Making the numbers count: can national carbon accounting systems support effective trade-related climate policies?

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Abstract
Companies and governments are paying increasing attention to the carbon emissions embodied in the supply chains for globally traded commodities, as they seek to achieve the goal of net-zero emissions articulated in the Paris Agreement and profit from the energy transition. Trade-related climate policy instruments – such as border carbon adjustments, linked emissions trading schemes, or hydrogen certification – will rely on robust and consistent calculation of embedded emissions, both for efficacy and for compliance with WTO rules. We compare current government-mandated carbon accounting in four Asia-Pacific countries, and assess their suitability to support trade-related climate policies, using the example of ammonia as a promising future energy commodity likely to develop Asia-Pacific supply chains. We find considerable variance in practices between countries, which could be an obstacle to emergence of effective trade-related climate policy in the region. Critical areas for consideration include harmonising global warming potential (GWP) factors, increasing minimum standards of accuracy, and harmonising methodologies for each part of the relevant supply chain. Countries seeking leadership in markets for green commodities have an opportunity to do so through filling methodological gaps in supply chain emissions assessments, capacity building for those with less robust practices, and seeking to establish their practices as the minimum standard.

Keywords:
trade-related climate policy; carbon border adjustments; emissions certification; embedded emissions accounting

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The Australian National University Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* transdisciplinary research project is a $10m investment between 2019 and 2023 that aims to help transform the way Australia trades with the world. It comprises five interrelated projects: Renewable Electricity Systems, Hydrogen Fuels, Energy Policy and Governance in the Asia-Pacific, Renewable Refining of Metal Ores, and Indigenous Community Engagement. The Grand Challenge's goals include developing zero-carbon export industries, creating new paradigms in benefit-sharing, and developing technologies, polices and approaches which can be applied in the Asia-Pacific and beyond.

Introduction

Trade-related climate policy (TRCP) is on the rise as many countries around the world step up their emissions abatement ambitions for the coming decades. These policies provide a means of maintaining the competitiveness of domestic industries through the transition to a low-emissions economy, and of ensuring climate action at home is not undermined by lack of action abroad. In particular, border carbon adjustments are being actively explored by major markets such as the United States, and the European Union. TRCP can also be used to target green industrial policy programs and support the emergence of zero-emissions supply chains. Certification schemes for low-emissions commodities such as “clean” hydrogen, ammonia, steel and aluminium are a case in point. If these TRCPs are to be efficient, non-discriminatory, and WTO compatible, they will need to be based on emissions accounting systems for the traded products.

The current paper considers whether existing government-mandated methodologies for emissions accounting can adequately support TRCPs in the age of global value chains. Mandated carbon accounting practices have their roots in national carbon inventories. Every country that is a party to the Paris Agreement has committed to ‘regularly provide… a national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change’ (UN, Paris Agreement, paragraph 7 of Article 13) (hereafter referred to as the *IPCC Guidelines*). These schemes, designed for National Accounts, are not designed to account for emissions of products along their value chains. None-the-less, they are worth considering as a starting point for TRCP.

Our primary motivation for focussing on the adaptation of public approaches to carbon accounting is realist. Regulatory path dependence, what Liu (2018, p534) calls “territorialised regulatory logic”, means that future embodied emissions accounting to underpin TRCP are likely to draw on existing public approaches. Already the boundaries of the EU’s pilot, industry-led, hydrogen certification scheme, CertifHy, are heavily influenced by the EU Renewable Energy Directive (Velazquez Abad & Dodds 2020, p8). It is likely that governments will want to go further, favouring the application of their own existing carbon accounting methodologies (developed originally for compliance with obligations under the Kyoto Protocol and adapted for subsequent climate change treaties) as they seek to develop and negotiate certification and accounting systems to support TRCP.

There are also normative motivations for focussing on mandatory (public) accounting methodologies rather than existing private certification schemes as a basis for TRCP. One motivation arises from differences in objectives and obligations compared to private schemes. The primary objective of private certification schemes is to support positive behavioural change by facilitating the comparison of trade-offs across goods and services. Minimizing omission (maximizing completeness as highlighted by Kennelly et al (2019)) is an important component of accuracy for these purposes. In contrast, the principle objective of emissions accounting to support TRCP is to allow fair comparison of “like products” – quiet literally – to compare apples with apples. Accuracy within the defined boundary remains central. However, for the purposes of trade law, completeness of the system boundary itself is less of a concern, as long as the emissions from components outside the boundary are similar across different ways of producing a given good or service.

Government designers of embodied emissions accounting schemes also face a more substantial set of obligations than designers of private, voluntary schemes. Compliance-cost minimisation and transparency are important for purely domestic-facing schemes, but even more so for those which may affect traded goods and services. WTO compliance will require transparency of trade-impacting policies and compliance costs for imported goods and services to be similar to those for their domestic counterparts. It will also require “product-specific” carbon calculations, that is, related to a specific batch of imports (Cognor & Ignacuik 2013, p13). Within the set of possible process-based, product-specific methodologies, adaptation of existing mandatory emissions-accounting methodologies scores very highly in terms of minimising implementation cost both for governments and businesses. These considerations have already seen accounting methodologies for National Accounts adapted for other purposes. For example, in Australia, these methods have further been adapted for policy development guidance (DCC 2011 p18); business energy management (DRET 2013, p148); carbon offsets (Commonwealth of Australia 2015); and carbon footprinting (Climate Active 2020). The current paper contributes to the literature on the adaptation of National Accounting methodologies for related purposes.

National carbon accounting methodologies, and the *IPCC Guidelines* on which they are based, are the subject of a substantial literature in their own right, but little of this relates to the role of carbon accounting in facilitating trade. Nevertheless, this broader literature has important insights for consideration of carbon accounting to support CRTP. Critical analysis of the *IPCC Guidelines* and associated emissions accounting practices highlights weaknesses such as self-interest by nation states, slow adoption of scientific advances in measurement, inconsistent use of spatial and sectoral boundaries, and resource heterogeneity, which affect robustness at every level from the national to the firm (Yona et al 2020, p1581-2; Kokoni & Skea 2013, p376; Singer et al 2014, p193; Wegener et al 2019, p662; Bellassen et al 2015, p325). While the focus of this literature has been national consistency, the current paper contributes to our understanding of consistency along international supply chains.

A further issue of concern in the literature on National Accounts is the use of default factors for carbon accounting. Use of global averages is widespread, particularly in developing countries that lack the capacity to collect the data required more accurate methods, (Yona et al 2020, p1582-1583), which introduces uncertainty in carbon calculations if fuel characteristics vary between countries (Konstantinaviciute & Bobinaite 2015, p606; Uvarova et al 2014, p542). We argue that in the context of TRCP, these discrepancies can have competitive implications.

The current paper contributes to the nascent literature on emissions accounting to support trade-related climate policies, including carbon border adjustments and international certification of traded products. We undertake an empirical case study of government-mandated carbon accounting methodologies in four Asia-Pacific countries – Australia, New Zealand, Japan and Korea – and consider how well these practices support development of TRCP. We begin by considering each country’s methodologies in isolation, before considering the case study of trade in ammonia between these countries. Our supply chain analysis contributes to the literature on the interoperability of emissions accounting systems for traded products. Specifically, it expands on the work of White et al. (2020), by showing that national accounting methodologies can be compatible with the modular approach to emissions accounting boundaries they recommend for the certification of hydrogen to support international trade. We conclude with recommendations for policymakers, and some suggestions for further research.

Criteria and Methodology

Our subset of countries - Australia, New Zealand, Japan and Republic of Korea - reflects four countries with stated ambitions to participate in green fuel supply chains. Even though discussion of climate-related trade policy is primarily taking place in the EU and USA, future growth of energy emissions is projected to take place almost entirely in the Asia-Pacifica region. As well, Australia and New Zealand are export-oriented economies, and our analysis applies equally regardless of the final destination of exports.

Our assessment focusses on mandatory emissions reporting schemes. Appendix A summarises the legislation that underpins each scheme and was the data source for our analysis. Our analysis focusses on three criteria: completeness, accuracy, and compliance.

Completeness: One of five principles of the Greenhouse Gas Protocol Accounting Standard, completeness means to "Account for and report on all GHG emission sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusions." (GHG Protocol, p.7) As TRCP are still in their early stages of development, it is not yet know which emissions in supply chains will be captured. As Velaquez Abad & Dodds (2020, p9) point out, choice of boundaries varies considerably between schemes just for one commodity, and between approaches. For the purposes of the current paper, our measure of completeness is the existence of a method to calculate scope 1 & 2 emissions from primary resource extraction to end use, but excluding emissions embodied in capital and in disposal. We used the *IPCC Guidelines* as an organising framework, focussing on energy and industrial emissions. For each of the 79 key categories, we evaluated whether each of the national emissions reporting schemes specified a method of calculating emissions for that key category. Categories that did not specify a method were tagged as "missing".

Accuracy: Another of the five principles of the GHG Protocol Accounting Standard, accuracy means "Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information." (GHG Protocol, p.7) We used two indicators of the accuracy of the assessed accounting methodologies. The first is the currency of the Global Warming Potential factors, or GWPs used. Carbon accounting includes processes for converting emissions from gases other than carbon dioxide to carbon dioxide-equivalent or CO2e, so that total impacts from all gases can be determined even though they have different lifespans in the atmosphere and different effects on solar forcing. This is done using GWPs. The IPCC regularly revises and publishes GWP factors, but there can be a lag between publication and adoption by individual countries. For each mandatory emissions reporting scheme, we identified which GWP is specified for use. Our second indicator of the accuracy of the methodologies was taken from the most recent Inventory Review Reports (IRRs) for each country. IRRs are independent reviews of national inventory processes which are mandatory for Appendix 1 countries under the Kyoto Protocol every two years. While IRRs are primarily concerned with how greenhouse gas inventories are compiled, they occasionally identify anomalies or poor practice with respect to emissions calculations. We checked whether these reviews had identified potential inaccuracies in each methodology. We recorded only where an issue identified in an IRR would also apply to the method outlined in the mandatory emissions reporting scheme. This assessment was made only for Australia, New Zealand and Japan; as the Republic of Korea was not an Annex One member of the Kyoto Protocol, it is not subject to the IRR process, and thus there is no data available.

Compliance: as noted above, to be WTO-compliant, any climate-related trade policy must allow for assessment of the embodied carbon of individual goods. The *IPCC Guidelines* outline a scale of methodological complexity from Tier 1 (a simple equation multiplying production data from national statistics by standard global factors) to Tier 3 and Tier 4, which can include plant-specific calculated approaches, modelling, and/or continuous monitoring. Tier 2 uses production data and country-specific emissions factors (IPCC 2006 p1.6)[1]. Mandatory emissions reporting schemes will set out one or more methods in each key category for each relevant greenhouse gas. For each of these methods, we assigned a score based on which Tier it corresponded to (1=Tier 1, 2=Tier2 etc), and recorded the lowest and highest Tiers for each greenhouse gas. “Missing” methods were not scored. Ideally, to be WTO-compliant, an average score for a commodity should be between 2.5 and 3.5, corresponding to a range that is closer to plant-specific than to a country or global average.

Table 1 summarises the results of our analysis for the example of emissions from flaring of natural gas and waste gas vapour streams and gas facilities for Australia and Japan, corresponding to IPCC key category 1B2bii.[2] Table B.1 in Appendix B summarises the full results of our analysis for the four countries.

Table 1: Example analysis for the IPCC key category 1 B 2 b ii: emissions from flaring of natural gas and waste gas vapour streams and gas facilities for Australia and Japan

		Australia	Japan
Completeness (Method present, reference)		Section 3.3.9.2, *National Greenhouse and Energy Reporting Measurement Determination*	Paragraph 3.2.3, *Greenhouse Gas Emission Calculation / Reporting Manual (Ver4.6) (Reiwa June 2), Volume 2*
Accuracy (year GWP published by IPCC)		2014	2007
Accuracy (Problems identified, Y/N)		N	N

[1] A country’s choices of Tiers for components of its emissions accounting system will be informed by data availability, capability, and the relative contribution of the emissions source to national emissions. As well, Appendix 1 parties to the Kyoto Protocol undertook to implement at minimum Tier 2 for national inventories. Tier 4 is not necessarily the most accurate, precise, and complete, however. Continuous monitoring of emissions has a far higher uncertainty than a stoichiometric/carbon balance method such as may be conducted for a Tier 3 calculation. Studies for a coal-fired power plant have shown Tier 3 methods to yield 27% less CO2, and Tier 1 methods to yield 20% less, compared to continuous monitoring (Tier 4) (Lee et al2014, p1171.)

[2] IPCC key category 1 B 2 b ii covers emissions from flaring of natural gas and waste gas vapour streams and gas facilities. Section 3.3.9.2 of the Australian National Greenhouse and Energy Reporting Measurement Determination describes a method named "Natural gas production and processing (emissions that are vented or flared)" which corresponds to this key category. The method allows two ways of calculating emissions. The first uses a national emissions factor, corresponding to a Tier 2 methodology. The second allows for a plant-specific emissions factor, and sets out rules for determining this factor, corresponding to a Tier 3 methodology. GWPs of 28 and 264 are used to convert emissions from methane and N2O to carbon dioxide-equivalent respectively, corresponding to those published in the 2014 IPCC Fifth Assessment Report. For the same key category, the Japanese Greenhouse Gas Emission Calculation / Reporting Manual (Ver4.6) sets out a method called “Crude oil or natural gas production - emissions associated with natural gas production". The method only allows one way of calculating emissions, using a global emissions factor from the IPCC Guidelines, and therefore corresponding to a Tier 1 methodology. GWPs of 21 and 298 are used to convert emissions from methane and N2O to carbon dioxide-equivalent respectively, corresponding to those published in the 2007 IPCC Fourth Assessment Report. No issues were identified for this category in IRRs.

Compliance (Tier score by gas, lowest and highest)	CO2	2	3	1	1
	CH4	2	3	1	1
	N2O	2	3	0	0

Country-level analysis

The complete results of our analysis of each of the four country's accounting methods are presented in Table B.1 in Appendix B. The current section provides a qualitative and quantitative summary of these results.

Completeness: Of the four countries considered, Australia and the Republic of Korea are the most 'complete', with emissions calculation methods assigned to 54 of 79 IPCC key categories of energy and industrial emissions. Japan is not far behind on 51, but New Zealand only has 22. The number of methodologies in a country's system will reflect the significant sources of emissions in that country's economy. New Zealand's low number is consistent with the fact that only around 6% of its GDP comes from industrial activity (Figure NZ 2020). Hence, the relatively high proportion of "missing" methods should not be seen as an inditement of New Zealand's national carbon accounting approach. As we will see in the case study section, however, missing methods do become a concern if a country wishes to use their current methods as a basis for participation in a supply chain where quantifying carbon is an enabler of trade.

Accuracy: The countries differ significantly on accuracy. Australia uses the most up to date GWPs (equivalent to the 5th assessment report); Korea is using factors form the 2nd assessment report of 1995. The GWP for N2O has declined between the Second and Fifth Assessment Reports, so using an older GWP is a more conservative approach. However, the GWP for methane has increased. As Table 1 in Appendix B shows, the difference between the methane GWP in the Australian system and the Korean system is around 25%, meaning that calculations for the same process using a similar method Tier could yield results that are markedly different. New Zealand's rules provide a single emissions factor in tonnes of carbon dioxide-equivalent (tCO2-e) that (presumably) includes relevant emissions from methane and nitrous oxide. This reduces the transparency of the NZ system, and also makes it impossible to see which GWP is used.

Identified problems with methods mostly involve inconsistent use of emissions factors or calorific values, so that a similar calculation for different processes may yield different results. Some relevant methods also had problems identified around boundaries (particularly including several processes within one calculation boundary). Australia and Japan were both identified as treating fugitive emissions from gas transmission and distribution in ways that make their accounts difficult to compare to other countries.

Compliance: None of the minimum requirements in any of the countries analysed fall into the ideal range for compliance. Figure 1 shows the average minimum Tier of methodologies for carbon dioxide, methane and nitrous oxide, for each of the four countries. Australia has the highest average minimum score at slightly above 2, and the Republic of Korea has the lowest, at slightly above 1. This means we could expect Australian practices to return the most accurate result relative to the others, but this result is likely to be closer to a country-specific than a plant-specific result. Korea's low minimum reflects that it allows Tier 1 to be used for every methodology, consistent with the differentiated approach allowed under the Kyoto Protocol where the IPCC *Guidelines* originate.

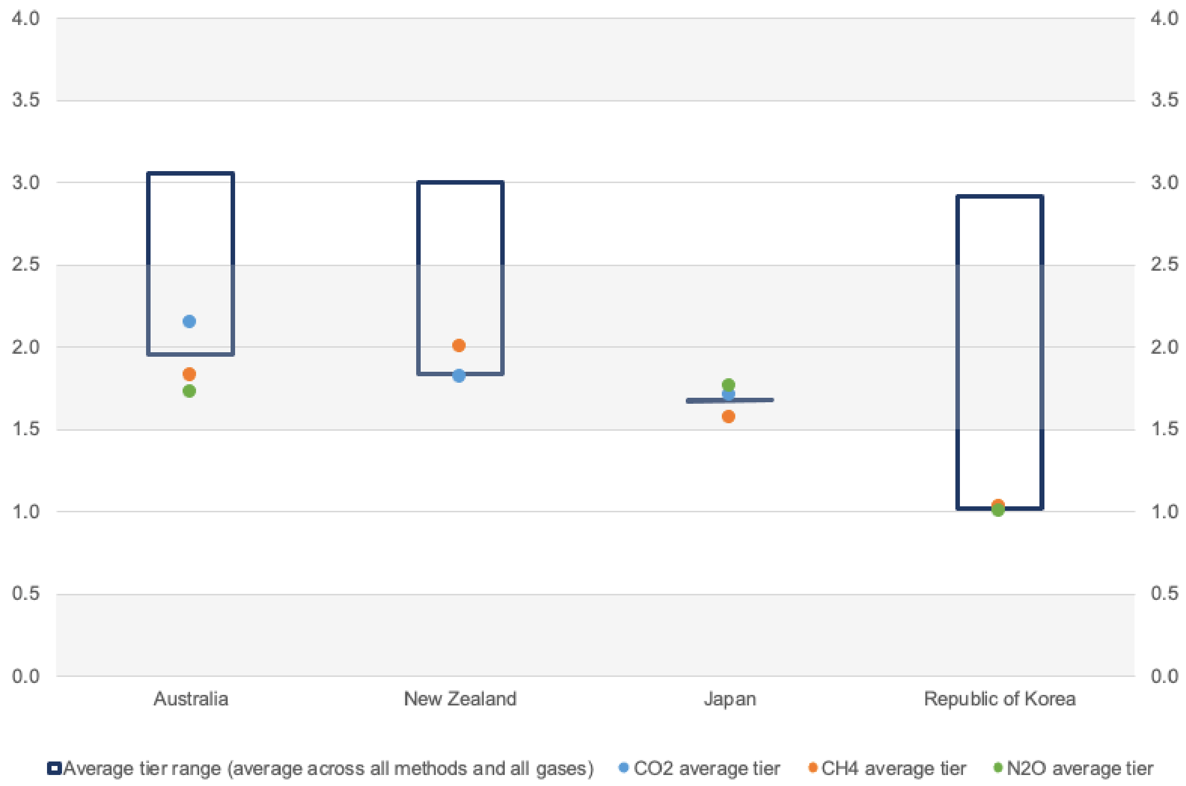

Figure 1: Comparison of average complexity for CO_2, CH_4, and N_2O; and average overall complexity range

However, minimum Tier is not necessarily the most common practice. All countries except Japan allow users to choose their Tier. The range of choice allowed could be a proxy for the potential for a system to support greater accuracy should users choose to. This is also shown in Figure 1. The Korean system has a low minimum Tier, but allows latitude for those seeking greater accuracy. Depending on what Tier individual users select, Korean practice may return results of comparable accuracy to Australia's or Japan's. All three countries that allow choice could support practices in the ideal complexity range of 2.5 to 3.5.

Supply chain analysis: ammonia case study

Thus far, our analysis only relates to carbon accounting practices within national borders. But supply chains for globally traded commodities cross borders, and carbon accounting for a supply chain will be influenced by the carbon accounting practices of multiple countries. Trade-related climate policies require carbon accounting systems applied to different parts of global supply chains to exchange and use each other's information. This raises the question of how *interoperable*[3] national carbon accounting systems are. Any assessment as to interoperability will be linked to the commodity under scrutiny and the start and end points of its supply chain. Our unit of analysis, therefore, shifts from a country to a specified supply chain. Analysis of all possible international supply chains of carbon-relevant commodities is beyond the scope of the current

[3] Diallo (2010, p77) defines interoperability as the ability to exchange information and use the information thereafter.

paper. To illustrate concepts, we analysed twelve theoretical supply chains for ammonia in the Asia-Pacific. Ammonia was chosen because, like hydrogen, it has the potential to be an important vector for low-carbon energy trade. Ammonia production is, however, slightly more complex than hydrogen, providing a richer case-study.

The twelve theoretical supply chains studied arise from a combination of four exporter-importer pairs and three ammonia production technologies. The exporter-importer pairs were Australia-Japan, Australia-South Korea, New Zealand-Japan and New Zealand-South Korea. The three ways of producing ammonia were the conventional (Haeber Bosch) method using natural gas as feedstock (with the option to include carbon capture and storage); a renewable pathway using 100% renewable energy to provide hydrogen and nitrogen feedstocks, and power the ammonia plant; and a hybrid process, where some of the hydrogen in a conventional process is replaced with hydrogen produced via electrolysis using 100% renewable electricity, but the remainder comes from natural gas.

White et al (2020) suggest that a modular approach to carbon accounting in hydrogen certification is a means of achieving interoperability – hence supporting the balancing environmental prerogatives for supply chain completeness with trade prerogatives of non-discrimination. Following White et al., for each supply chain, we created 'modules' as illustrated in Figures 2, 3 and 4, where each module represents part of the supply chain that consumes or produces energy and/or emissions.[4] Each module boundary therefore contains only Scope 1 and Scope 2 emissions. Scope 3 emissions for a particular module are not absent, rather, they are represented in the Scope 1 and 2 emissions of modules elsewhere in the chain. Figure 2: supply chain for conventional ammonia

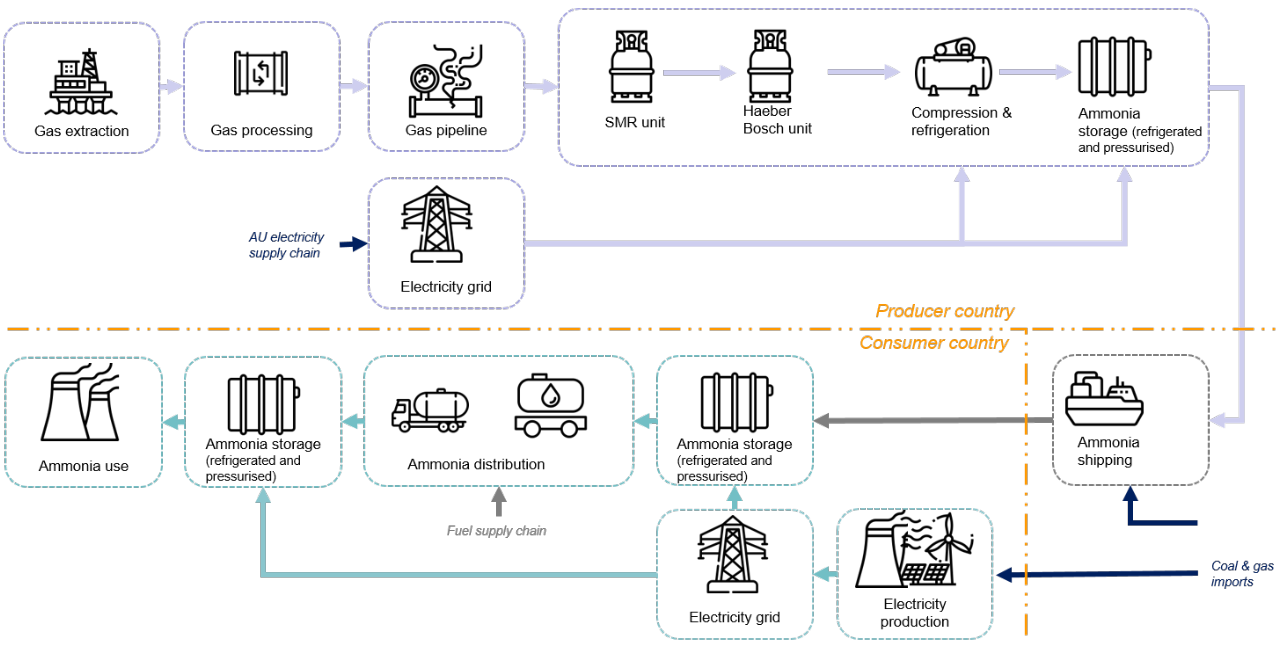

Figure 2: supply chain for conventional ammonia

[4] Two sources of potential supply chain emissions were excluded: emissions from the production and delivery of liquid fuels for transportation; and emissions from production and import of coal and gas to produce electricity in Japan and Korea. In both cases, the countries in question import these fossil fuels from multiple other countries, and including the supply chain emissions would add much complexity to the analysis without contributing to answering the fundamental question of how national practices in the four countries support emissions certification.

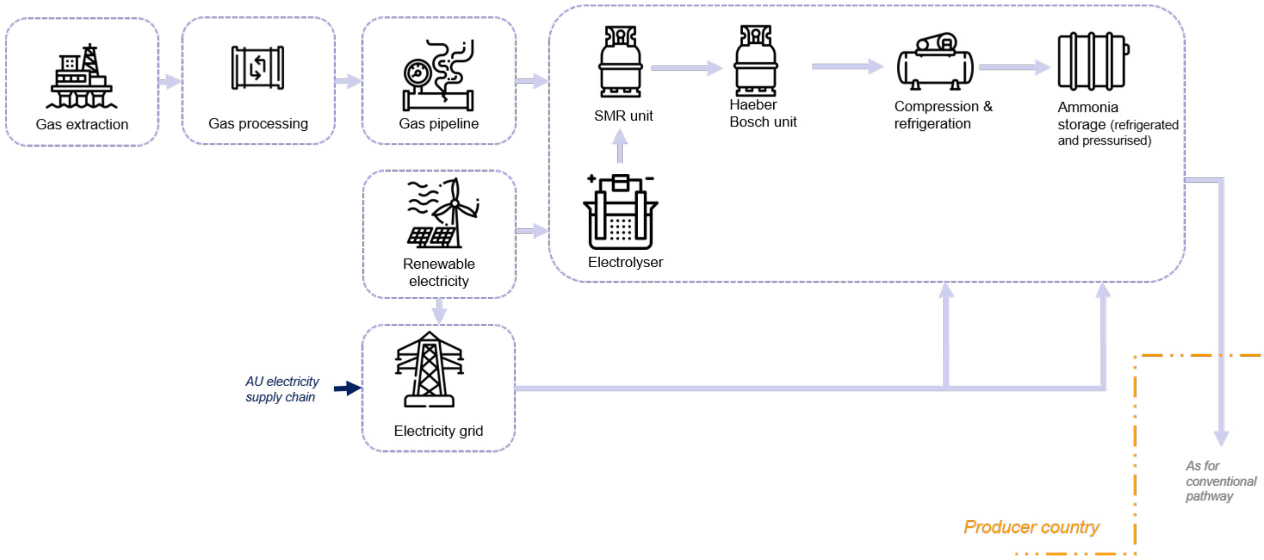

Figure 3: hybrid ammonia supply chain

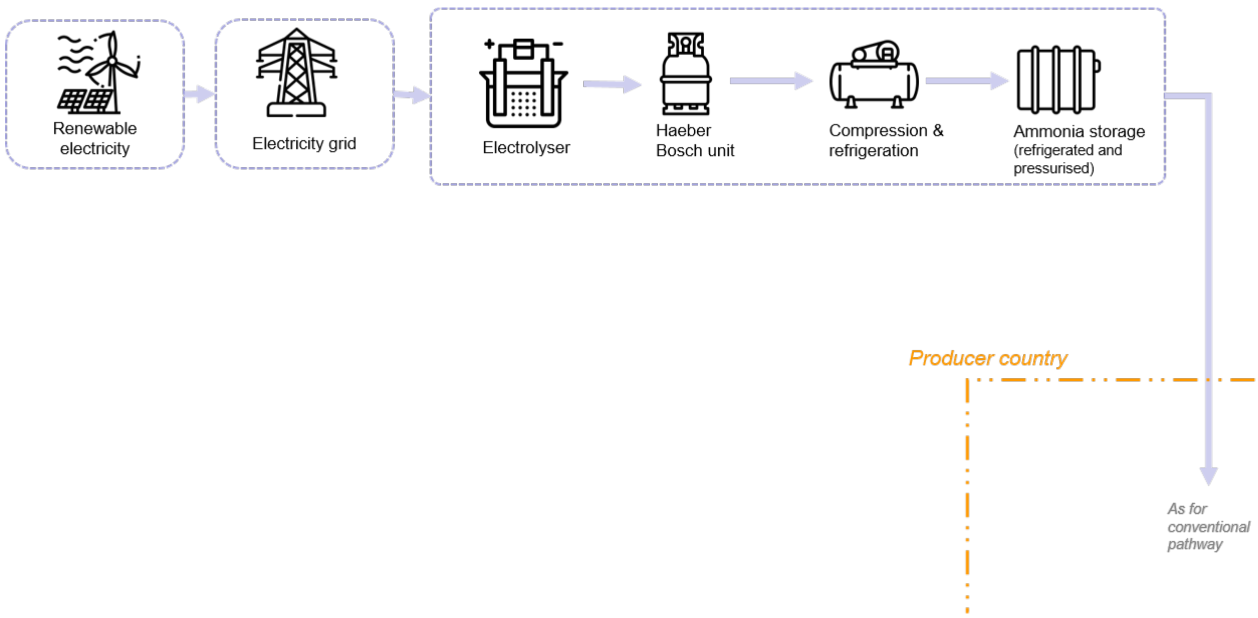

Figure 4: renewable ammonia supply chain

We assigned relevant methodologies from the *IPCC Guidelines* to each module in each supply chain, then matched the equivalent methodologies from the relevant national accounting system. The fact that these methodologies were able to be matched to modules suggests that methodologies based on IPCC Guidelines have potential to be interoperable. On this basis we proceeded to assess completeness, accuracy and compliance of each supply chain, using the methodology outlined above for the country-level assessment.

Full results for each supply chain and each production method are shown in tables 2, 3 and 4 of Appendix B.

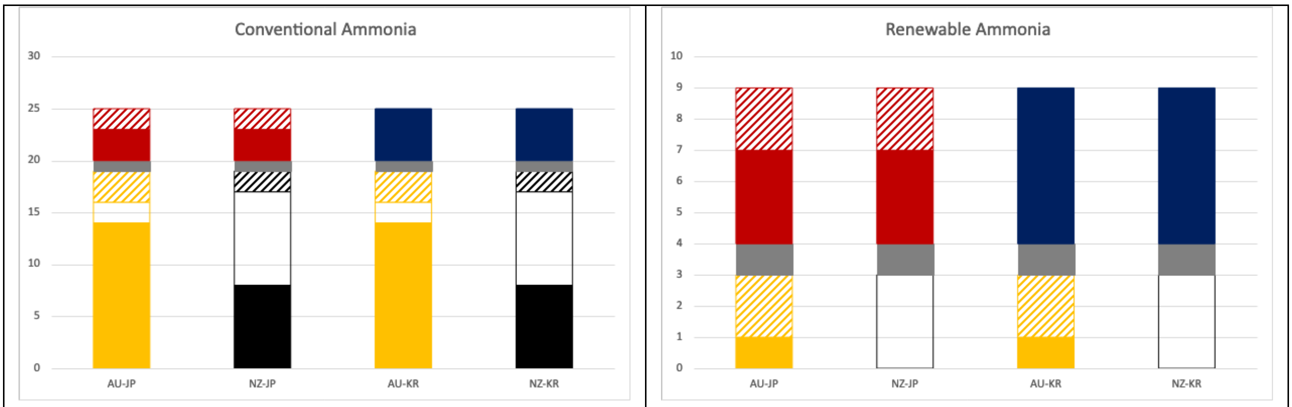

Figure 5: map of emissions calculation methods for conventional (left) and renewable (right) ammonia supply chains, showing number of methods in producer and consumer countries, missing and problematic methods.

Key: Australia methods Japan methods New Zealand methods Republic of Korea methods	Supply chain outside jurisdiction Cross-hatched = method with known issues blank = missing method

Figure 5 shows results for completeness and accuracy for conventional (left) and renewable (right) ammonia supply chains.[5] The conventional supply chain requires 24 methods to calculate all relevant emissions, the majority of which relate to activities in the producer country (Australia or New Zealand in this case). All supply chains have missing methods, and all have methods where problems have been identified. It should be noted that, while Korea’s data shows no problems, this is because there is no data source, rather than because problems do not exist. Common to all supply chains is the lack of a method to calculate emissions from international shipping: as these occur outside the geographical boundaries of all countries, national emissions accounting systems do not include them. The International Maritime Organisation provides a calculator for shipping emissions, which assumes all ships use the same fuel with a single global emissions factor.

Figure 5 highlights a key difference between mandatory emissions reporting in Australia and New Zealand. New Zealand's system centres on compliance with the New Zealand Emissions Trading Scheme. This scheme does not separate out emissions by industrial activity; rather, it assigns responsibility for emissions accounting as far upstream as possible, and combines all emissions from production, use and transportation together into a single emissions factor. This makes it difficult to repurpose the accounting practice to support certification, and is why, in Figure 5, New Zealand shows many missing methodologies.

Figure 6 shows the results of compliance analysis for each supply chain. No supply chain falls into the desirable (plant-specific) range between 2.5 and 3.5. We can see why, when we examine the minimum standard required for each country: Australia comes close (scoring 2.42 for conventional production and

[5] Methods for the hybrid supply chain are the same as for conventional, so are not shown here.

2.46 for renewable production); New Zealand and Korea score lower and hence supply chains involving these countries have an overall lower score. This effect is more pronounced in the conventional ammonia chain, which is much more emissions-intensive in the producer countries (19 relevant methods) than in consumer countries. In the renewable ammonia chain, emissions are more evenly spread between producer and consumer countries as most emissions are associated with transportation of ammonia rather than production.

Figure 6: comparison of compliance scores for carbon accounting practices for ammonia production and use in Australia, New Zealand, Japan and Korea, and for supply chains between these countries.

Discussion

Our analysis demonstrates the variance in mandatory carbon accounting practices between four countries with stated ambitions to participate in green fuel supply chains. This variance could become as source of contestation and dispute should trade-related climate policies be introduced, either by these countries or others. Of the four countries examined, only the Republic of Korea has a complete set of methods legislated for all sources of industrial emissions. Others have gaps where no method is legislated, and/or known problems. We did not analyse whether these gaps represent insignificant sources of emissions; it may be that a 'near enough' estimate of emissions in a supply chain can be obtained without filling them.

Choice of GWP has a significant bearing on accuracy and comparability between systems. Of the four countries examined, three use different GWPs, and one (New Zealand) does not disclose which GWP it uses. It is particularly concerning that some countries use quite out-of-date GWPs, which could mean emissions are chronically underestimated. Material differences in emissions from methane (up to 25%) are potentially observed. Climate-related trade policies must grapple with and resolve GWP differences from the outset. Failure to do so, and defaulting to the GWP currently used in each country potentially opens the gates to strategic behaviour if firms perceive an emission windfall by locating part of a manufacturing process in a country with a lower GWP. Such behaviour will work directly against the problem of 'emissions leakage' that trade-related climate policies set out to solve.

Our work also identified that some methods used in mandatory carbon accounting systems have known issues which may impact accuracy. Again, we did not test the materiality of these inaccuracies, nevertheless they may be a source of contention between countries as trade –related climate policy develops.

While all four countries examined currently have minimum practices that fall short of WTO compliance, Australia, New Zealand and Republic of Korea already have rules in place that could support WTO-compliant TRCP, as Figure 1 shows. Australia's system in particular would need relatively minor modification to calculate and certify emissions content of ammonia in a way that complies with WTO rules.

Our analysis is an initial examination of carbon accounting practices and how they might support TRCP such as certification or border carbon adjustments. We did not test national practices against one another by calculating actual embodied emissions, nor did we compare emissions calculations using current methods against engineering calculations. Both these may be fruitful areas for future work. We also examined only one commodity, with very simple supply chains involving only two countries. More complex green supply chains – such as steel – that cross multiple borders and involve multiple processes will be more difficult to certify embedded emissions. Examining national practices for countries in these supply chains is a necessary next step.

TRCPs are being actively pursued, and so-called "green commodities" are being spruiked as a way to profit in this new regulatory environment. But calling something "green" is not sufficient: it is the number – the embodied carbon-equivalent – not the colour that tells us whether the policy is effectively combatting climate change. Without agreement between producers and consumers on how to calculate these numbers, trade-related climate policies will be little more than a new colour of protectionism. Because in the end, the numbers – the greenhouse emissions in the atmosphere – are what count.

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Icons in supply chain diagrams supplied by FlatIcon https://www.flaticon.local

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Appendix A

Summary of mandatory emissions reporting schemes examined

	Australia	Japan	Korea	New Zealand
Scheme name	National Greenhouse and Energy Reporting Scheme	Greenhouse gas emission calculation / reporting / publication system	Emissions Target Management Scheme	New Zealand Greenhouse Gas Emission Trading Scheme
Legislative basis	National Greenhouse and Energy Reporting Act 2007 National Greenhouse and Energy Reporting (Measurement) Determination 2008	Act on Promotion of Climate Change Countermeasures 2006	Framework Act on Low Carbon Green Growth 2010	Climate Change Response Act 2002
Participation threshold	For controlling corporations: annual greenhouse gas emissions above 50,000 tCO_2-e; or annual energy production or consumption above 200 TJ For individual facilities: annual greenhouse gas emissions above 250,000 tCO_2-e; or annual energy production or consumption above 100 TJ per year	Annual energy consumption above 1,500 kl crude oil equivalent across all business sites Transportation companies identified in the *Energy Conservation Law* Freight companies with annual freight transport volume above 30 million ton-kilometres Businesses with annual greenhouse gas emissions above	Annual energy consumption above 80 TJ Annual greenhouse gas emissions above 15,000 tCO_2-e	Owning more than 50,000 l of liquid fossil fuel annually Importing coal Mining or owning more than 2,000 tonnes of coal annually Importing more than 10 000 litres of natural gas annually. Extracting natural gas, other than for export.

		3000 tCO_2-e and with more than 21 full-time employees.		Using geothermal fluid for the purpose of generating electricity or industrial heat Combusting used oil, waste oil, used tyres, or waste for the purpose of generating electricity or industrial heat. Refining petroleum where the refining involves the use of intermediate crude oil products (for example, refinery fuels and gases) for energy or feedstock purposes.

Appendix B

Analysis tables

Table 1: comparison of mandatory emissions reporting elements for Australia, Japan, Republic of Korea and New Zealand.

		Australia			Japan			Republic of Korea			New Zealand		
Methodologies	Number of unique methodologies	35			26			31			13		
	Number of IPCC categories assigned a methodology (out of 79)	54			51			54			22		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
	Number of methodologies for greenhouse gas	46	34	22	38	37	21	41	36	19	22	2	0
Complexity	Average minimum complexity (for gas)	2.15	1.82	1.73	1.71	1.57	1.76	1.02	1.00	1.05	1.82	2.00	0.00
	Average minimum complexity (all gases)	1.95			1.67			1.02			1.83		
	Average maximum complexity (for gas)	3.05	3.04	3.07	1.71	1.57	1.76	3.71	2.30	2.11	3.00	0.00	0.00
	Average maximum complexity (all gases)	3.05			1.67			2.92			3.00		
Choice	No.offering choice of Tier	37	23	15	0	0	0	41	18	10	8	0	0
	Most common no. of choices	2	2	2	1	1	1	4	1	1	1	1	1
Emissions factors	Separate emissions factors	yes			yes			yes			no		
	GWPs used	5th assessment report			4th assessment report			2nd assessment report			Can't determine - amalgamated emissions factor		
	GWP (tCO2-e)	1	28	264	1	25	298	1	21	310	n/a	n/a	n/a

Table 2: relevant emissions calculation methods for producer, consumer, and full supply chain for conventional ammonia production

Conventional ammonia		AU-JP	NZ-JP	AU-KR	NZ-KR
Producer:	Methods	19	19	19	19
	(missing)	2	9	2	9
	(problems)	3	2	3	2
	Complexity	2.42	1.93	2.42	1.93
International:	Methods	1	1	1	1
	(missing)	1	1	1	1
	(problems)	0	0	0	0
	Complexity	0	0	0	0
Consumer:	Methods	4	4	4	4
	(missing)	0	0	0	0
	(problems)	2	2	0	0
	Complexity	2.00	2.00	1.86	1.86
Supply chain:	Methods	24	24	24	24
	(missing)	3	10	3	10
	(problems)	5	4	3	2
	Complexity	2.39	1.96	2.32	1.89

Table 3: relevant emissions calculation methods for producer, consumer, and full supply chain for hybrid ammonia production

Conventional ammonia		AU-JP	NZ-JP	AU-KR	NZ-KR
Producer:	Methods	19	19	19	19
	(missing)	2	9	2	9
	(problems)	3	2	3	2
	Complexity	2.42	1.93	2.42	1.93
International:	Methods	1	1	1	1
	(missing)	1	1	1	1
	(problems)	0	0	0	0
	Complexity	0	0	0	0
Consumer:	Methods	4	4	4	4
	(missing)	0	0	0	0
	(problems)	2	2	0	0
	Complexity	2.00	2.00	1.86	1.86
Supply chain:	Methods	24	24	24	24
	(missing)	3	10	3	10
	(problems)	5	4	3	2
	Complexity	2.39	1.96	2.32	1.89

Table 4: relevant emissions calculation methods for producer, consumer, and full supply chain for renewable ammonia production

Renewable ammonia		AU-JP	NZ-JP	AU-KR	NZ-KR
Producer:	Methods	3	3	3	3
	(missing)	0	3	0	3
	(problems)	2	1	2	1
	Complexity	2.46	n/a	2.46	n/a
International:	Methods	1	1	1	1
	(missing)	1	1	1	1
	(problems)	0	0	0	0
	Complexity	0	0	0	0
Consumer:	Methods	4	4	4	4
	(missing)	0	0	0	0
	(problems)	2	2	0	0
	Complexity	2.00	2.00	1.86	1.86
Supply chain:	Methods	8	8	8	8
	(missing)	1	4	1	4
	(problems)	4	3	2	1
	Complexity	2.27	2.00	2.09	1.86