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Oberthur, Sebastian; Khandekar, Gauri Amarsinh; Wyns, Tomas

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Research article

Global governance for the decarbonization of energy-intensive industries: Great potential underexploited

Sebastian Oberthür [a, b, *], Gauri Khandekar [a], Tomas Wyns [a]

[a] Institute for European Studies, Vrije Universiteit Brussel, Pleinlaan 2, B-1050, Brussels, Belgium
[b] University of Eastern Finland, Centre for Climate Change, Energy and Environmental Law, Yliopistokatu 2, FI-80100, Joensuu, Finland

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ABSTRACT

This article investigates the contribution of global governance to advancing the decarbonization of energy-intensive industries (EIIs – steel, chemicals, cement, aluminium, etc.). It explores to what extent relevant intergovernmental and transnational institutions have exploited the potentials of global governance to address related barriers and challenges, in particular competitiveness concerns, the need to incentivise investments in breakthrough technologies and enhance circularity across global value chains. We find that global governance's high potential to contribute to the decarbonization of EIIs has remained very much underexploited. Few international institutions contribute and there is no clear centre. Existing institutions have especially not delivered a sector-specific signal/vision and consequent international rules. In response, the formation of a central institution and/or subsector-specific initiatives might be considered. We argue that advancing global governance to tap into its considerable but so far underexploited potential ought to be an integral part of any strategy for the decarbonization of EIIs.

1. Introduction

Achieving the objectives of the Paris Agreement requires the deep decarbonization of energy-intensive industries (EIIs) within the next few decades. EIIs comprise a number of different industries with high energy inputs, including iron and steel, basic chemicals, cement, aluminium, glass, ceramics and pulp and paper. Globally, EIIs contribute more than 20 per cent of total greenhouse gas (GHG) emissions (Fischedick et al., 2014; Climate Watch, 2020). CO_2 emissions arise from direct use of energy and fossil fuels, from reactions in the production processes (process emissions), indirectly through use of electricity and heat, and – to a very small extent – from waste/wastewater. In addition, N_2O emissions result from the production of ammonium and adipic acid and sulphur hexafluoride (SF_6) emissions from aluminium production (process emissions) (Fischedick et al., 2014). In order to realize the Paris Agreement's temperature goal of limiting the increase of global average temperature to 1.5/2 °C, net zero emissions will have to be achieved world-wide as early as possible after 2050, including in the EIIs (IPCC, 2018).

In this article, we focus on four key industries that are responsible for the bulk of the EIIs' GHG emissions. Iron and steel, cement, chemicals and aluminium account for nearly 70 per cent of industrial emissions; other subsectors contribute smaller portions of the remainder, including glass production, pulp and paper, ceramics and others (Kechichian et al., 2016). We submit that much of the analysis of the four aforementioned key industries is also relevant for the other, smaller EIIs.

EIIs tend to be highly concentrated and trade exposed. The top 12 steel companies accounted for about 30 per cent of global crude steel production in 2018 and just 10 companies produce almost half the world's aluminium. Generally, China, the EU, the US, Japan and India dominate these industries, with China alone accounting for more than 50 per cent of global steel and aluminium production. Furthermore, most basic materials are traded internationally to a very significant extent (either globally or regionally). 25 to 35 per cent of all steel and aluminium produced is traded. Chemical industries are also trade exposed. The cement subsector is somewhat special in both respects since virtually every country produces cement and less than five per cent of global production is traded internationally (Baron et al., 2007; World Cement, 2013; Fischedick et al., 2014; Åhman et al., 2016; World Steel, 2019).

This article investigates the promise and potential of global

* Corresponding author. Institute for European Studies, Vrije Universiteit Brussel, Pleinlaan 2, B-1050, Brussels, Belgium.
E-mail address: sebastian.oberthuer@vub.be (S. Oberthür).

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governance for advancing the decarbonization of EIIs.[1] It picks up on and goes beyond existing literature on "sectoral approaches" to mitigating GHG emissions that was especially pursued in the 2000s (e.g., Baron et al., 2007; Meckling and Chung, 2009; Sawa, 2011). Closely linked to the multilateral climate regime, these discussions were very much driven by the political demands to expand international mitigation obligations/actions to developing countries, provide a level playing field to EIIs across international markets, and promote technology transfer. Accordingly, the focus was on possible agreements on sectoral mitigation commitments or technology cooperation. Starting from the global decarbonization impetus of the Paris Agreement, we aim to advance thinking about a sectoral approach to global climate governance of EIIs (see also Åhman et al., 2016) by approaching the issue more broadly and more generally. Based on firm conceptual thinking about the performance profile of international institutions (Oberthür et al., in this issue), we in particular ask what global governance has on offer for specifically advancing the decarbonization of EIIs. What promise do intergovernmental and transnational institutions hold for moving the phase out of GHG emissions in this sector forward? What have they contributed so far? And how could the institutional landscape be further developed for this purpose?

Overall, we argue that global governance possesses a high potential to help advance the world-wide decarbonization of EIIs. However, existing international institutions have left this high potential greatly underexploited. Consequently, there is a clear rationale for enhancing global governance for the climate transition of EIIs. While enhanced global governance could contribute to several key functions (including technology transfer and knowledge and learning), a particular potential exists to establish firm international guidance and signal as well as for international rule-setting. General options to this end are explored in the concluding section.

We develop our argument in four steps. In the next section, we first identify the key challenges and barriers to the deep decarbonization of EIIs. On this basis, section 3 analyses the *general potential* of global governance to address these barriers and challenges, along the lines of five key governance functions of international institutions. Section 4 then analyses to what extent existing intergovernmental and transnational institutions relevant for the decarbonization of EIIs have so far realised this potential. Section 5, finally, draws conclusions identifying existing gaps and underexploited potentials as well as general options for enhancing the contribution of global governance to the decarbonization of EIIs. Given the focus of this article and special issue, this discussion of options remains preliminary and focuses on institutional design and structure rather than on politics, which remains to be further investigated in future research (Rayner et al., in this issue).

2. Main barriers and challenges for deep decarbonization

We in the following highlight what can be considered the main of the manifold barriers for and challenges to the decarbonization of EIIs. This decarbonization requires employing several measures and strategies, including the development and use of new breakthrough technologies, the introduction of low-carbon substitutes for materials and fuels, smarter design of end products to reduce basic materials' intensity, efficient consumption and a circular resource model with increased reuse and recycling (e.g., Allwood et al., 2012; Fischedick et al., 2014; Åhman et al., 2016; Wesseling et al., 2017; Wyns et al., 2018; Material Economics, 2019). The discussion in this section does not yet relate to global governance but especially builds on literature on technology and economics of the decarbonization of EIIs.

Lack of mature low-CO_2 technologies

Technologies that allow a full phase-out of GHG emissions from EIIs are still at a relatively early stage of development. Table 1 gives a brief overview of some major new or improved processes that would enable deeper emission reductions in EIIs. However, few of these technologies enable a full decarbonization of production and several of them are still under development. The potential of best available technologies and best-practice solutions is limited. Overall, there remains a need for further development of technologies and processes ('breakthrough technologies') to this end, including higher levels of electrification of energy intensive processes (using renewable energy sources), the use of carbon capture and utilisation/storage and the transition towards non-fossil fuel feedstocks (Kechichian et al., 2016; Lechtenböhmer et al., 2016; Wyns et al., 2018).

The development of new breakthrough technologies is also hindered by EIIs (with the exception of chemicals) having a relatively low R&D intensity (expressed as R&D expenditure over revenues) compared to other industrial sectors (see Hernández et al., 2018). Smaller new entrants in these sectors show more interest in R&D but have lower means than larger incumbent companies and lack sufficient market access (e.g., into consolidated cement, steel and chemicals markets) for their innovative products and processes (Wesseling et al., 2017).

High Capex, long investment cycles and technology risk

To the extent that low-carbon technologies are available, their deployment and diffusion is hampered by the particular characteristics of EIIs. Production facilities generally require high capital expenditures (Capex) and are usually made for 10–30 years (depending on the subsector), creating a considerable danger of carbon lock-in (Wesseling et al., 2017). New technologies that are not yet proven hence face a major barrier at the demonstration to commercialization stage, since investments carry a high risk. Innovative technologies are therefore financially less attractive, require longer paybacks and may necessitate longer operational shutdown periods to integrate changes in production process/existing assets (Hart, 2017). The resulting technological inertia hinders the deployment of promising technology options that may therefore never become mainstream solutions. Due to the long investment cycles, the uptake of new breakthrough technologies faces an uphill struggle against existing installations (Fischedick et al., 2014; Wesseling and Van der Vooren, 2017).

Costs and competitiveness

New breakthrough technologies for the decarbonization of EIIs and relevant low-emission solutions usually carry higher (operational) costs than established technologies – in particular as long as they are not fully developed and commercialized, but possibly also beyond (Material Economics, 2019). Such costs are an obvious barrier to the uptake, diffusion and use of low-carbon technologies in industries that are characterized by intense international trade

[1] We follow the understanding of global governance as the steering of actors' behaviour through the setting of rules, standards and guidelines, or through targeted support, towards a common or shared goal, as developed in the introductory article of this special issue. Accordingly, international institutions (both intergovernmental and transnational) form the principal fora of global governance (Oberthür et al., in this issue).

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Table 1
Deep decarbonization options for EIIs.

Sector	Deep decarbonization options	Technology readiness
Steel	Improving energy efficiency beyond best available technologies	At commercial scale (TRL 9) & new technologies close to marketization (TRL 5–8).
	Use of biomass in steel production	Commercially applied (e.g. bio-char) TRL 9
	New smelting reduction technologies	Being piloted (TRL 5–7)
	Using hydrogen for iron ore reduction	Pilot plant under construction (TRL 5)
	Use of waste gases from coke/iron/steel production as feedstock for ethanol and chemicals production	Pilot plant under construction (TRL 5)
	Carbon capture and storage	Carbon capture-ready hot iron production piloted (TRL 5)
	Using electricity for iron ore reduction	Small scale testing (TRL <4)
	Technologies to refine impurities (e.g. copper) in scrap steel	Approaching piloting (TRL <4 for advanced recovery of copper contamination)
Cement	Use of alternative binders (to Portland cement) in concrete	Commercially available (TRL 9) or close to marketization (TRL 7–8)
	Reducing clinker content in concrete	Close to marketization (TRL 8–9)
	Extend lifetime of concrete (e.g. through self-healing concrete)	Close to marketization (TRL 8)
	Higher energy efficiency of processes and fuel switching (to low carbon fuels)	Market ready/close to marketization (TRL 5–8)
	Carbon capture at process level or during concrete formation	Pilot and demo plants under construction (TRL 5–7)
	Cement recycling	Close to/approaching piloting (TRL <5)
	CO_2 utilisation incl. carbonation	Commercially available for carbonation (TRL 9). Approaching piloting for utilisation of waste gases (TRL 4–5)
Chemicals	Major improvements in resource/energy efficiency of processes	Market ready (TRL 9) or close to marketization (TRL 5–8)
	Advanced (plastics) recycling processes (chemical recycling)	Between piloting and marketization (TRL 5–8)
	Large scale production of H_2 using electricity	First plants operational (TRL 9), other technologies at earlier stages of development (TRL 4–7)
	Higher use of biomass, waste and recycled materials including from other industries	Some commercially available or close to commercialization; biobased/CCU basic chemicals at pilot stage or earlier (TRL 4–5/< 5)
Aluminium	Major improvements in resource/energy efficiency of processes	Market ready (TRL 9) or close to marketization (TRL 5–8)
	Non-oxidising (i.e. CO_2 emitting) anodes in primary aluminium	Close to/approaching piloting plant (TRL <5)

Source: Wyns et al. (2018).

and competition. Under the circumstances, higher costs can be handed down to consumers only to a very limited extent and, without accompanying enabling policies (see below), question the competitiveness of related investments (Neuhoff et al., 2016). Competitiveness concerns have been a major driver of the aforementioned discussion on sectoral approaches under the multilateral climate regime that unfolded in the 2000s (Baron et al., 2007; Meckling and Chung, 2009; Sawa, 2011).

Complex global value chains

Complex global value chains hamper the realization of a significant part of the emission reduction potential of EIIs. Over the past decades, value chains have become more complex and global. Since many basic materials and intermediate products are now traded globally, producers compete on a global market. In some cases (e.g. non-ferrous metals) there even is a global price setting. Furthermore, this growing internationalization and complexity limits the ability of a basic materials company to track and control the end use of its products. This makes recycling and upcycling difficult and/or expensive, hindering new business models aimed at the lease and return of basic materials. Costly labour-intensive smart design of products to minimize input of basic materials also handicaps their competitive position on international markets (Fischedick et al., 2014).

Lack of policy frameworks

Appropriate policy frameworks to advance the decarbonization of EIIs and address the aforementioned barriers are lacking. R&D policies can support the development and demonstration of low-carbon breakthrough technologies and solutions. Financial support (subsidies) for the deployment of these technologies/solutions, carbon pricing, product standards, procurement policies, labelling and other measures could help in addressing cost and competitiveness concerns, creating a market for low-carbon products and enhancing circularity and recycling. However, the global nature of EIIs limits the effectiveness and feasibility of measures at national level – that may lead to carbon/investment leakage (providing a strong rationale for international action).

3. The promise and potential of international cooperation

In this section, we analyse what the promise and potential of international cooperation is to address the aforementioned barriers toward the decarbonization of EIIs. We focus on five general functions that international institutions can principally perform, as derived in the introductory article of this special issue on the basis of the relevant literature: (1) providing guidance and signal to actors, (2) setting rules to facilitate collective action, (3) enhancing transparency and accountability, (4) offering means of implementation (finance, technology, capacity-building), and (5) promoting knowledge and learning (for more detail, see Oberthür et al., in this issue). This discussion remains at the conceptual level by comparing what is needed, as identified in the preceding section, with this five-dimensional performance profile of international institutions. What specific contribution to addressing the barriers and challenges discussed in the previous section could global governance through international institutions theoretically make (in addition to other levels of governance)? As summarized in Table 2, we find that all five governance functions of international institutions possess significant potential, although to varying degrees. Overall, there is therefore a strong rationale for engaging global governance for the decarbonization of EIIs.

3.1. Guidance and signal

An *international* decarbonization vision with clear timelines and differentiated mitigation pathways could provide important guidance to decision-makers in industrial sectors. It could help address

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Table 2
Main potential for international governance of EIIs.

Guidance & Signal	Setting Rules	Transparency & Accountability	Means of Implementation	Knowledge & Learning
Sectoral decarbonization objectives and roadmaps	International emission limits and/or carbon pricing	Required to monitor and verify implementation of rules	Financing of breakthrough technologies, technology transfer and R&D coordination	Policy learning, supply and value chains

Source: Authors (Rayner et al., 2018).

the aforementioned barriers and challenges by focusing these decision-makers on the overall task to be accomplished, so that, for example, relevant technological development and appropriate policy frameworks are advanced. Establishing such guidance at the international level seems particularly appropriate because of the international structure of the industry. Such "governance through goals" (Kanie and Biermann, 2017) could help align them towards decarbonization.

A global timebound decarbonization vision for EIIs could become particularly tangible for sectoral actors if it was translated into roadmaps towards this objective. Global roadmaps could build on and be concretized in national, regional and sectoral roadmaps. Taken together, these roadmaps could present an integrated view of how the industries can transform their supply, production and value chains while maintaining competitiveness and supporting economic development. Given inter-regional disparities, regional roadmaps may be particularly useful, taking into account interactions with downstream demand/industries and the need for enhanced resource efficiency and circularity (Samadi et al., 2016; McKinsey, 2017; Stork et al., 2018).

3.2. Setting rules to facilitate collective action

EIIs' globalized nature and resulting strong competitiveness concerns (see above) provide for a strong rationale for international rules. Such rules could take the form of different regulatory instruments, including carbon pricing (CO_2 tax or emissions trading) or international regulations and/or standards. These can target the production processes (e.g., CO_2 emission limits per tonne of production) or the consumption side (limit on emissions embedded in final product). The latter would avoid discrimination between domestic and foreign production (Neuhoff et al., 2014) but would require reliable information on emissions across these producers. International labelling and information requirements could also facilitate circularity of global flows of materials and products. Overall, common regulations and standards (like procurement policies, customs exemptions, labelling schemes) could help provide more levelled global playing fields fostering competitiveness towards decarbonization and address barriers to circularity arising from global value chains (Kechichian et al., 2016). Such rules and related information requirements were a major focus of the discussion on sectoral approaches under the multilateral climate regime in the 2000s (see above).

3.3. Transparency and accountability

A need for international action to enhance transparency and accountability especially arises in the context of the aforementioned international regulation. For example, to ensure that any international emission standards or a carbon price are effectively implemented, common monitoring, reporting and verification standards and metrics for industrial emissions, preferably even including the whole supply and value chain, would be required (also Sawa, 2011). Such standards enable comparison of efforts and identification of varying efficiencies and CO_2 intensities of production. Transparency of GHG impact of various products across complex global value chains would require common/global GHG accounting standards.

3.4. Means of implementation

Global cooperation on finance and technology can help address barriers related to costs, Capex and technology risk highlighted above. Appropriate international financing channels and coordination of national and transnational financing can help address the higher costs of innovative breakthrough technologies and other solutions, especially in developing countries – while avoiding a potential race to subsidizing EIIs. This could concern both the development and the deployment and diffusion of such technologies. Accordingly, technology development and transfer was a major focus of debates on sectoral approaches in multilateral climate policy in the 2000s (Baron et al., 2007; Meckling and Chung, 2009; Sawa, 2011; see also Åhman et al., 2016).

Concretely, processes, platforms and funds could help address the high capital cost and risk associated with large industrial breakthrough technologies. R&D cooperation and coordinated international technology projects could help combine the knowhow and finance from different countries and across different stages of technology readiness. While potential for building new large low-carbon demonstration plants particularly exists in emerging economies (where EIIs are expanding), more advanced economies could pioneer circular economy related technologies. National or regional investment banks could enable these investments by leveraging private capital. According to the IEA, holding temperature increase to well below 2 °C will require OECD countries to urgently transfer innovative technologies for industry to non-OECD countries to avoid carbon lock-in/stranded assets (IEA, 2017).

3.5. Knowledge and learning

Knowledge and learning at the international level have a comparatively limited, supportive role to play. To be sure, knowledge and learning are crucial for advancing breakthrough technologies, addressing global supply and value chains, and promoting effective policy frameworks (see section 2). However, much valuable knowledge and learning is usefully promoted elsewhere, e.g. by industrial actors and through domestic research (e.g. on breakthrough technologies) as well as bilateral channels. Nevertheless, global governance can contribute. The aforementioned R&D cooperation may involve the creation of relevant technical knowledge. In addition, international cooperation could facilitate cross-country learning regarding policies and practices to advance circularity and foster industrial innovation (for example, through the creation of a related global knowledge and learning platform). A particular need exists for international cooperation to enhance knowledge on global supply and value chains to enable their tracking and control for greater circularity (as such chains are by definition transboundary). Overall, though, international institutions seem, in view of other actors and channels, less central for advancing knowledge and learning than for guidance and signal, international rule-setting, and means of implementation.

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Table 3
International institutions on EIIs in overview.

Institution	Main governance contribution
UNFCCC/PA	Signal/Setting rules/Transparency/Means of implementation/Knowledge and learning: general objectives, requirements and means (not sector-specific)
IEA	Means of implementation: technology collaboration programs Knowledge and learning: analysis/data and technology roadmaps
UNIDO	Means of Implementation: project finance, tech. development/transfer Knowledge and learning: data and reports, knowledge exchange
G20	Setting Rules: phase out of subsidies, anti-dumping, overcapacity in the steel sector
UNEP	Means of Implementation: technology development Knowledge and Learning: data and reports
WTO	Setting Rules: impedes trade measures to address carbon leakage
Mission Innovation/Breakthrough Energy Coalition	Means of Implementation: financing, investment Knowledge and learning: workshops, stakeholder dialogues
World Bank (and other MDBs)	Means of Implementation: financing, investment Knowledge and Learning: data, stakeholder dialogues
CSI/GCCA	Transparency/Knowledge and learning: action plan, guidelines, exchange of information, measurement and reporting
ICCA	Transparency/Knowledge and learning: guidelines for assessing and reporting avoided GHG emissions
ResponsibleSteel	Transparency/Knowledge and learning: certification guidelines, measurement and reporting

Source: Based on Rayner et al. (2018).

4. The supply of global governance

This section turns from the theoretical to the empirical analysis by investigating what actual contribution existing international institutions have made to delivering on the five aforementioned governance functions. This enables us to assess how much of the theoretical potential of global governance for advancing the decarbonization of EIIs identified in section 3 has been exploited.

4.1. The governance landscape in overview

The landscape of global climate governance of EIIs is relatively scarcely populated. Our inventory of international institutions that significantly affect the decarbonization of EIIs (through contributing to the performance of the five governance functions) does only contain 11 entries, as also reflected in Table 3 (as of 2018/19). The inventory is the result of a screening of existing databases of international/transnational climate-related institutions, which was complemented by own research and through the review of two further EII experts (Rayner et al., 2018: 15–18).[2]

None of the identified institutions is primarily or even strongly focused on the decarbonization of EIIs as a whole. In other words, the institutional complex on the decarbonization of EIIs so far has no centre, but governance is dispersed among the elemental international institutions.

The governance landscape is dominated by intergovernmental institutions. Eight out of the 11 identified institutions are established UN bodies or otherwise operated by state governments, including the UN Framework Convention on Climate Change and its Paris Agreement (UNFCCC/PA), the International Energy Agency (IEA), the United Nations Environment Programme (UNEP), the United Nations Industrial Development Organization (UNIDO), the World Trade Organization (WTO), Mission Innovation/Breakthrough Energy Coalition, the Group of 20 (G20) and the World Bank and other multilateral development banks (MDBs) such as the African Development Bank, the Asian Development Bank, the Inter-American Development Bank, the European Bank for Reconstruction and Development, and the European Investment Bank (for all of which the World Bank is used as a proxy in the following). Only three institutions are transnational in character as they are operated by industry actors, the Cement Sustainability Initiative (CSI – merged into the Global Cement and Concrete Association, GCCA, in 2019), the International Council of Chemicals Associations (ICCA), and ResponsibleSteel.

The remit of the identified intergovernmental institutions is generally much broader than GHG mitigation of EIIs (and even climate change), which only forms a smaller part of their portfolios. Only the UNFCCC/PA and, to a somewhat lesser extent, Mission Innovation – which was established in 2015 as an intergovernmental platform consisting of 22 countries and the European Union (EU) with the aim to accelerate global clean energy innovation (Sanchez and Sivaram, 2017) – are focused on climate governance. The IEA, UNIDO, UNEP, the World Bank (and other MDBs) and the G20 all operate relevant initiatives within their much wider portfolio of activities. The WTO is the primary international institution for addressing trade related aspects, which figure prominently among trade-exposed EIIs.

The three transnational sectoral industry initiatives are focused on a particular EII (cement, chemicals, steel), but also have a larger scope by addressing concerns beyond climate change. The CSI included a strong focus on climate protection, but also pursued wider sustainability issues (and has since 2019 been largely superseded by the broader GCCA). With a membership that accounts for more than 90 percent of global chemical sales, the ICCA is a general platform for the chemical industry under which climate change is one particular action area. ResponsibleSteel is an industry-led global multi-stakeholder standard and certification initiative established in 2017–19.

Overall, all international institutions relevant for the decarbonization of EIIs hence have a much broader focus and mandate. A minority of institutions have a strong focus on either EIIs and/or climate change (UNFCCC/PA, Mission Innovation, CSI, ICCA, ResponsibleSteel). With the exception of Mission Innovation and ResponsibleSteel, all institutions of the governance landscape have existed for at least 20 years and in several cases much longer (UNIDO, the World Bank, the IEA, UNEP). This landscape contrasts starkly with that of other sectoral systems that have seen strong growth of focused/targeted initiatives (e.g., Hermwille, in this issue).

4.2. Guidance and signal function

The main international institution that has provided a general signal towards decarbonization also of the EIIs is the Paris

[2] Responsible Steel, which only became operational in the late 2010s, was added on the suggestion of one of the peer reviewers – many thanks!.

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Agreement. The Agreement establishes the temperature target of 2/1.5 °C (Article 2) and the objective of phasing out net GHG emissions in the second half of the 21st century (Article 4.1), clearly pointing to the need to fully decarbonize. A "shared statement of ambition" of CSI members to aim to reduce GHG emissions by 20–25 percent below business as usual by 2030 remained noncommittal (Busch et al., 2008; CSI, 2015).

However, the Paris signal lacks sectoral specification. Whereas multinational EII companies are well placed to understand that the Paris Agreement implies the decarbonization of their business, the Paris signal leaves room for different interpretations of what it may mean in practice for EIIs. Especially, it remains unclear how much emissions need to be reduced as compared to other sectors or could be balanced by carbon sinks such as forests. Hence, the Paris Agreement provides a diffuse signal towards decarbonization to EIIs that does not exploit the potential of sectoral decarbonization objectives with clear timelines and regional and global mitigation roadmaps.

4.3. Setting rules to facilitate collective action

The potential of international institutions to set relevant rules that would drive EIIs towards decarbonization and address related competitiveness concerns has hardly been tapped into at all. Only very few institutions have passed relevant rules. The Paris Agreement requires its parties to have medium-term climate action plans in the form of "nationally determined contributions" in place and to elaborate long-term low GHG emission development strategies but does not focus on EIIs. In addition, the G20 has pledged to phase out subsidies, enhance anti-dumping and cut over-capacity in the steel industry (Darabshaw, 2017). Neither comes close to establishing effective international emission limits and/or carbon pricing for EIIs (see section 3).

WTO rules have even significantly constrained countries that would like to apply emission limits or carbon pricing to imported goods to ensure a level playing field with domestic production. While it may not be impossible for countries to restrict imports of products on the basis of how they have been produced, WTO rules prohibiting unfair and disproportionate treatment of imports have in practice very much impeded such measures (for recent accounts of the evolving discussion, see Cosbey et al., 2019; Mehling et al., 2019).

4.4. Transparency and accountability

Existing international institutions have also hardly supported transparency and accountability for EII decarbonization. Four of the identified institutions have made relevant contributions. First of all, the UNFCCC/PA operates a fundamental transparency system including regular reporting on and accounting of GHG emissions. The relevant emission inventories also contain industrial emission data, but they do not enable monitoring of emissions of (individual) EIIs. Furthermore, the CSI has developed a CO_2 Protocol and relevant tools to measure emissions of the cement industry and involves a commitment by members to report on their emissions accordingly. Similarly, ICCA has developed guidelines for its members assessing and reporting avoided GHG emissions (ICCA, 2013) and ResponsibleSteel has elaborated a broad certification standard, including climate-related aspects (ResponsibleSteel, 2019).

Further and broader efforts would be required to provide for sufficient transparency in support of future international rules, to support monitoring and implementation and to counter incentives for free riding (see also Sawa, 2011). Since such international rules are lacking, it may be no surprise that transparency and accountability arrangement are in their infancy, at best. They could build on extensive experience with the relevant large point sources from domestic emissions trading systems such as the EU's (Meadows et al., 2019).

4.5. Means of implementation

Means of implementation have constituted one of the focal points of the activities of the identified international institutions. Several of them have provided relevant financing, including the UNFCCC/PA (especially through its Green Climate Fund), the World Bank (and other MDBs), UNIDO and Mission Innovation/Breakthrough Energy Coalition. Under the Green Climate Fund, projects and programmes for the decarbonization of EIIs in developing countries are generally eligible. The World Bank (and other MDBs) have financed numerous projects targeting EIIs in developing countries (energy efficiency, heat recovery, waste reduction: World Bank, N.D.). UNIDO has similarly provided limited project support for more resource and energy efficiency and cleaner industrial processes (UNIDO, 2015). Mission Innovation has focused on catalysing private sector investment in transformative clean energy technologies, including in EIIs. In support of Mission Innovation, the Breakthrough Energy Coalition has mobilized capital from private investors and financial institutions to develop, market and upscale breakthrough technologies, including in EIIs (chemicals, cement, steel).[3]

Especially the UNFCCC/PA, UNEP, and UNIDO have also engaged in targeted technology development and/or diffusion activities. The Technology Mechanism under the UNFCCC/PA has supported technology diffusion but is not known to have a strong focus on decarbonising EIIs (de Coninck and Sagar, 2017). A limited number of projects under the Kyoto Protocol's (now largely historical) Clean Development Mechanism (CDM) have also addressed EIIs (especially steel and cement; Erickson et al., 2011). The IEA has contributed through its Technology Collaboration Programmes (IEA, 2016a), and IEA implementing agreements have provided a framework for sharing research on breakthrough technologies, building pilot plants and carrying out deployment or demonstration programmes (IEA, 2017). Among its broad portfolio of activities, UNEP has also funded research into low-carbon strategies in EIIs (KLH Sustainability, 2017). UNIDO has specifically fostered technology transfer, technology demonstration and upscaling in the industry sector, including EIIs (UNIDO, 2015). Furthermore, several of the mentioned institutions have also engaged in targeted capacity-building activities (training, etc.).

Nevertheless, financing and technology development and diffusion by existing international institutions have remained insufficient in two respects. First, several of the indicated institutions have not focused on decarbonization in their EII activities. For the World Bank (and other MDBs), UNIDO and the IEA, emission mitigation has been one objective among several in their general support for industrial development. Consequently, they have even supported various investments that lock in carbon-intensive infrastructure (EIB, 2016). Similarly, EII projects under the CDM have focused on best available technologies rather than decarbonization (Erickson et al., 2011).[4] Second, financing and technology development support have remained inadequate. The IEA (2016b, pp. 102) estimated in 2016 that there is a need for energy efficiency investment in EIIs of USD 35 billion

[3] See http://www.b-t.energy/.

[4] Article 6 of the Paris Agreement foresees the establishment of a mechanism similar to the CDM, which is likely to face similar limitations.

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per year by 2020, with particularly high demand for piloting and diffusion. While it is unclear how much of the overall investment demand (which should be even higher for deep decarbonization) international institutions should meet, combined MDB climate finance for 2016 at best mobilized a minimal fraction of this amount (EIB, 2016), leaving much scope for additional contributions.

4.6. Knowledge and learning

Knowledge and learning have provided another focal point of the activities of international institutions governing EIIs. Most of the identified institutions have fostered knowledge and learning through reports and data collection and analysis, or exchange/meetings. Besides providing emission data, the UNFCCC/PA has in particular contributed through its Technology Executive Committee that has produced relevant papers and reports and convened dialogues.[5] In addition to hosting workshops and seminars with EII stakeholders, the IEA has provided analysis, technology roadmaps, modelling and data on EIIs, including in its annual Energy Technology Perspectives reports (e.g. IEA, 2006ff.) and Technology Roadmaps (e.g., IEA, 2009ff.). IEA implementing agreements have constituted a framework for sharing research on breakthrough technologies and filling existing research gaps. UNEP and UNIDO similarly have produced relevant reports and data and have supported research into low-carbon strategies in EIIs (KLH Sustainability, 2017). The Metals Working Group of UNEP's International Resource Panel, set up in 2007, has created relevant knowledge as well. UNIDO has served as a general knowledge sharing platform for member states, including through mechanisms such as the Vienna Energy Forum (Matteini, 2015). Mission Innovation has also served to exchange relevant knowledge and has convened workshops and stakeholder dialogues. The World Bank has brought together stakeholders on similar issues, while also making available relevant data.[6] Finally, the CSI and ICCA have provided for exchange of relevant knowledge and have issued related guidelines to their members from the cement and chemical industries, respectively (and ResponsibleSteel may develop similar activities in the future). Other institutions such as the IPCC which has addressed energy-intensive industries in its regular assessment reports (e.g., Fischedick et al., 2014) have also contributed to knowledge creation and diffusion.

While this flurry of activities has significantly contributed to transboundary knowledge and learning about the decarbonization of EIIs (thereby complementing and amplifying national, private and bilateral mechanisms), it has also left important issues unaddressed. In particular, efforts at enhancing knowledge on global supply and value chains have been lacking. Furthermore, potential to foster transboundary learning on policies and practices to advance circularity and foster industrial innovation, and to coordinate relevant activities across institutions, has remained untapped.

5. Conclusions and policy options

5.1. Main findings

While not a panacea, global governance holds great potential for contributing to the world-wide decarbonization of EIIs. An international decarbonization vision and related roadmaps can provide important guidance to these industries for their future orientation. International rules can help address competitiveness concerns, serve to coordinate incentivising investments in breakthrough technologies, and facilitate enhanced circularity across global value chains. Cooperation in international institutions can also enhance coordination of R&D efforts and pool scarce resources for developing and transferring new breakthrough technologies and other solutions required to phase out GHG emissions of EIIs.

This high potential of global governance has so far remained greatly underexploited. The number of relevant international institutions is limited and there is no central international institution governing EIIs and their decarbonization. A firm international decarbonization vision for the decarbonization of EIIs and related common rules remain wanting. The Paris Agreement's general vision of climate neutrality needs to be specified for EIIs. Furthermore, common rules, targets and roadmaps have not been developed to any significant extent and coordination of R&D efforts has remained in its infancy. Further potential also exists to activate global governance for providing means of implementation (finance and technology) and advancing knowledge and learning. While several channels of international support for new breakthrough technologies exist (including the World Bank and other MDBs, Mission Innovation and the related Breakthrough Energy Coalition, and the UNFCCC/PA's Green Climate Fund), the level of support provided has remained insufficient for effectively driving EIIs toward decarbonization. Similarly, important further potential exists for upgrading the promotion of international knowledge and learning by existing international institutions (including UNEP, the IEA, the CSI/GCCA and others).

Some activities of international institutions have even impeded the decarbonization of the sector. The World Bank and other MDBs as well as UNIDO have continued to finance the expansion of EIIs using existing, non-decarbonized technology. Even if employing best available technologies, this has created carbon lock-in as the new installations will emit GHGs for years and decades to come. Furthermore, WTO disciplines have hindered border tax adjustments to address carbon leakage concerns (while also providing an international forum for potentially coordinating responses and advancing compatibility with trade rules).

Overall, there is a dearth of global governance to mobilize the potential of international institutions for the decarbonization of EIIs. This raises the question how this potential could be exploited more fully, especially with respect to the guidance/signal and rule-setting functions. In the next, final subsection, we begin to explore this question by briefly exploring key institutional issues and options.

5.2. Key institutional options for enhancing global governance of EIIs

We conclude this article by beginning to explore how the landscape of global climate governance could be further developed to advance the decarbonization of EIIs. To what extent can incremental change of existing institutions (such as upscaling of their activities) contribute to this end? Where may more fundamental change be required in view of existing institutional objectives, memberships and capacity/expertise? In line with the overall thrust of the article and special issue, we leave a deeper investigation of the politics of institutional reform for later research (see also Rayner et al., in this issue).

Means of implementation and knowledge and learning may be enhanced through incremental change of existing institutions. The required upscaling of resources could by and large occur through existing channels (Green Climate Fund, etc.), and the WB and other MDBs could phase out financing for non-decarbonised/high-carbon

[5] See http://unfccc.int/ttclear/tec/impact.html#Breakdown.

[6] See "energy intensive industries" at https://www.worldbank.org/en/search.

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EIIs by further greening their policies. Efforts to enhance knowledge and learning can also build on existing efforts by UNEP, CSI/GCCA, ICCA, the IEA and others. Targeted international knowledge platforms (e.g., on global value chains to facilitate circularity and/or policies and practices) might usefully complement the current portfolio of activities and could also serve to better coordinate knowledge and learning activities among existing institutions.

Advancing guidance and signal and international rule-setting may be more demanding. Delivering on these functions would presumably entail participation by key governments (for ensuring authority of agreed decarbonization objectives and rules; see also Meckling and Chung, 2009), in addition to companies and other societal stakeholders. Furthermore, performing the functions in question implies a degree of legal authority (as is required for rule-setting) and decision-making capacity as well as an appropriate mandate supporting a focus on the decarbonization of EIIs.

Delivering on these requirements asks for new institutions or a far-reaching reform of existing institutions beyond incremental change. Although in principle possessing the authority and means, the UNFCCC/PA may not be ideally placed to provide for a more specific international vision and rule-setting for EIIs (and other sectoral systems). Engaging in sectoral governance of this sort would imply a considerable increase in its scope of activities and its already considerable complexity. It would also require a build-up of sectoral expertise, while facing limited decision-making capacity in view of the global consensus required (see the inconclusive debates on sectoral approaches in the 2000s). Though not unthinkable, the current role of the UNFCCC/PA in global climate governance might rather point to it supervising and orchestrating sectoral initiatives (cf. Hermwille et al., 2017). Other existing international institutions even seem less suitable. The G20 is more general, requires consensus and lacks in legal authority. UNIDO is limited by its focus on developing countries and their industrial development and has limited membership of key developed countries. Other existing institutions such as the CSI/GCCA, ICCA, ResponsibleSteel, the IEA and UNEP are constrained by their mandates and legal authority as well.

Whether through far-reaching reforms of existing institutions or the creation of new ones, two principal models for advancing global climate governance of EIIs might be considered so as to deliver on the guidance and signal and international rule-setting functions. First, a central institution could address the decarbonization of EIIs as a whole (as part or focus of its mandate). Since both production and consumption of relevant basic materials are relatively concentrated, a limited number of countries and companies would be required to participate, with existing global industry associations as potentially useful interlocutors of industry participation. Second, subsector-specific initiatives and 'clubs' could zoom in on specific EIIs (steel, aluminium, cement, chemicals) reflecting the considerably diverging challenges (for the case of steel, see Hermwille, 2019). Participation could focus on governments and companies most relevant for the sub-sector in question. Both models do not exclude but can complement each other. The central institution could focus on cross-cutting issues, whereas sub-sector initiatives could address sub-sector specifics. Such initiatives could reside under the umbrella of a central EII institution or operate formally independently.

In conclusion, there are promising institutional options for upgrading global governance for the decarbonization of EIIs. Especially to enhance international guidance to these industries and develop related international regulation, institutional reform may have to go beyond incremental change. Doing so requires sufficient political will and support, a factor that may itself affect the choice of institutional form and the path towards realising it. As the world moves towards implementing the Paris Agreement and the need to decarbonize all sectors of the economy (including EIIs) gets clearer and more accepted, political will should grow. Under the circumstances, it should be useful for future research to further elaborate institutional options and pathways — and to investigate how they may best be aligned with evolving politics. The case for upgrading global governance for the decarbonization of EIIs is strong.

CRediT authorship contribution statement

Sebastian Oberthür: Conceptualization, Methodology, Roles, Writing - original draft, lead author. **Gauri Khandekar:** Writing - original draft, empirical analysis. **Tomas Wyns:** Methodology, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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