International Green Economy Collaborations: helping the energy transition go global?

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Abstract[1]
To avoid catastrophic climate change, the energy transition needs to go global, fast. A timely global energy transition requires new technologies be developed rapidly and deployed in every country. Given nearly a quarter of global emissions are embedded in trade flows, it also requires coordinated decarbonization of cross-border supply chains. International Green Economy Collaborations (IGECs) are emerging as a key tool through which governments can help the energy transition to go global. The regulatory collaboration featured in some IGECs is reminiscent of deep trade agreements. However, IGECs seem to predominantly perform novel international functions. Their facilitation of technology incubation, R&D, coordination, and information sharing can be understood as enabling Green Industrial Policy at the international level. Development finance commitments included in some IGECs are also novel in international regulation, though appear to have roots in the climate agreement commitments. Despite the bi- and pluri-lateral nature of IGECs potentially leading to efficiency losses compared to multilateral approaches, on balance IGECs are an important tool helping the energy transition go global.

Keywords: clean technology; international technology collaboration; trade & investment; Green Industrial Policy; green supply chains; International Green Economy Collaborations

1 The short version of the paper was presented at Applied Energy Symposium: MIT A+ B, July 5-8, 2022, Boston. This paper is a substantial extension of the short version of the conference paper." (Aisbett et al., 2022)

1 Introduction

In order to avoid catastrophic climate change, it is imperative that the energy transition go global, fast. Globalizing the energy transition means decarbonizing cross-border supply chains, collaborating across countries to push the clean technology frontier, and deploying frontier technology at scale in every region of the world. Globalizing the energy transition is essential to successful climate change mitigation for several reasons. Firstly, 22% of global annual emissions are estimated to be embedded in trade flows – a.k.a. cross-border supply/value chains (Greene et al., 2020). Secondly, rapidly moving down cost curves for new green technologies requires economies of scale that few countries can achieve alone. Thirdly, many less advanced (but rapidly growing) economies do not alone have the capacity to develop or deploy frontier technologies at a pace consistent with science-based targets. Lastly, there is a danger that domestic Green Industrial Policies become antagonistic to international trade, investment, and technology transfer, particularly when technology competition is a driver for them. The U.S. Inflation Reduction Act has caused particular concern, even with allies such as the European Union (EU) (Thomas, 2022).

International Green Economy Collaborations (IGECs) are international collaborations aimed at achieving mutual economic and environmental benefits through supporting structural change in both domestic economies and shared value chains. Although a relatively new phenomena, the government resources directed at establishing IGECs is growing fast. Recent notable examples include the Indonesian Just Energy Partnership, the Australia-Singapore Green Economy Agreement, the proposed U.S.-EU Carbon-Based Sectoral Arrangement on Steel and Aluminium Trade, and the Africa-EU Energy Partnership. These collaborations range from single-page joint statements, to lengthy formal agreements between states.

Our use of "international" in IGECs should be understood as it is in International Law and International Relations literatures – that is – as an interaction between nation states. Thus, our definition does not include what these literatures would call "transnational" (public-private and private-private) partnerships and collaborations (Hoffmann, 2021). Transnational collaborations - often measured by joint patents - have been the subject of previous literature (Andersen et al., 2007; Geerts, 2022; Gerhartinger et al., 2014; You et al., 2022). The importance of private involvement for both innovation and financing is widely understood. For this reason, many IGECs include mechanisms to encourage transnational partnerships and collaborations.

The current paper argues that IGECs have potential to substantially impact the speed at which the energy transition goes global. The first contribution of our paper is descriptive; providing a definition and gathering data on IGECs. The second contribution is conceptual; providing a framework through which to understand the role and purpose of IGECs. We then use this conceptual lens to undertake a descriptive analysis of the data on IGECs and to point the direction for future research. Lastly, we provide insights for policy-makers and technology developers on how best to design and engage with IGECs.

This paper contributes to several strands of literature. The first is the literature on policy approaches to support green technology innovation and deployment. Within this substantial literature, our paper is most closely related to that on Green Industrial Policy (GIP). Several authors have argued that need for international Green Industrial Policy (sometimes referred to as international green technology partnerships) (Grimm et al., 2022; Meckling & Hughes, 2018; Moral et al., 2022). We argue in Section 4

that IGECs can be understood, in part, as an answer to these calls. Our definition of IGECs is close to an international version of the definitions of GIP proposed by Altenburg and Assmann (2017, p.xii). Our analysis of the contents of IGECs highlights their commonalities both with Rodrick (2014)'s green-technology innovation definition GIP and Hallegatte et al., (2013) or Pegels et al.'s (2018) conceptualization of GIP as primarily a process of systematic learning.

Our paper also contributes to the literature from both International Economics and International Law on the conflicts between international economic law and environmental policy and regulation (Copeland & Taylor, 2004; Grossman & Helpman, 1994). This lengthy literature is increasingly focused on conflicts with climate policy and/or Green Industrial Policy (Espa, 2019; Robert Howse, 2021; Viñuales, 2017). The current paper is of relevance to this literature because IGECs represent a new approach to this age-old debate. For example, some elements of IGECS can best be understood as attempts to minimize conflicts between the parties' respective green industrial and/or climate policies. We find that many IGECs support regulatory collaboration on topics such as green taxonomies and embedded emissions accounting methods. Regulatory collaboration – a form of trade facilitation - has traditionally been a feature of Deep Trade Agreements (Mattoo, Aaditya, Rocha, Nadia, Ruta, 2020). Although some authors have noted the potential for trade facilitation to support environmental objectives (Hale, 2022; UNEC, 2021), traditional forms of international collaboration have thus far failed to deliver on this potential (Hicks, 2021).

Of relevance to the literature on international economic regulation and governance more broadly, IGECs are a prime example of the broader shift in international economic cooperation: away from multilateralism and a focus on efficiency, towards bi- or pluri-lateral approaches with an emphasis on resilience, sustainability and diversification (Mallach et al., 2021; Roberts et al., 2018).

Lastly, this paper contributes to the literature on international climate governance. Specifically, we observe that finance commitments are sometimes found in IGECs. These can be understood as a response to calls for better governance of (Phillips et al., 2013; Qian & Bin, 2011; Schroeder, 2009), and greater technology transfer accompanying (Hackenesch et al., 2019), financial commitments made in climate agreements.

2 Method: a snapshot of the IGEC universe

One of the contributions of this paper is an initial survey of the universe of IGECs in existence (or publicly announced as under negotiation).

2.1 Search method

Given that no comprehensive database currently exists, IGECs were identified by a range of processes, including targeted searches of existing databases and the internet and a review of existing literature on IGEC-related phenomena.

Databases consulted included the Oregon Environmental Agreements Database Project and the International Energy Agency Policies Database.

Entries in the Oregon database are categorized by subjects and lineages, the former organized around a unifying focus (e.g. "energy" or "fisheries") and the latter around iterations of policies under the same

name or set of terms (e.g. “Central America Framework Agreement” or “Climate Change”) (Mitchell et al., 2020). IGECs were found by a survey of entries under the following relevant subjects and lineages:

Subjects: Energy (Bilateral); Energy (Multilateral).

Lineages: Climate Change; Inter-American Institute for Global Change Research; International Energy Program; International Renewable Energy Agency; International Solar Alliance; EU-Central America Framework Agreement; Energy Charter; Central American Climate Change; ASEAN; African Energy Commission.

In addition, the International Energy Agency Policies Database was surveyed in its entirety, applying “international” as the only policy criteria in the search.

Further IGECs were identified, in keeping with the criteria set out in this paper, by means of an extensive literature review. In the course of this review, a range of search terms were applied in Google Scholar. Key terms, in varied combination (as represented by brackets) included: *(International/Global/Transnational/Cross-border/Multilateral/Plurilateral/*) + (green/environment/climate/clean energy/*) + (economy/industrial policy/*) + (collaborations/partnerships/deals/agreements/*)*. Direct searches were also made for *Memorandums of understanding* and *Joint statements of intent*.

2.2 IGEC definition, inclusion and exclusion criteria

We define IGECs as international collaborations aimed at achieving mutual economic and environmental benefits by structurally altering shared value chains. As explained in detail in later sections, we conceptualize IGECs as a combination of international Green Industrial Policy, and international collaboration to reduce negative economic impacts (particularly on trade and investment) of domestic Green Industrial Policies.

The “international” in IGEC is used in the sense of “between nation states”. To qualify as an IGEC under our definition, the collaboration or partnership must primarily be between national governments and be substantiated, at a minimum, by an official statement (joint declaration) by the national government partners. Some IGECs are substantiated by formal international agreements (treaties) under international law.

Theoretically IGECs can be multi-lateral, pluri-lateral (including regional) or bi-lateral. Their nature and purpose, however, means that no multi-lateral (i.e. open to all nations) IGECs yet exist.

Collaboration on actions that have both environmental and economic gains is at the heart of IGECs. Collaboration on R&D funding for clean technologies is a leading example. As a result, not all environmental collaborations between nation states qualify as IGECs, even where there is an economic mechanism or incentive involved. For example, MOUs to establish a joint emissions trading scheme do not qualify as IGECs under our definition. This criterion distinguishes IGECs from the much larger category of international environmental collaborations.

Similarly, trade and investment agreements do not generally qualify as IGECs. Even so-called Deep Trade Agreements (Mattoo, Rocha & Ruta, 2020) containing environmental chapters do not necessarily qualify. While these agreements will often have separate components that further economic objectives

and environmental objectives they rarely have components that aim to do both simultaneously. Their economic components (such as tariff liberalization) will often have little regard to the environmental implications, while their environmental components usually establish "obligations" or constraints on exporters to protect consumer and environmental welfare. This contrasts with IGECs focus on supporting exporters involved in green value chains and achieving simultaneous wins.

Trade facilitation and regulatory collaboration to avoid non-tariff barriers to trade are the areas in which IGECs and Deep Trade Agreements most overlap. Indeed some regulatory collaboration text in some IGECs may be found in almost identical form in some trade agreements. Generally though, there are important differences between what is traditionally included in trade agreements and what we understand IGECs to comprise. In trade agreements, rules around technical barriers to trade are usually aimed at ensuring domestic-market focused environmental rules do not pose a greater barrier to trade than is necessary to achieve the environmental outcome. In IGECs, by contrast, regulatory collaboration is often targeted at the cross-border value chain – that is, at the trade itself. Collaboration to achieve interoperability of embedded emissions accounting for cross-border supply chains is an example of the IGEC approach to these issues.

The final distinction between IGECs and trade agreements is that IGECS do not place binding obligations on parties or have dispute settlement mechanisms. Even the recently signed Singapore-Australia Green Economy Agreement and the under-negotiation Indo-Pacific Economic Framework (Green Economy Pillar)[2] conform to this aspect of the definition.

2.3 Variables

For each qualifying IGEC, we coded the following variables.

Official title: The official title, as listed on the relevant document. Where an official title is not given or multiple titles are used interchangeably, a descriptive title is substituted.

Partners: The official signatories to the statement or policy. Where parties to a treaty are supranational bodies (e.g., the European Union) they are recorded as a bloc rather than individual states.

Industries: The broad industries with which a given policy is concerned. Where policies address varied sectors, they are marked "cross-economy". Where relevant, multiple industries are listed for a given policy.

Approaches: A descriptive category capturing the means by which a policy's objectives are achieved – e.g., financing, investment or trade. Where relevant, multiple approaches are listed for a given policy.

Date: The date of signature and/or public announcement.

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[2] While the Indo-Pacific Economic Framework overall is likely to have binding commitments and dispute settlement mechanisms, the Green Economy Pillar "involves deepening cooperation on technologies, on mobilizing finance, including concessional finance, and on seeking ways to improve competitiveness and enhance connectivity by supporting the development of sustainable and durable infrastructure and by providing technical assistance." Source: https://www.dfat.gov.au/news/media-release/launch-indo-pacific-economic-framework-prosperity-ipef-joint-statement

Technology Innovation Collaboration: Coded as either a 1 or a 0, this category captures whether parties pursue (or pursued) technological innovation as a component of their collaboration. Joint research and development projects are the leading example of such.

Financing: Coded as either a 1 or a 0, this category captures whether a commitment to financial support is made by either or both parties for projects other than R&D (regardless of whether the exact value is explicitly stated or not). This includes cases where partners agree to coordinate their funding of third parties.

Regulatory Collaboration: Coded as either a 1 or a 0, this category captures whether parties commit to establish or help uphold standards, certification schemes or policies as part of their agreement.

Education: Coded as either a 1 or a 0, this category captures whether a collaboration explicitly incorporates the education of governments, industry or the public on matters of climate change and related governance.

Information Sharing: Coded as either a 1 or a 0, this category captures whether parties commit to share information as part of their collaboration, whether that information be technical, political or strategic.

Market Coordination, Trade or Supply Chain Development: Coded as either a 1 or a 0, this category captures whether a collaboration seeks to use or leverage market forces, whether by stimulation of trade and investment or by other supply chain interventions. Such interventions might include a commitment to invest in a particular renewable technology, should it be successfully developed, or to forgo investment in an emissions-heavy area, thereby stimulating investment in alternatives.

Partner Tech Rankings: We use the ArCo ranking of countries by level of technology development. This ranking is broadly comparable with its WEF, UNDP and RAND competitors, provides a ranking of the top 25 states in terms of technological development, which is derived from several factors, including technological capital and scientific/technical expertise (Archibugi & Coco, 2005). Collaborations are accordingly categorized by whether all, some or no parties are ranked in the top 25 most developed states. Where an entire bloc is party to a collaboration (e.g. the EU), the bloc is coded as “top 25” if some or all of its members are ranked as such by ArCo.

Partner Kyoto Status: The Kyoto Protocol’s Annex II countries “are required to provide financial resources to enable developing countries to undertake emissions reduction activities under the Convention and to help them adapt to adverse effects of climate change. In addition, they have to "take all practicable steps" to promote the development and transfer of environmentally friendly technologies to EIT Parties and developing countries” (https://unfccc.int/parties-observers). In order to identify IGECs that were potentially a mechanism to help an Annex II country fulfill these obligations, collaborations were categorized by whether all, some or no parties are Annex II countries. In cases where a supranational body represents one of the parties, the body is coded as belonging to Annex II if some or all of its members belong to that category.

3 Theory: IGECs role in globalizing the energy transition

3.1 IGECs as an instrument for international Green Industrial Policy

One way of viewing international green economy collaborations (IGECs) is as a form of international Green Industrial Policy (GIP). Several definitions of [domestic] GIP have been proposed in the literature. In Table 1 we reproduce some of the leading definitions, and propose an international version of them. The definitions are ranked in approximate decreasing order of breadth of definition.

With reference to Table 1, it is clear that our definition of IGECs (international collaborations aimed at achieving mutual economic and environmental benefits by structurally altering shared value chains) is closest to an international analogue of Altenburg and Assman's (2017) definition of Green Industrial Policy. International analogues of the definitions proposed by Rodrick (2014) and Karp & Stevenson (2012) are subsets of our conceptualization of IGECs. While support for green technologies a la Rodrick is a key component of most IGECs, green trade facilitation via regulatory collaboration is also a common feature. Similarly, while low-carbon alternatives to fossil fuels are the dominant category of technologies/industries supported by IGECs, they are not the only one. Industries with environmental benefit include other "environmentally preferred products", as well as "goods and services for environmental management" (UNCTAD 2003).

The analogues of Harrison et al.'s (2017) and Hallegatte et al.'s (2013) definitions are broader than our definition of IGECs, because we exclude collaborations which do not have economic benefit at their center. Thus, we do not include collaborations that focus on *encouraging traditional shared value chains to produce goods and services in greener ways*. For example, MOUs and agreements aimed at establishing a shared emissions trading scheme or a common carbon price floor fall into this excluded category. Similarly, with reference to Hallegatte et al, we exclude collaborations that focus on *affecting parts of the international economic production structure with the aim of generating environmental benefits,* where that affect is negative. Agreements to end financing of coal fired power stations are an example of this category of collaboration. They do not fall within our definition of IGECs.

Table 1: Definitions of [Domestic] Green Industrial Policy and their international analogues

Author (date, p.p.)	Domestic Green Industrial Policy Definition	International Green Industrial Policy Analogue
Harrison et al. (2017, p.253)	promote industries that produce green technologies and encourage traditional industries to produce goods and services in greener ways	promote shared value chains that produce green technologies and encourage traditional shared value chains to produce goods and services in greener ways
Altenburg and Assmann (2017, p.xii)	policy options for managing structural change that accounts for both the productivity and the environmental challenges in a harmonized way	intl. collaborations for managing structural change in shared value chains that accounts for both the productivity and the environmental challenges in a harmonized way
Hallegatte et al. (2013, p.3)	industrial policies with an environmental goal—or more precisely, as sector-targeted policies that affect the economic production	industrial policies with an environmental goal—or more precisely, as sector-targeted policies that affect the international economic production structure with the aim of generating environmental benefits

	structure with the aim of generating environmental benefits	
Rodrick (2014, p.469)	[Policies to increase availability of] green technologies: production techniques that economize on exhaustible resources and emit fewer greenhouse gases	[Intl. collaborations to increase the availability of] green technologies: production techniques that economize on exhaustible resources and emit fewer greenhouse gases
Karp and Stevenson (2012, p.1)	government attempts to hasten the development of low-carbon alternatives to fossil fuels	international collaborations to hasten the development of low-carbon alternatives to fossil fuels

Economy-wide policies such as carbon pricing also seem to fall outside the definition of GIP proposed by Hallegatte et al. (2013, p.3). According to them, GIP comprises "industrial policies with an environmental goal—or more precisely, as sector-targeted policies that affect the economic production structure with the aim of generating environmental benefits." So, while collaborations on embedded emissions accounting methodologies for specific sectors (e.g. steel and aluminium) would seem to fit under the international analogue of Hallegatte et al's definition, collaborations on economy-wide embedded emissions accounting frameworks would not.

3.2 IGECs to address market failures limiting the global energy transition

While the exact definitions may vary, there is a common understanding among economists such as Rodrick (2014), Harrison (et al., 2017) and Karp and Stevenson (2012) that Green Industrial Policy is a tool for addressing market failures that are inhibiting environmentally beneficial structural change. "Market failures" in neoclassical economics are failures of the assumptions one which the First Welfare Theorem is based. The First Welfare Theorem says that under these assumptions the market will achieve the most efficient (optimal/first-best) outcome without any government intervention. A corollary is that failures of these assumptions – market failures – mean government intervention can potentially improve efficiency.

While government intervention can be efficiency-enhancing, it is by no means a given. Every intervention involves costs – both bureaucratic and distortionary. The intervention will only be beneficial overall if the efficiency benefit from its effect on the market failure outweighs these costs. Targeting government interventions to address as directly as possible identified market failures is essential to keep the benefit to cost ratio as high as possible.

In this section, we consider the potential for IGECs to help the energy transition go global by considering relevant market failures and their potential to address them.

Knowledge spillovers: are a well-known market failure that plagues private research and development (R&D) activities. Where the knowledge cannot be entirely captured, private investment in R&D will be lower than the socially efficient level, slowing the development and emergence of green technologies. This problem can be particularly acute where the spillovers and benefits therefrom may be international

- accruing to trading partners at least as much as domestically. In this case, no one government may be willing to provide funding to achieve the globally optimal level of R&D. IGECs that contain commitments for joint government R&D funding of green technologies and industries are well-targeted to address this market failure. IGECs with features designed so address knowledge spillovers are coded as having "Technology Innovation Collaboration".

External economies of scale: refer to benefits of one producer's output or inputs on other producer's (Bohm, 2008). Knowledge spillovers are an example of a phenomenon that can cause external economies of scale. These spillovers are generated not only by R&D, but also by learning-by-doing as industries scale up (otherwise known as dynamic economies of scale). External economies of scale can also occur through the generation of a pool of people with relevant expertise (e.g. hydrogen plumbers), or through establishment of service industries (e.g. wind turbine manufacturing facilities). In the international context appropriate port and shipping facilities can be a key source of external economies of scale. As with knowledge spillovers - when individual firms are unable to capture all the benefits of their own activities - there will be lower than optimal private investment. This discrepancy between private and social benefits of investment is particularly acute in the early stages when learning economies and knowledge spillovers are greatest. IGECs can address this limitation by either providing coordinated support for private entities that are generating the external benefits, or by directly undertaking some of the activities that generate these (public) benefits. Joint feasibility and costing studies for green supply chains are an example of the latter found in some IGECs. We have coded this feature of IGECs as "Market Coordination, Trade or Supply Chain Development".

Coordination failures: are possibly the most important market failure in the context of novel, green, cross-border supply chains. Failing to maximize positive spillovers of the type discussed above is one form of coordination failure. Chicken and egg problems are another important form. For example, potential hydrogen importers such as Japan and Germany may be reluctant to invest in hydrogen using industries such as green steel until they are confident, they will have access to low-cost green hydrogen. Meanwhile, potential hydrogen exporters may be reluctant to invest in large-scale green hydrogen production until they are confident there will be sufficient off-takers. Network externalities are another relevant source of coordination failure. For example, the cost of running ammonia versus methanol-based ships will depend on how many other countries or firms choose each option, and consequently the fueling facilities available at ports. One of the most important roles for IGECs compared to domestic Green Industrial Policy is to help overcome these coordination failures among trading partners. Joint supply chain studies and coordinated scale-up support are examples of mechanisms included in IGECs that address coordination failures. These features are also coded as "Market Coordination, Trade or Supply Chain Development".

Information failures: due to lack of information, biased information, or asymmetric information can seriously inhibit the development of new green supply chains. Asymmetric information occurs when one party has better information than another, for example, a producer of green steel knows its embodied emissions are low, but the potential buyer cannot observe this information independently. This sort of asymmetric information can prevent the emergence of premium markets for low-emissions products. It is particularly acute for cross-border trade, where information asymmetry is generally more extreme than in purely domestic markets. Regulatory collaboration on topics such as interoperability of embedded emissions accounting schemes, or mutual recognition of "low-emissions" certification schemes – can help to reduce information asymmetry and support the emergence of low-emissions

cross-border supply chains. “Regulatory collaboration” is one of the IGEC features we have coded. Beyond this specific example, information failures arguably pervade all the other market failures discussed thus far, due to the novelty of the technologies and supply chains that IGECs seeks to promote. Furthermore, information is “non-rival” meaning that one person using it will not decrease the ability of another to use it (c.f. a cake). This means that government investments in gathering and producing the necessary information can have broad benefits to a range of actors in both partner countries. For all these reasons, information sharing is a pervasive form of IGEC remedy. Lack of information also inhibits government design of appropriate policy interventions. We discuss IGECs role in supporting policy learning in Section 3.3.

Government-induced distortions: While it is theoretically possible to perfectly target a government intervention at a market failure, in practice it is impossible. As a result, all government interventions, no matter how well-meaning and well-designed, will cause their own market distortions. Regulatory collaboration in IGECs can help avoid or ameliorate distortions that negatively affect the development of green supply chains between the partner countries. We discuss this role of IGECs in more detail in Section 3.4.

Credit constraints: can prevent otherwise efficient investments from being made. Credit constraints are often more extreme in lower-income countries and are exacerbated in high-risk situations such as new cross-border supply chains. Finance mechanisms found in some IGECs are a means of addressing credit constraints, though current IGECs do not seem to target cross-border supply chains. We discuss an alternative explanation for the prevalence of finance mechanisms observed in current IGECs in Section 3.5.

Table 2: Mapping between international market failures and IGEC remedies showing the central role of information failures and information sharing.

<table>
<tr><th colspan="2">Market failures</th><th colspan="2">IGEC remedies</th></tr>
<tr><td rowspan="6">Information Failures</td><td>Knowledge spillovers</td><td>Technology collaboration</td><td rowspan="6">Information sharing</td></tr>
<tr><td>External economies of scale</td><td rowspan="2">Market coordination</td></tr>
<tr><td rowspan="2">Coordination failures</td></tr>
<tr><td rowspan="2">Regulatory Collaboration</td></tr>
<tr><td>Government-induced distortions</td></tr>
<tr><td>Credit constraints</td><td>Financing</td></tr>
<tr><td colspan="2"></td><td>Education</td></tr>
</table>

3.3 IGECs as a tool to support systematic learning for green supply chains

Some leading authors view a process of systematic learning on behalf of policy-makers and industry participants as a central component of Green Industrial Policy primarily (Hallegatte et al., 2013; Pegels et al., 2018). In neoclassical economic language, these authors see addressing information failures as the central role of GIP. Governments often lack the information they need to design appropriate policy interventions, for example, the cost structures of new industries and how they will evolve over time, the competitiveness of domestic producers compared to foreign competitors, or the market demand curves. Well-designed Green Industrial Policy allows governments to systematically learn, gaining the

information they need; and it allows them to update their policies in light of their learnings (Hallegatte et al., 2013; Pegels et al., 2018; Rodrik, 2014). For globally novel industries, such as new, low-emissions technologies and products, governments around the world are learning simultaneously about the same industries. Processes for sharing information in IGECs allows governments to benefit from each other's learnings (and potentially avoid their mistakes). It also potentially allows them to gain important information about supply, offtake or competitor markets. The importance of this way of understanding IGECs is highlighted by the almost ubiquitous mention of information sharing as one of the goals of IGECs.

3.4 IGECs as a means of reducing clashes between domestic GIPs

Governments have a tendency to pay relatively little attention to market distortions resulting from their actions when the negative consequences of those distortions are born predominantly in other jurisdictions. As result, even well-intentioned Green Industrial Policy (and environmental policy more broadly) can cause what trade economists refer to as “non-tariff barriers” to international trade and investment. These barriers can inhibit the development of mutually beneficial green cross-border supply chains.

International economic law provides only a partial remedy to distortions arising from domestic Green Industrial Policy. The General Agreement on Tariffs and Trade under the World Trade Organisation can provide legal remedies for parties negatively affected by trade-distorting policy actions in another country. Similarly, international investment agreements often provide direct recourse for private investors whose investments in a country are harmed by the host government’s actions. Cognizant of international economic law, governments that have the necessary bureaucratic resources usually try to design their policy interventions such that they are in line with international trade and investment law. The European Union’s attempts to design a WTO-compatible carbon border adjustment mechanism are an excellent example of such attempts. Nonetheless, formal international law and its dispute settlement options are a costly and confrontational remedy for governments who are trying to work in good faith to design policies to address complex challenges such as the energy transition. We are not aware of any completed IGEC that contains binding obligations or dispute settlement mechanisms. Rather, they rely on trade and investment facilitation measures.

Increasingly, facilitation is seen as the best way to avoid environmental policies having negative impacts on trade and investment. Regulatory collaboration on potentially trade- or investment-impacting environmental rules and/or Green Industrial Policy is the main element of trade facilitation relevant to our context. While trade- and investment facilitation are by no means the sole purview of IGECs, there is a sense in which IGECs play a novel role. Regulatory collaboration in other contexts usually involves retrospective alignment of regulation to provide mutual market access. Regulatory collaboration in IGECs is often forward-looking, co-development of new regulation. Similarly, it is sometimes undertaken with a clear view to facilitating a supply chain which flows is a certain direction, rather than reciprocal market access. Collaboration on embedded emissions accounting practices, certification of green products (especially hydrogen and derivatives), and green investment taxonomies are examples of regulatory collaboration in IGECs.

3.5 IGECs as a channel for climate finance

As discussed in Section 3.2, the inclusion of financing in IGECs could be understood as an international Green Industrial response to help overcome credit constraints in lower income partner countries. An alternative driver for the inclusion of financing commitments could, however, be the financing commitments made by Annex II countries to the Kyoto Protocol that have since been reinforced and expanded under subsequent UNFCCC agreements. Meeting such obligations through an IGEC has advantages for both Annex II countries and their partners. For Annex II countries, IGECS provide a highly visible means through which to signal they are meeting their commitments. For their partner countries, IGECs provide a framework to link climate finance to technology and knowledge transfer, and to help ensure the promised finance is forthcoming. Both partners benefit from IGECs providing frameworks to elaborate how the finance will be coordinated, regulated and governed. These advantages mean that Annex II countries are also likely to increase the amount of finance they are willing to provide.

We also observe that IGECs can perform a coordination function with regard to financing. Increasingly, IGECs that contain finance commitments involve coordination between Annex II countries in regard to their financing of non-Annex II countries.

3.6 Third-party impacts of IGECs

Despite calls by China in the lead-up to COP27[3], there is no multilateral IGEC and no serious momentum behind the negotiation of one. Rather, IGECs are exclusively either bilateral (between two partners) or pluri-lateral (between more than two without extending to potential global membership). The reasons for this pattern are numerous. On the one hand, IGECs, and the actions to be taken under them can be highly complex. Regulatory collaboration, for example, is notoriously difficult to achieve in a multilateral setting. The fact that the WTO has failed to even agree on a list of environmental goods for preferential liberalization despite decades of efforts is a case in point (Reinsch and Benson 2021).

An additional explanation for the lack of multilateral momentum behind IGECs is that they can be seen as geo-economic tools. It is no surprise that China is calling for a multilateral approach, since some recent IGECs could be interpreted as designed to increase trade partner diversity and decrease dependence on China (Guild, 2023). Unsurprisingly, given the technological rivalry between the US and China, IGECs involving the US show the strongest geoeconomic tendencies. For example, while the "US EU Carbon-Based Sectoral Arrangement on Steel and Aluminum Trade" is ostensibly aimed at encouraging production and trade in green steel and aluminium, it also seeks to reduce China's share of the global export market for steel and aluminium, which it has dominated for years. Similarly the joint statement on the launch of the Indo-Pacific Economic Framework for Prosperity[4] (IPEF) lists resilience as its first goal. While we only consider the "Clean Energy, Decarbonization, and Infrastructure" pillar as an IGEC, it is notable that the IPEF is also proposed to contain a "Supply Chains" pillar which seeks among other goals to improve the security and diversity of supply chains and to "ensure access to key raw and

[3] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/101222-china-calls-for-partnership-to-develop-global-clean-energy-supply-chains-ahead-of-cop27

[4] Statement source: Australian Government Department of Foreign Affairs and Trade website, date 23 May 2022, https://www.dfat.gov.au/news/media-release/launch-indo-pacific-economic-framework-prosperity-ipef-joint-statement. Accessed 5 February 2023.

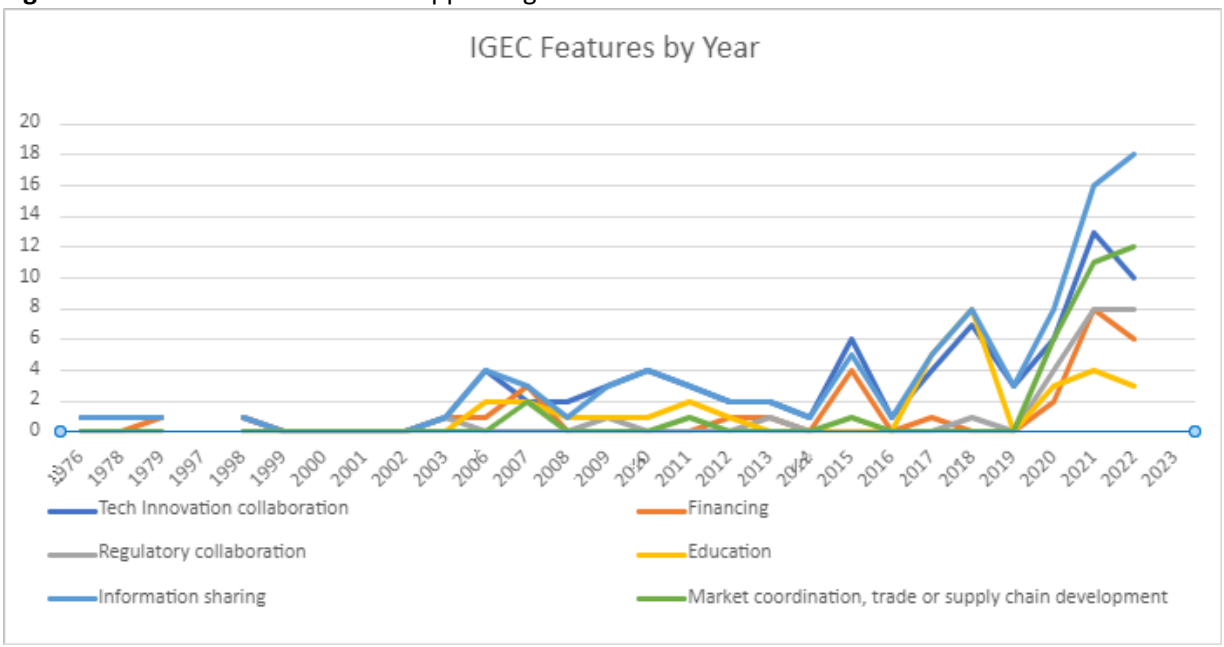
processed materials, semiconductors, critical minerals, and clean energy technology." It is possible to view trade diversification strategies as aimed at avoiding accumulation of market power, which if exploited can lead to inefficiency. A more plausible explanation, is that where once "efficiency" and "multilateralism" were gospel, increasingly governments are viewing their trade and industrial policy through a lens of resilience, sustainability and diversification (Mallach et al., 2021; Roberts et al., 2018).

Aside from questions about fairness, the problem with sacrificing efficiency to other objectives, is that it raises the cost of the energy transition. Preferential liberalization that diverts trade and investment away from the lowest cost producers lowers global efficiency relative to no liberalization at all. The trade diverting aspects of IGECs may even go beyond the relatively benign effect of excluding some countries from preferential supply chain development. In so far as the regulatory collaboration aspects of IGECs are partly designing the new rules of the global green economy, they may be contributing to raising non-tariff barriers to trade and investment for third-parties. Consider, for example, a jurisdiction applies a carbon border adjustment mechanism unilaterally, while co-developing the embedded emissions accounting that underpins it through IGECs. Countries not party to the co-development process may find the emissions accounting approaches particularly costly and unsuited to their producers.

4 Results and Discussion: IGEC patterns and features

Our search identified 108 unique IGECs involving over 70 countries spanning 1976-2022. Figure 1 illustrates key trends in IGECs over time. The colored lines indicate the number of IGECs formed in a given year which feature the each collaboration mode: Technology innovation collaboration; Regulatory collaboration; Information sharing; Financing; Education; and Market coordination, trade or supply chain development. Several observations can be made based on Figure 1.

Figure 1: Annual count of features appearing in new IGECs



Firstly it is worth noting that the first IGECs signed were in the late 1970s, around the first global energy crisis. Between the 1979 and 1998, we identified no IGECs. IGECs reemerge post Kyoto Protocol, with an agreement between Norway and Slovakia on "Initiating A Project on Biomass In Fulfillment Of Obligations Under The Framework Convention On Climate Change" that involved joint finance, diplomatic coordination and information sharing. IGECs begin to become more frequent around COP15 in Montreal (2005) and pick up strongly round the Paris Agreement (2015), rising sharply in 2020-21 round the planned and actual COP26 in Glasgow. Over 40% of the identified IGECs were formed in the last two years. COVID recovery efforts and energy diversification strategies following the Russian invasion of Ukraine likely also contribute to the high rate of IGECs formed in the last few years.

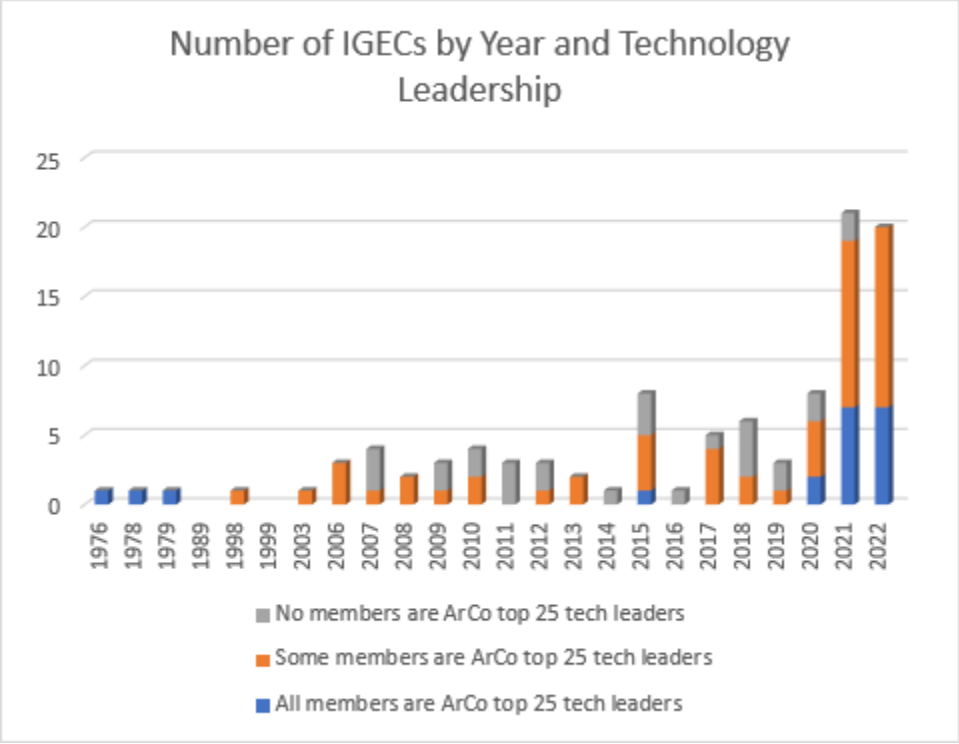
Comparing the features of IGECs over time in Figure 1, it is clear that information sharing and technology innovation collaboration are the dominant features of IGECs. Indeed, information sharing is almost ubiquitous as a collaboration mechanism, explicitly mentioned in all but eight of the IGECs identified. Of these eight, all but two related to "Just Energy Partnerships", with one being a finance-focused IGEC and one strictly R&D collaboration. Although not explicitly mentioned, all of these would require information sharing to achieve their objectives.

Education is also a relatively frequent component of IGECs. According to our definition of education, it could be aimed at market participants from consumers to technology developers, or government officials. IGECs referring to joint workshops and seminars were coded as including an education component. Where information sharing is about joint discovery of information, education is the complement to ensure it is shared with relevant decision-makers.

Regulatory collaboration and Market coordination, trade and supply chain development are more recent additions to IGECs. Emerging round 2020, these features indicate a shift toward scale-up and fundament transformation of supply chains, rather than simply research and innovation. They are indicative of the broader shift towards net zero commitments and implementation plans round COP26, as well as "build back better" initiatives post COVID and supply chain diversification strategies in response to sharply rising geopolitical tensions.

Figure 2 illustrates IGECs formed per year according to technology leadership ranking of the partners. The very first IGECs identified involved only top 25 ranked countries, comprising agreements between the US and Japan and Italy respectively, and one between Germany and Spain. All were specifically on the topic of energy research collaboration, with the US-Italy IGEC focusing on geothermal energy and Germany-Spain on solar energy technology. IGECs exclusively between technology-leading countries then essentially disappeared, reemerging in 2020.

Figure 2: IGECS according to technology leadership of partners



The clear majority of IGECs formed since 2000 have involved at least one top 25 technology partner and at least one outside the top 25. While in some cases the non-top 25 partner may be close behind and the partnership involving co-development of technology, the majority of these IGECs represent technology transfer, adaptation and adoption from leaders to followers.

Given the focus on innovation, the number of IGECs involving no top 25 partners may seem surprising at first. However, major emerging technology leaders, such as China and India, are not among the top 25. India, in particular, is responsible for the bulk of the grey colored IGECs in Figure 2. The Indian Ministry for New and Renewable Energy has had an active program of collaborations since 2006, and India has formed 42 partnerships that qualify under our definition of IGECs. These partnerships cover all the major technology-leading countries, the so-called BRICS countries, middle powers, and oil states, as well as small and lower income countries such as Guinea.

Given the timing of IGEC formation appears to correlate with major UNFCCC COPs, Table 3 examines the patters of IGECs and features according to whether partners are Annex II parties to the Kyoto Protocol.

Table 3: IGEC features by Kyoto Protocol status of partners; count (% of IGECs by group)

	All Annex II	Some Annex II	None Annex II	All
Information sharing	20 (91)	55 (90)	25 (100)	100 (94)
Education	4 (18)	16 (26)	13 (52)	33 (31)
Technology collaboration	14 (64)	43 (70)	21 (84)	78 (72)
Financing	7 (32)	24 (39)	1 (4)	32 (31)
Regulatory collaboration	5 (23)	21 (34)	1 (4)	27 (25)
Market coordination	13 (60)	20 (33)	2 (8)	35 (33)
Total IGECs	22	61	25	108

Table 3 confirms that more than half the identified IGECs involve a mixture of Annex II and non-Annex II parties to the Kyoto Protocol. Examining IGECs with financing, it is clear that financing commitments are rare in IGECs without any Annex II partner. The relatively high proportion (32%) of IGECs with only Annex II partners that have financing commitments is at first surprising. All except two of these, however, actually concern collaboration over financing of third-party, non-Annex II countries. The two remaining IGECs are between Australia-Japan and Australia-Germany. They represent examples of Australia's efforts to support scale-up of supply chains for potential new low-emissions export industries. Although Australia has potential natural advantages for renewable-energy based exports, its exports are currently highly emissions intensive and exposed to transition risk (Burke et al., 2022). The single IGEC with finance commitments among non-Annex II countries is between Estonia and Latvia, close neighbors who both relatively recently joined the EU.

IGECs involving Annex II countries also differ from those between non-Annex II countries in terms of the proportion involving regulatory collaboration and market coordination. This is consistent with Annex II countries' stronger commitment and ability to progress to scale up and supply chain transformation.

5 Conclusion

This paper has introduced and described an emerging phenomena relevant to the development and scale up of clean energy technologies and industries. We define International Green Economy Collaborations (IGECs) as collaborations between national governments (or the EU) aimed at achieving mutual economic and environmental benefits through supporting structural change in both domestic economies and shared value chains.

Our definition of IGECs is close to an international analogue of some leading definitions of Green Industrial Policy. We consider the potential for IGECs to support the global energy transition as a tool for international Green Industrial Policy. From the perspective, IGECs can be viewed as a means of addressing market failures affecting cross-border supply chains for new clean industries, as well as a process of systematic learning between partners. We explained how specific features of IGECs help to address market failures including imperfect information, knowledge spillovers, external economies of scale, coordination failures, government-induced distortions, and credit constraints.

We identify additional ways in which IGECs may support the global energy transition. Firstly, they can help reduce clashes between and distortions caused by domestic Green Industrial Policies. Secondly the can help improve governance and technology transfer associated with climate finance committed by Annex II parties to the Kyoto Protocol. Finally, we note that IGECs may have some negative consequences for the globalization of the energy transition due to potential detrimental effects on trade and investment with non-partners.

Drawing on existing databases, literature review, and internet search, we identified 108 unique IGECs involving over 70 countries. All but three of these were formed since the Kyoto Protocol, and over 40% were formed in the last two years. Consistent with the pervasiveness of information imperfections, IGECs almost universally involve promises to share information. Features that help address other market failures were also evident. Nearly three quarters involve technology innovation partnerships; and regulatory collaboration, market coordination, education, and financing are each found in round a

quarter to a third of IGECs. Examining the content of IGECs according to whether all, some or none of the partners was an Annex II party to the Kyoto Protocol provided support for the argument that IGECs are used to support better governance and technology transfer under climate finance commitments for Annex II parties. IGECs involving Annex II parties were also more likely to involve market and regulatory coordination, consistent with these countries progressing to scale-up of clean technologies and transformation of their supply chains.

The objective of this paper was to provide a definition, conceptual basis, and initial empirical description of IGECs. We hope that it will be useful not only to policy-makers designing IGECs, but also to third-party governments seeking to understand their implications, as well as technology developers seeking to engage with IGECs and the processes flowing from them. We also hope that this paper provides a useful foundation for future research into this rapidly evolving regulatory approach to clean energy innovation and transformation. Although our analysis supports our theory about the role and purpose of IGECs, future research could undertake causal analysis of both the drivers and impacts of IGECs. This analysis could shed light on the effectiveness of particular features of IGECs, as well as their third party implications. Such analyses would help to answer questions about the emphasis that should be placed on complex collaborations versus broader, potentially multilateral approaches. Such analyses would be beneficial, because in one form or another, IGECs look set to play a substantial role in the governance of the global energy transition.

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