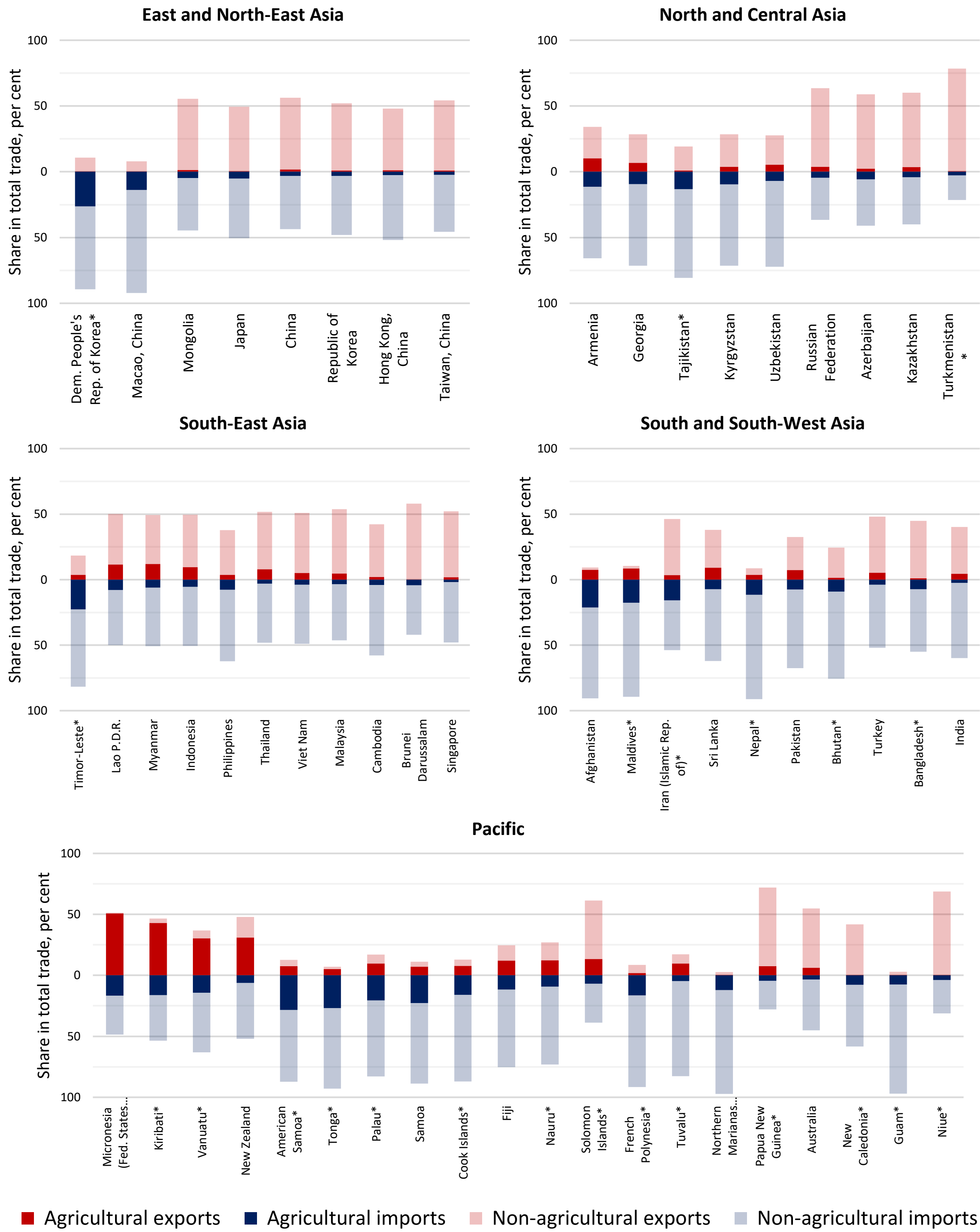
2. Asia-Pacific agricultural trade and its exposure to carbon border policies

In 2019, Asia-Pacific economies have exported $408 billion and imported $521 billion worth of agricultural goods, representing 18% and 7.6% of the region’s total exports and imports, respectively. This contrasts to the rest of the world, where 9.1% and 9.1% of exports and imports are in the agricultural sector. This implies that Asia-Pacific economies are twice as dependent on agriculture for exports, but less relatively reliant on foreign trade for agricultural imports.

When looking at individual economies (figure 2), for 36 out of 59 economies, for which trade data is available, agriculture constitutes more than 10 per cent of their total trade, and for 17 out of 59 economies more than 20 per cent of their total trade Notably, the pacific island developing states (PIDS), together with their Pacific neighbour New Zealand, seem to have particular reliance on trade in agricultural goods, although there is diversity in the source of reliance (high share in exports for some, high share in imports for others).

[4] Iron, steel, cement, fertilizers, aluminium and electricity.

Figure 2 Share agricultural trade in total trade in Asia-Pacific economies, 2019

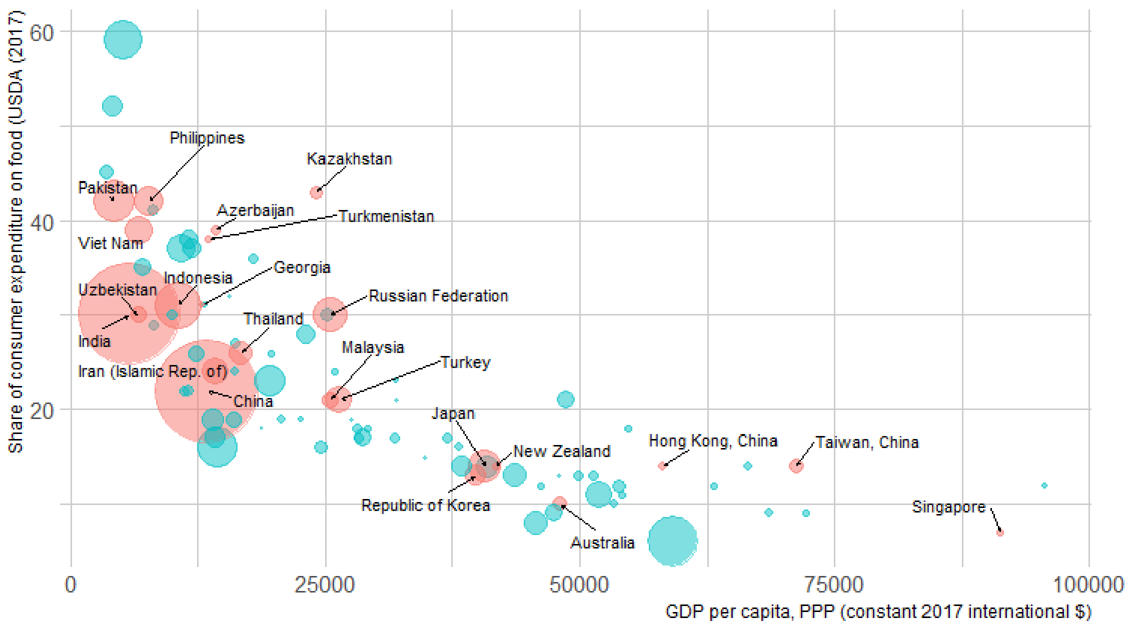


Source: Authors' calculations based on data from UN COMTRADE, accessed October 2021.

Note: Agricultural goods correspond to HS chapters 1-24; *denotes economies for which trade values were not available but were estimated using mirror technique and as such may be underestimated.

The trade statistics above point to potentially significant socio-economic repercussions in Asia and the Pacific, if the global carbon markets start internalizing agricultural GHG emissions (or, as noted, consumer preferences shift to less carbon intensive products). Economies reliant on agricultural exports will find themselves facing higher carbon tariffs that could potentially reduce their export proceeds. Conversely, economies reliant on agricultural imports, if implementing carbon tariffs themselves, will see increases in the costs of agricultural imports. In both cases, poorer households are likely to experience higher incidence of such tariffs: agricultural producers and labour in the case of exporters, and lower income consumers who have a higher relative share of food products in household expenditure in the case of importers (figure 3).

Figure 3 Share of consumer expenditure spent on food vs. GDP per capita, latest years, selected countries



Source: Authors' calculations based on data from Our World in Data, accessed January 2023.

Trade diversion and supply chain effects through patchy implementation of carbon tariffs can potentially be very diverse and warrant a study on their own: it is conceivable that carbon tariffs could depress world market prices if substantial markets (such as the EU) are closed off with high tariffs and exporters seek to re-route their produce elsewhere (which may benefit some importers and consumers due to localized increases in supply, but at the expense of local producers). For the EU consumers, on the other hand, introduction of carbon tariffs may increase domestic prices for the affected agricultural goods, hurting consumers, but potentially benefiting local EU producers. As discussed in ESCAP, UNEP & UNCTAD (2021), however, many of such risks can be successfully mitigated through effective implementation of domestic carbon pricing mechanisms internalizing GHG emissions. Most importantly, however, any carbon tariff, by definition, will be calculated based on GHG emission content associated with the production processes, rather than on the trade value of the goods. As such, it is necessary to understand how much of the GHG emissions is embedded in the traded products.

3. GHGs embedded in agricultural products

As in the case of products within the currently proposed scope of the EU's CBAM,[5] the carbon border tariffs on agricultural imports would likely be based on carbon-equivalent content,[6] rather than on the raw dollar values of the agricultural products traded (ad valorem basis). There are potential significant issues with estimation, certification and validation[7] of the carbon-equivalent content within any product. Various competing methodologies exist (discussed in detail in chapter 6 of ESCAP, UNEP & UNCTAD, 2021), typically requiring a trade-off between accuracy and cost. Smaller firms in developing countries are likely to be particularly affected by the certification processes down the line, as they will have the least capacity to adhere to new regulations.

There are significant variations in carbon-equivalent content between producers of the same product between different countries (or even within countries) due to differences in production processes. For example, according to Saunders, Barber & Taylor (2006), even when accounting for the transportation-related emissions, UK lamb was estimated to contribute four times more emissions than the New Zealand lamb sold in the UK. The same study showed that New Zealand products sold in the UK, inclusive of all associated transportation emissions, had half the emissions for dairy, and two thirds of the emissions for apples when compared to their counterparts of local origin. The difference in emissions largely came down to the fact that in New Zealand most of the agricultural systems required fewer fertilizers (which are highly energy intensive products) and animals grazed outside the whole year rather than relying on brought-in feed typical in colder climates.

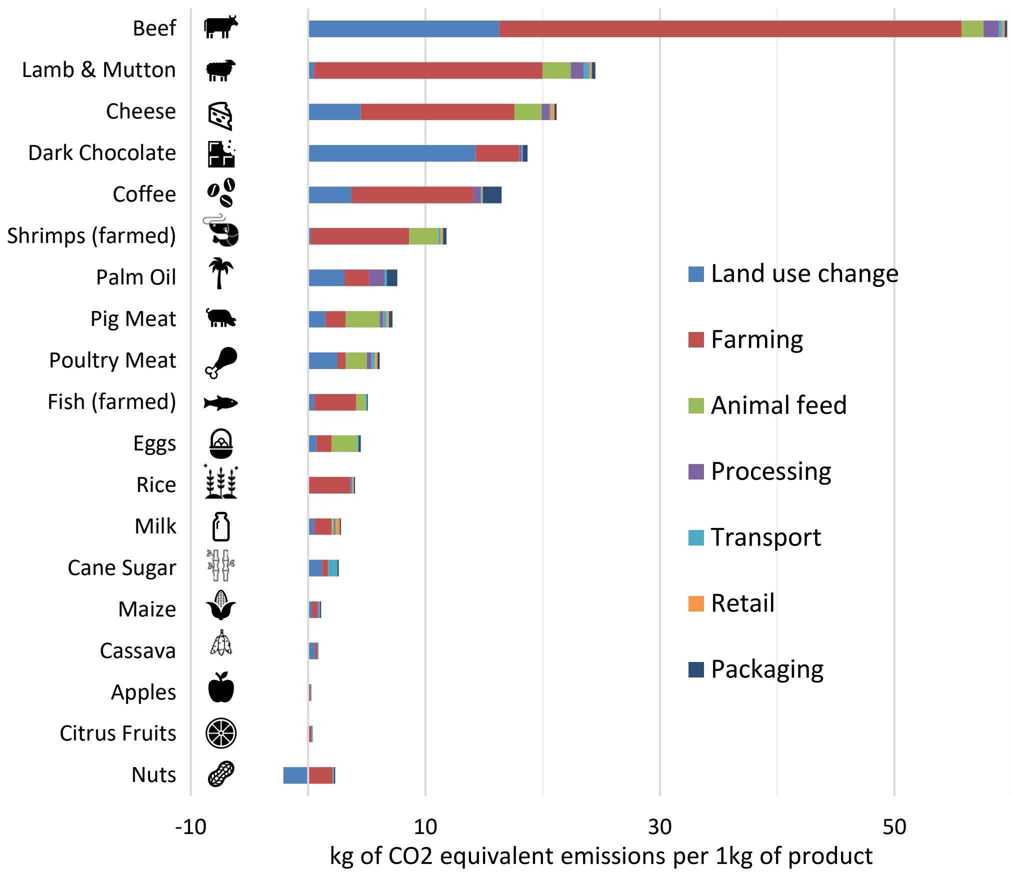
To provide high-level product-specific (but not country/production method specific) estimates, this study uses CO2-equivalent estimates from Poore and Nemecek (2018). In their meta-analysis, the authors consolidated GHG emissions estimates for more than 38,000 farms producing 40 different agricultural goods in 119 economies. For example, production of 1 kg of beef is estimated to contribute to, on average, 60 kg of CO2-equivalent GHG emissions (out of that only 0.3 kg is due to transportation; the bulk of GHG emissions are due to methane emissions through belching (39 kg) and forest loss due to pasture increases (16 kg)). Dark chocolate is nearly as bad as beef when it comes to land-use change – the production of 1 kg of dark chocolate contributes to 14 kg of CO2-equivalent GHG emissions due to forest loss. Poultry (a non-ruminant animal) produces nearly 10 times less total GHG emissions per kg than beef. A kilo of nuts, on the other hand, is almost carbon neutral, as emissions from growth, transport and retail are nearly offset by carbon storage in the wood of the nut trees – see figure 4 for a selection of products.

[5] Iron, steel, cement, fertilizers, aluminium and electricity

[6] Or, more accurately, based on differential between foreign and domestic carbon prices and carbon content.

[7] Digital trade facilitation will almost certainly reduce costs associated with validation and certification, and basing estimation and certification on international standards would also help.

Figure 4 GHG Emissions embedded in production of selected agricultural products, selected categories



Source: Poore and Nemecek (2018); icons from MS Word, TheNounProject.com by Fiza Alamsyah & IconFinder.com

4. GHGs embedded in agricultural products in Asia-Pacific

Table 1 summarizes the CO2-equivalent GHG emissions embedded in agricultural trade of the Asia-Pacific region (see Annex for a methodological overview), together with the corresponding trade flow values.[8] The importance of accounting for embedded emissions rather than relying on raw trade values alone when evaluating the potential impact of carbon tariffs on trade in agricultural goods is highlighted, for example, by the case of goods falling under chapter 8: Fruit and Nuts. Even though in dollar value terms, this category is the top category (18% of total examined agricultural exports in the region), its CO2 equivalent emissions constituted less than 2% of region's emissions embedded in the examined agricultural exports.

[8] As noted in the Annex, due to data gaps both in matching and in availability of data on quantities traded, the share of trade in agricultural commodities (falling under the agricultural chapters of the HS) covered by this analysis is lower than the total trade values – 56% and 52% of agricultural (HS chapters 1-24) imports and exports, respectively.

Conversely, while meat (HS chapter 2) accounted for 17% of the examined agricultural imports by value, it accounted for 37% of CO2-equivalent GHG emissions embedded in the examined agricultural imports. Based on the available trade and emissions data, Asia-Pacific was a net importer of GHG emissions embedded in agricultural products considered. Furthermore, the emission intensity per $1 was lower for exports than for imports (3.3 CO2 kg per $1 for exports vs 3.5 CO2 kg per $1 for imports), signifying that domestic demand was more emission intensive than foreign demand.

Table 1 GHG emissions embedded in agricultural trade in Asia-Pacific

H2	Chapter name (shortened)	**Exports**		**Imports**	
		USD (bil)	CO2 MT	USD (bil)	CO2 MT
2	Meat and edible meat offal	24.7	213	51.0	384
3	Fish and crustaceans…	10.8	15	8.4	11
4	Dairy produce, eggs, honey	16.2	25	23.5	45
7	Vegetables	19.4	10	16.6	10
8	Fruit and nuts	37.5	12	42.7	13
9	Coffee, tea and spices	4.2	17	4.7	16
10	Cereals	31.8	152	41.4	161
11	Products of the milling industry	5.1	8.6	3.7	5.5
12	Oil seeds and oleaginous fruits, grains seeds	1.7	4.3	47.7	190
15	Animal or vegetable fats and oils	27.8	215	23.8	158
16	Preparations of Meat, fish or crustaceans,	8.6	11	5.4	7.6
17	Sugars and sugar confectionery	2.4	6.1	5.7	12
18	Cocoa and cocoa preparations	3.3	10	4.9	16
20	Preparations of vegetables, fruit, nuts…	16.6	5.6	12.4	4.3
22	Beverages, spirits and vinegar	0.7	0.4	0.4	0.3
	TOTAL	**211**	**705**	**292**	**1,033**

Source: Authors' calculations based on data from UN COMTRADE, accessed October 2021.

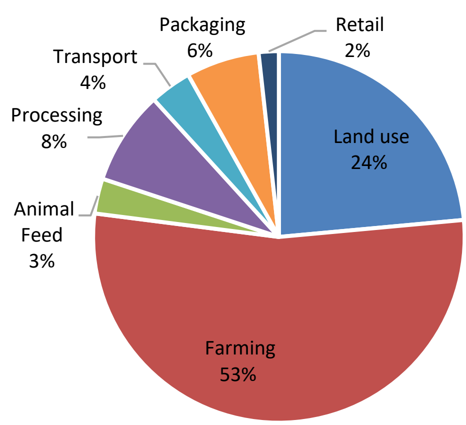
In terms of the sources of GHG emissions: for imports and even more so for exports, farming-related emissions account for approximately half of the total emissions embedded in trade (figure 5). As noted earlier, these emissions are primarily due to ruminants' methane belching for dairy and beef cattle, as well as methane emissions from droppings of animals. The next largest source is land-use change, which entails land clearing for crops and pastures.

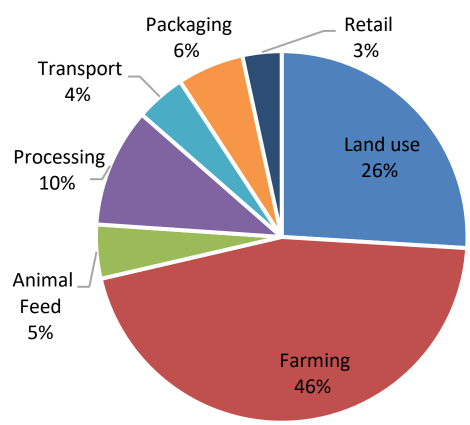
Transport, which is typically the focus of attention when it comes to GHG emission action, accounts for only 4% of GHG emissions embedded in traded agricultural goods. This means that climate-oriented trade policy targeting transport alone would be of little or no relative consequence when trade in agricultural goods is considered, putting into question the "consume locally" campaigns on climate ground.[9] Indeed,

[9] For a recent paper on this issue and related literature, see https://www.scielo.br/j/sa/a/DNPPhm8L8RD9zGQtzrjCwhf/?lang=en

such policies may actually be counterproductive by increasing the prices of bulkier but less expensive foods, relative to calorie-dense foods, which in case of animal-based proteins have a higher GHG footprint.

Figure 5 CO2-equivalent shares of GHG emissions embedded in examined agricultural trade in Asia-Pacific, by source





Source: Authors' calculations

5. Impact analysis of carbon border taxes on agricultural imports

As outlined in Chapter 6 of ESCAP, UNEP & UNCTAD (2021), impact analysis of carbon border adjustment taxes and other climate-related trade policies is a complex undertaking that requires detailed information on trade-embedded GHG emissions, behavioural parameters and interconnectedness between sectors. Interconnectedness between sectors, in particular, is important since, for example, in the case of agriculture, a decrease in quantity demanded in one product (due to, for example, tax-induced price increase) would most likely increase the quantity demanded for its substitutes – crocodile meat vs pork,[10] for example – and decrease demand for compliments (feed for pigs in this example). Decrease in prices in one market may be offset by increases in quantity demanded in another market. As such, to account for such interconnectedness, general equilibrium analysis is typically conducted. However, current computable general equilibrium models and databases often lack sufficient details in terms of economies examined and products covered.

For the reasons described above, as well as for reasons of parsimony, partial equilibrium analysis is used in this study. The intuition behind partial equilibrium is fairly straightforward – if the price of a product increases, the quantity demanded falls depending on behavioural demand elasticity parameters estimated separately (see Utoktham, Kravchenko & Duval, 2020). While missing sectoral dynamics, such

[10] Azubel, D.. (24 January 2022). Thailand turns to crocodile meat as pork prices rise – in pictures. *The Guardian*. Extracted 27 January 2022, from: ttps://www.theguardian.com/artanddesign/gallery/2022/jan/24/thailand-turns-to-crocodile-meat-as-pork-prices-rise-in-pictures

analysis gives a six-digit HS product level indication of potential exposure to carbon-related trade policies for those economies for which trade data could be derived (including through mirror trade data analysis). The net effect on imports is composed of trade diversion and trade creation. Trade creation involves changes in demand due to changes in price of an imported good caused by implementation of a trade policy instrument; and trade diversion is due to changes in relative prices determined by a difference in price changes from different sources or trade partner countries (for more details see UNCTAD and WTO (2012)).

To study the effect of carbon tariffs, ad valorem carbon tariffs were calculated. To do this, we assumed a certain price of carbon (e.g., \$0.005/kg of CO2, or \$50 per MT of CO2, which is the minimum price estimated by the IPCC that would have any chance of achieving climate-related goals). We then multiplied the CO2-equivalent GHG content of each product (based on Poore and Nemecek (2018) and quantity derivation described in Annex) by the assumed carbon price (i.e. CO2-equivalent GHG content per kg × Carbon Price per kg) to obtain the product costs associated with the GHG emissions embedded in them. This cost was then expressed in ad valorem terms, i.e. based on the trade value of 1 kg of the traded product.

For example, the cost of the embedded GHG emissions in beef is: 59.6 CO2[11]/kg × \$0.005/kg[12] = \$2.98/kg of beef. Given the median import price of beef calculated earlier at \$4.81/kg[13], the ad valorem carbon tariff that would need to be implemented to fully internalize the price of the embedded CO2-equivalent GHG emissions is: \$2.98 ÷ \$4.81 × 100 = **61.9%**.

At present, no markets implement carbon pricing for agriculture produce (let alone carbon tariffs), and as such, for the purposes of estimating market exposure to hypothetical carbon trade levies imposed by every economy in the world, trade diversions effects can be omitted, leaving only trade creation effects, calculated using the following formula:

$$TC_{ijk} = M_{ijk} \cdot E_{m_{kj}} \cdot \frac{dt_{ijk}}{(1 + t_{ijk}) \cdot (1 \cdot \frac{E_{m_{kj}}}{E_x})}$$ [14]

where M_{ijk} is the value of imports of product k from economy j to economy i, $dt_{ijk}$is the change in tariff rate t_{ijk} (calculated as described above for each HS six-digit product code); product (k) and origin (j) import demand elasticities $E_{m_{kj}}$ are derived from Utoktham, Kravchenko & Duval (2020), and the elasticity of supply (E_x) was assumed to be elastic for simplicity and set at 999. Global average elasticities for each HS six-digit code were used for those reporters that are not present in the database.

[11] Poore and Nemecek (2018), figure 1
[12] Assumed carbon price per kg - 0.005/kg of CO2, or \$50 per MT of CO2
[13] See Annex for methodological notes.
[14] Adapted from Laird, S. and Yeats, A. (1986) and UNCTAD and WTO (2012), “Chapter 4. Partial Equilibrium Trade Policy Simulation in A Practical Guide to Trade Policy Analysis”, UNCTAD & WTO: Geneva.

The trade impact of carbon taxes set at the levels of $10 and $50 per ton of CO_2 can then be calculated. Since the European Union+ members[15] (EU+) are likely to be the first globally to implement such levy as part of CBAM (yet to be considered for agriculture), an additional scenario where only EU+ members imposed a $50 charge per ton of CO_2 to non-EU+ economies was also simulated (in this case the trade diversion effects were also calculated as per UNCTAD and WTO (2012)). An important shortcoming is that due to data limitations, internal markets are excluded, potentially exaggerating the trade impacts from relatively more expensive imports in the case of the scenario where only EU+ countries impose carbon tariffs.

The results are presented in table 2 and figure 6. As expected, meat sector bears the brunt of global charges in both $10/ton and $50/ton of CO_2 scenarios, followed by animal oils. Fruit and nuts – the largest sector by initial export values – experience the least impact. The relationship, however, is not linear, demonstrating that even relatively small surcharges will have a large effect on meat exports EU's CBAM would only reduce regional exports by 3%, with trade diversion (absent from the first two scenarios) responsible approximately for 15% of the decrease in exports.

[15] Comprising the European Union; United Kingdom; Norway; Iceland; Lichtenstein; and Switzerland

Table 2 Simulated changes in Asia-Pacific exports due to carbon taxes, by HS chapters

h2	Chapter name (shortened)	Asia-Pacific Exports (USD, bil)	Change, percent		
			$10	$50	EU+ CBAM ($50)
2	Meat and edible meat offal	22.1	-38%	-78%	-4%
3	Fish and crustaceans…	10.8	-4%	-19%	-4%
4	Dairy produce, eggs, honey	16.0	-6%	-24%	0%
7	Vegetables	17.2	-2%	-11%	-1%
8	Fruit and nuts	33.2	-1%	-6%	-1%
9	Coffee, tea and spices	4.7	-14%	-47%	-12%
10	Cereals	32.9	-17%	-58%	-4%
11	Products of the milling industry	4.8	-5%	-23%	0%
12	Oil seeds and oleaginous fruits, grains seeds	1.7	-11%	-40%	-8%
15	Animal or vegetable fats and oils	29.1	-25%	-63%	-9%
16	Preparations of Meat, fish or crustaceans,	7.8	-4%	-20%	-6%
17	Sugars and sugar confectionery	3.6	-10%	-35%	-1%
18	Cocoa and cocoa preparations	3.1	-11%	-40%	-3%
20	Preparations of vegetables, fruit, nuts…	13.9	-1%	-5%	-1%
22	Beverages, spirits and vinegar	0.8	-1%	-6%	-4%
	TOTAL	**201.6**	**-12.9%**	**-36.4%**	**-3.0%**

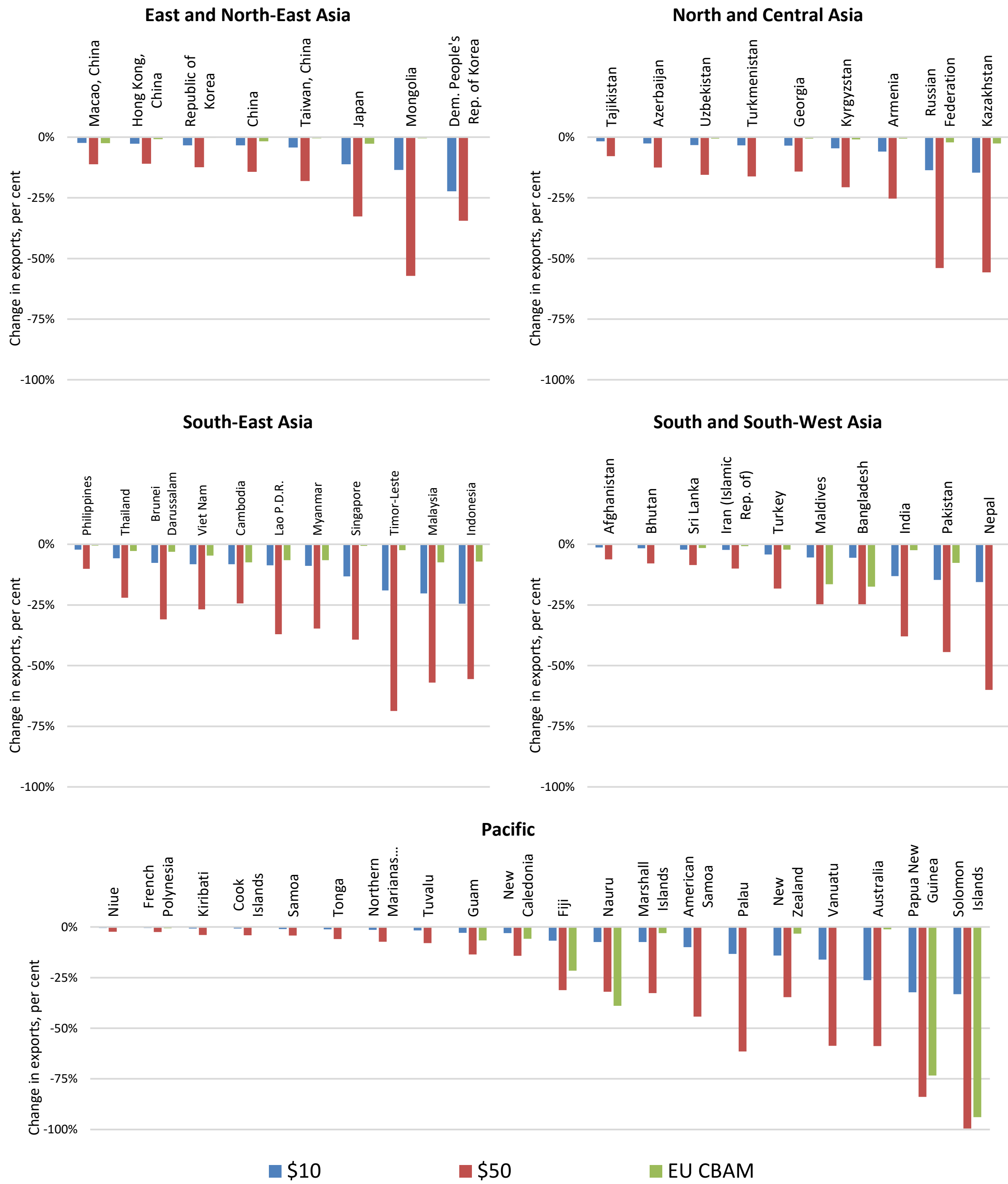
Source: Authors' calculations

Note: Only imports are used in the Partial Equilibrium simulations, hence exports presented here are global imports from trade partners of Asia-Pacific economies (i.e. mirror exports), and as such the totals are slightly different from those featured in table 1 due to differences in c.i.f. vs f.o.b. pricing, time lag and other causes of statistical discrepancies.

In terms of imports by countries from partners of the Asia-Pacific economies [16] (figure 6), EU+'s CBAM has a particularly strong estimated impact on some SIDS. The magnitude of this effect essentially comes down to the share of meats, and more specifically beer and dairy, in countries' agricultural exports.

[16] Essentially representing exports of Asia-Pacific economies, though with some differences due to c.i.f. vs f.o.b. pricing, time lag and potentially misinvoicing – see Kravchenko (2018) Annex.

Figure 6 Simulated changes in Asia-Pacific exports due to carbon border tariffs, by economy



Source: Authors' calculations

6. Summary and implications

At the time of writing this study, only New Zealand thus far has indicated any plans to address farm-based GHG emissions through carbon pricing mechanisms, and there are no plans anywhere to introduce carbon pricing on agricultural trade. Indeed, even EU+'s CBAM at this stage only intends to target selected carbon-intensive products, such as steel and cement. However, as pointed out in ESCAP, UNEP and UNCTAD (2021), climate action needs to permeate all sectors with utmost urgency, and climate-smart NTMs, voluntary standards and rising consumer awareness can potentially accelerate changes in international trade in carbon-intensive agricultural goods even before GHG emissions are formally internalized in markets. It is worth noting, however, that the Asia-Pacific region as a whole is a net importer of CO2-equivalent emissions embedded in agricultural products. As such, for most of the economies in the region, it may indeed be worthwhile to potentially implement carbon tariffs as part of their trade-related climate action, particularly on high emissions-to-calorie ratio foods, such as beef.

The results presented in this study indicate significant implications for those economies in the Asia-Pacific region that are reliant on agricultural exports. In particular, economies that export a lot of carbon intensive agricultural products, such as beef, are especially in danger. The study applies a parsimonious approach to examine exposure, but such high-level results should be interpreted with caution. First, farm systems vary significantly between product categories, and a detailed analysis would be required for an in-depth understanding of individual products. For example, as mentioned earlier, GHG emission footprints differ vastly between New Zealand's and the UK's lamb products, implying that New Zealand's lamb may be at a relative advantage facing carbon tariffs. Indeed, its demand may actually increase if trade diversion effects outweigh trade destruction effects. Second, as noted, partial equilibrium analysis misses important sectorial dynamics which may become pivotal in case of wide-sweeping policies. For example, a shift away from animal-based diets (whether carbon price induced or through changing consumer preferences) would mean that the resultant calorie deficit would necessarily need to be accounted for elsewhere. As such, demand for less carbon intensive food products would increase, and producers in the Asia-Pacific region may gain significant benefits.

Readers are reminded that the results are subject to further study, in particular given the significant uncertainties associated with data limitations mentioned in the paper. Policy changes in this area are evolving quickly both at national and international levels, and more research is needed to fully capture the impacts of domestic and border carbon policies and regulations on trade and welfare.

Annex: Estimating CO2-equivalent content in agricultural products

The 40 categories used in Poore and Nemecek (2018) were manually matched with 490 six-digit level harmonized system (HS) classification products categories (H4 (2012) version).[17] By trade values, 61% and 64% of the $408 billion of Asia-Pacific agricultural exports and $521 billion imports, respectively, were accounted by matching. The HS chapters not covered by the matching mostly include those agricultural products that are not intended as food, such as live animals, live plants, tobacco, etc. (e.g. thoroughbreds, bonsai trees, and ciggies), but also categories too broad to generalize (see table which lists covered HS chapters).

Table 3 Agricultural trade in Asia Pacific, by HS chapter, and share of trade values for which GHG emissions data were matched

H2	Chapter name (shortened)	Exports		Imports	
		USD (bil)	Matched (%)	USD (bil)	Matched (%)
1	Live animals	4.3	0	5.5	0
2	Meat and edible meat offal	25.5	97	51.8	99
3	Fish and crustaceans…	48.0	75	47.2	72
4	Dairy produce, eggs, honey	17.7	92	24.6	96
5	Animal originated products	4.2	0	3.6	0
6	Live plants and flowers	1.5	0	2.3	0
7	Vegetables	19.4	100	16.6	100
8	Fruit and nuts	37.5	100	42.7	100
9	Coffee, tea and spices	15.7	27	11.1	42
10	Cereals	32.0	99	41.9	99
11	Products of the milling industry	7.2	71	6.4	58
12	Oil seeds and oleaginous fruits, grains seeds	10.4	16	61.8	77
13	Lac, gums, saps and resins	3.5	0	2.4	0
14	Vegetable plaiting materials	0.6	0	0.7	0
15	Animal or vegetable fats and oils	40.1	72	37.6	75
16	Preparations of Meat, fish or crustaceans	23.1	77	12.4	74
17	Sugars and sugar confectionery	11.0	22	12.5	46
18	Cocoa and cocoa preparations	6.4	51	9.7	51
19	Preparations of cereals, flour, starch or milk;	18.2	0	19.7	0
20	Preparations of vegetables, fruit, nuts…	16.6	100	12.4	100
21	Miscellaneous edible preparations	24.4	0	24.1	0
22	Beverages, spirits and vinegar	18.5	24	28.7	31
23	Food industries, residues and wastes thereof	11.8	0	29.0	0
24	Tobacco	10.8	0	16.2	0
	TOTAL	**408**	**61**	**521**	**64**

Source: Authors' calculations based on data from UN COMTRADE, accessed October 2021.

Note: Highlighted rows indicate HS agricultural chapters that had no six-digit HS codes that could be matched to farm emissions data in Poor and Nemecek (2018)

[17] Concordance tables are available separately at https://unstats.un.org/unsd/trade/classifications/correspondence-tables.asp

Next, corresponding GHG emission estimates per kg from Poor and Nemecek (2018) were multiplied by the weight of the respective product categories. Closer examination of the initial results, however, uncovered significant abnormalities. For example, Malaysian egg exports to Singapore had some of the highest absolute levels of embedded GHG emissions in Asia Pacific region (values and quantities were confirmed by matching Singapore's import statistics). Further examination showed that in 2019, it was reported that Malaysia exported more than 25 million metric tons of eggs to Singapore. Assuming an average of 20 eggs per kg this means that Singapore imported over 500 billion eggs, or nearly 100,000 eggs for every man, woman and child in Singapore. The derived price (i.e., reported value / reported quantity - at a price of about $0.02 per 100 eggs – great deal!) [18] was orders of magnitude lower than for other economies trading in the same product.

To address this issue, for every HS six-digit code, rather than taking at face value reported quantity, an average price was derived by obtaining a median derived price of all available value/quantity data points across all products at HS six-digit level. The median price for each six-digit HS code for exports and imports was then used to derive quantity estimates (i.e. trade value / median price). The added advantage of this method was that quantity estimates were derived for trade flows that had quantities missing from the database (though issue still remained for some product categories for which quantity units were not kgs, e.g. HS chapter 22, beverages). Finally, because HS nomenclature does not differentiate between farmed and fresh fish, "Farmed fish" category from Poore and Nemecek (2018) was dropped from the subsequent analysis.

[18] The authors reached out to UN COMTRADE who noted the abnormalities and since corrected estimated quantities.

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