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Preface

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Abstrakt/Abstract

The energy intensive industry, producing basic materials, is responsible for 25 to 30% of today's global greenhouse gas emissions. The future supply of GHG neutral basic materials (e.g. steel, cement, aluminium, plastics, etc.) is a necessity for building a sustainable modern society. Deep decarbonisation of the energy intensive industries is technically possible but will require a major systemic shift in production processes and energy carriers used, which will require large public support in the form of subsidies and high carbon prices. A key barrier for implementing ambitious climate policies targeting energy intensive industries is the inherent conflict between the global nature of energy intensive industries and the existing climate policy framework that is based on nation states taking action according to the principle of "common but differentiated responsibilities". This approach could lead to carbon leakage and the introduction of carbon trade measures has been the default proposition from academics to ameliorate these concerns. However, another way is to define the task of decarbonizing EIIs as a global task and not as a purely national matter and to cooperate internationally. In this paper we analyse what it takes to decarbonize energy intensive industry and what implications this transition can have for trade. From here we explore the opportunities for enhanced cooperation for deep decarbonisation for EIIs within the Paris Agreement. We argue for international cooperation by establishing a green materials club that would focus on long-term technology development. This could be a viable way to ease the current short-term conflicts and mitigate the need for carbon tariffs. However, a green materials club should still be a part of a wider discussion around what is considered fair trade practices under the climate convention and how this relates to national interest and industrial policy for the decarbonisation of basic materials production.

Nyckelord/Keywords

Energy intensive industry, deep decarbonisation, EU, sectoral approaches, climate policy, Climate Clubs

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Content

1. Introduction

The 2015 Paris Agreement states that the concentration of greenhouse gases in the atmosphere should be limited to a level that corresponds to an increase of the global temperature not more than 1.5 to 2 °C above the pre-industrial average levels (UNFCCC 2015). In practice this means that global greenhouse gas (GHG) emissions need to be reduced to zero between 2050 and 2070 and thereafter become negative (IPCC 2018).

Under the common responsibility of all countries to jointly fulfil the overarching goal of the agreement, each party (country) sets their own targets and communicates these as Nationally Determined Contributions (NDC) to the UNFCCC. These NDCs are voluntary in nature but follow the basic principles of the original framework convention from 1992 (UNFCCC 1992). The most central principle in the framework convention (UNFCCC) related to the aim of this paper is article 3 that stipulates that all parties have a "*common but differentiated responsibility according to their respective capabilities*" (CBDR). In practice, this has meant that industrialised countries should take a greater responsibility and mitigate GHGs faster compared to developing countries. In the first implementation phase of the UNFCCC, the 1997 Kyoto protocol, the principle of article 3 was implemented by way of putting industrialised countries (Annex 1 in the Kyoto-protocol) under binding reduction targets whereas developing countries (non-Annex 1) had no targets and were allowed to increase their emissions. This "burden sharing principle" led to a discussion on carbon leakage, i.e. that increasing cost of carbon would lead to a shift in production from countries with binding climate reduction targets to countries with no binding targets. The consequences of carbon leakage would be less GHG-reductions than anticipated, loss of competitiveness and thus political costs for Annex 1 countries. It was feared that in worst cases, carbon leakage might even lead to an overall net increase in emissions. Not all industries are equally exposed to the risk of carbon leakage. The EU, for example, has identified the industries that are "at risk of carbon leakage" which mainly includes all energy intensive industries (EIIs) such as steel, cement, aluminium, petrochemicals, oil extraction and processing, and fertilizers.

The EU fulfilled its commitments under the Kyoto-protocol by reducing GHG emission with 11.7% by 2012 (EC 2020a). Several studies tried to estimate if there was any evidence of carbon leakage in the EU due to climate policy. The conclusion was that at least up to 2011 no strong evidence for this exists (Bolsher et al 2013)[1]. The lack of any evidence of carbon leakage so far can be explained by that the EU introduced several measures to shelter the EIIs from the direct and indirect carbon costs induced by climate policy. Measures included free allocation of emission allowances within the EU ETS, exemptions from levies for renewable electricity expansion, partial exemption from energy taxes, and financial support to increase energy efficiency (Åhman and Nilsson 2015).

The EU has far adopted the most stringent and comprehensive climate policy among industrialised countries with strict targets for 2030 and a long-term strategy for achieving carbon neutrality 2050 (EC 2019). Reducing the risk of carbon leakage as the EU has done by sheltering domestic industries from the direct and indirect carbon costs will only work for a limited time. Eventually, as EU climate targets

[1] The discussion on carbon leakage becomes more complex if we not only include "operational leakage", i.e. short term reductions in production volumes, but also includes the long-term effects of "investment leakage", i.e. that industries increases their investments outside the EU due to the high carbon costs. Investment leakage is much more difficult to decompose from other factors driving foreign direct investment, but the few studies done so far have not seen any major evidence of investment leakage either (Koch and Basse Mama 2019).

gets stricter, the shrinking carbon budget of the EU ETS will require EIIs to invest in advanced mitigation options that will make their production more costly. As an alternative the European Commission in its Green New Deal (EC 2019) suggests the implementation of a border carbon adjustment mechanism. Put simply, such a mechanism would tax imported products relative to their carbon footprint. Adjusting for this cost differentiation vis-à-vis imports at the border with "border carbon adjustments" (BCA) based on the embodied carbon content of a product could in principle level the playing field on the EU market[2].

The discussions on whether a BCA is compliant with WTO rules has been going on for a while and most legal analysts agree that, if designed right, a BCA could very well survive a challenge in the WTO (Cosbey et al. 2019, Mehling et al. 2019). However, the WTO is not the only international treaty that we need to consider here. Also the UNFCCC states that "*measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade*" (art 3.5 in UNFCCC 1992). From a UNFCCC perspective, BCAs are not forbidden but neither endorsed (Bodansky et al. 2017). The UNFCCC is especially concerned about negative impacts for developing countries and at COP17 in Durban, India tried to introduce a text that would expressively forbid trade measures, but this was not accepted (Bodansky et al. 2017). The trade discussion within the UNFCCC is not resolved and continues. Eckersley (2011) points out the underlying trend for increasing industrial production in developing countries exists for several reasons including developing country industrialisation which a BCA design that respects the principle of CBDR must consider. Åhman et al. (2017) argues that whether BCAs are compatible with CBDR, for EIIs it all comes down to the interpretation of what is "differentiated responsibility" in terms of industrial development including the right to both export markets and to strategic industrial policy interest.

Associated with the introduction of BCAs is the idea of establishing "climate clubs". The idea of a climate club is that a group of countries with similar climate ambitious, who join together and impose carbon tariffs on trade for non-members (see e.g. Nordhaus 2015, Victor 2011). The benefit of joining the club and accepting to impose high national climate legislation would be to avoid the tariff (the "club good"). This would, according to the proponents, create momentum where more countries join and adopt binding climate targets as the benefits of joining the club (free trade) outweigh the cost of domestic climate policy. Most ideas around climate clubs centre on imposing trade restrictions as the main leverage point and thus the avoidance of BCAs as the "climate good". However, as shown by e.g. Sabel and Victor (2017), Hovie et al. (2016), Green (2017), and Prakash and Potoski (2007), the idea of Climate Clubs could also include more nuanced and positive views on what could constitute a climate good such as sharing intellectual properties rights, free access for renewable energy or simply good reputation.

In this working paper, we explore the potential for developing a "green materials club" with the aim to support the adoption of green industrial policies for deep decarbonising of EIIs as a part of the global climate policy framework (UNFCCC). The starting point is the climate club idea, but with a wider set of "positive club goods" instead of using the threat of BCAs as the main leverage point. We argue that a green materials club could create increasing returns for progressive members and build an international momentum for deep decarbonisation of EIIs. This would be a viable way to ease the current conflicts

[2] From a company perspective, a BCA needs also be complemented with a carbon credit at the border so not to disadvantage EU manufacturing on export markets.

between ambitious national climate targets and protecting the carbon leakage exposed EIIs and thus reduce the need for BCAs or even make them redundant.

This paper begins with a description of systemic barriers (both technical and institutional) and of what it takes for a deep decarbonisation of energy intensive industries. In section 4 and 5 we review which industrial sectors are important from a trade and carbon intensity perspective and how EIIs have been dealt with in the UNFCCC negotiation process. From here, we analyse the opportunities for developing a green materials club as part of a "cooperative sectoral approach" within the current Paris Agreement. We base this analysis on the idea of building "winning coalitions" for climate change laid out by Levin et al. (2012) and Meckling et al. (2015) Throughout the paper, we adopt an EU perspective.

2. Pathways to deep decarbonisation of EIIs

The production of basic materials such as steel, cement, aluminium, petrochemicals and fertilizers account for approximately 22 % of global GHG emissions (Bataille 2019). Global demand for basic materials is projected to further increase in the future (Fischedick 2014). Several approaches need to be pursued simultaneously in order to reduce emission for this sector including increasing recycling and circularity, reducing demand through material efficiency, increasing energy efficiency along the whole value chain, and reducing both the combustion and the process emissions from both primary and secondary production routes. Deep decarbonisation of energy intensive industry will mean that major technological shifts will have to occur within these industries including transforming some core production processes.

Several technological options are currently explored that all require R&DD efforts to demonstrate functionality and competitiveness in the coming 5 to 10 years (Bataille et al. 2017; Wyns and Axelsson 2016; Napp et al. 2016). The measures envisioned for deep decarbonisation of EIIs are just not about substituting specific components but require technological change in the very core processes of producing basic materials and will thus be systemic, i.e. will require changes to all surrounding systems that support this technology such as infrastructures, regulations & market regimes.

The technical options available for a deep decarbonisation in industry can be structured as:

(i) *Electrification:* Avoiding fossil energy/feedstock at all by shifting the production process to the use of renewable electricity, either directly or via e.g. hydrogen
(ii) *Biomass:* Replacing fossil energy/feedstock with the various types of biomass-derived energy carriers or feedstock
(iii) *CCS/CCU:* Maintaining fossil-based production processes but reducing emissions by adopting carbon capture and storage/utilization technologies

Electrification is currently the option with most optimism around. This optimism has been driven by the rapid decline of renewable electricity costs the past 10 years (IRENA 2019) and the view that the techno-economical potential for expanding renewable electricity production is less limited compared to expanding biomass use or adoption of CCS at large scale (Lechtenböhmer et al. 2016). Much still speaks for CCS in regions with access to storage and infrastructure, but CCS has suffered from poor acceptability in the countries where actual investments have been done, resulting in wavering political support, economic uncertainties and stalling investments (Åhman et al 2018). Biomass will be needed as part solution everywhere but the amount of available biomass for industry or energy will be limited if sustainability is to be taken seriously. How much global bioenergy can be produced under sustainable conditions is still being debated (Wang et al. 2019).

Examples of systemic shifts in the energy intensive industry are the replacement of blast furnaces with a new system around hydrogen direct reduction for steel (Vogl et al. 2018), shifting from fossil feedstock to "electric feedstock" for chemicals (Palm et al. 2015), or rebuilding cement kilns for capturing CO_2 from flue gases (Rootzén and Johnsson 2016). Biomass as an energy source can be used for many applications in industry with varying needs for further processing but can also substitute fossil feedstock for the chemical industry (Cherubini and Strömman 2011). Another "systemic change" required is the building of infrastructure for supporting the supply of new energy carriers at scale such as electricity, hydrogen or biogenic CO_2 and the abandonment or repurposing of old infrastructures (harbours for coal, oil storages etc.).

Decarbonising industry will come at a cost but how much will differ from sector to sector. Steel and cement could be made carbon neutral for about 50 to 80 euros/ton CO_2 (Vogl et al. 2018, Rootzen and Johnsson 2016a). Petrochemicals would require higher CO_2 prices in order to motivate a shift from fossil to renewable feedstock (electricity or biomass) of around 200 to 300 Euros/ton CO_2 (Palm et al. 2015).

3. Unlocking fossil dependency and the need for a green industrial policy

The path-dependent process (Pierson 2000) of using fossil fuels for energy and feedstock has been going on for centuries and has resulted in a strong lock-in of industry. Carbon lock-in is based on technical and economic realities but also the co-evolution of technology and infrastructure with institutional regimes (Seto et al. 2016, Unruh 2000). Breaking carbon lock-in is challenging but recent developments in renewable electricity generation show that it is possible. Meckling et al. (2015) argues that a pragmatic policy mix that rewards the few at the start for building up momentum has worked better as a strategy for breaking carbon lock-in compared to punishing the many via a strong carbon price. This is what has been evidenced for electricity generation, where several sequential policies including generous support for renewable niche markets (feed-in tariffs, quotas etc.) created the momentum needed to eventually break away from the incumbent large thermal power plants as the dominating option (Meckling et al. 2015)[3]. His argument is based on the theoretical underpinnings of Levin et al. (2012), who argue that policy packages should be "sticky" and thus directly attractive and makes reversibility difficult once adopted, they should "entrench" the support for a policy as the actors involved see increasing returns with the actions induced and thus increases the support for with the policy, and eventually that the policy should "expand" over time and that actors get involved. Together, these attributes of a policy build momentum and create a *positive path dependency* for low-carbon options that could challenge the incumbent carbon lock-in.

The EIIs are a case of strong carbon lock-in that has developed over a century for most industries. For EIIs, fossil fuels are not just used for energy purposes but also as feedstock for petrochemicals and further GHG emissions also come from the process itself (so called process emissions). The technical and economic dependencies arise from long investment cycles where e.g. a blast furnace, cracker or a cement kiln normally operate continuously for 18 to 23 years before they are temporarily closed for

[3] The "stick" in climate policy in the form of carbon pricing is still needed but not as a single policy instrument. This resonates with the evolution of ideas governing how we implement climate policy developing form pure neoclassical (putting a price on carbon) to be complemented with Schumpeterian arguments for a larger role of the state (Meckling and Allan 2020, Rosenbloom et al 2020).

major renovations (Wesseling et al. 2017). These assets don´t really have a fixed lifetime as long as they are relined/renovated and normally they will be replaced only due to increasing demands on size and efficiency (Lempert et al. 2002). The institutional dimension of carbon lock-in comes from the long co-evolution of regulating authorities and industrial practices. Janipour et al (2020) gives a detailed example of this from the chemical sector and Wesseling and Van der Vooren (2017) from the cement sector.

The strong carbon lock-in and the need for radical technology shifts in the industrial sector necessitate a change of attention from currently preserving industrial policies towards an industrial policy focussing on change and transformation. Industrial policy is generally defined as the combination of instruments and measures that directly or indirectly affect industrial development in a certain direction (Rodrik 2014). Based on this, a framework for an industrial policy with the *specific aim of decarbonising the EIIs* is outlined in Nilsson et al. (2020). It builds on six pillars: (i) directionality, (ii) knowledge creation and technological development, (iii) creating and (re)shaping markets, (iv) building capacity for governance, (v) international coherence and (vi) managing the socio-economic effects of phasing out carbon-intensive infrastructures. This framework provides the basic preconditions for industrial decarbonisation but leaves room for adapting to various national political contexts and to the specific industries involved.

After establishing directionality via long term climate targets and supporting climate relevant R&D, pillars (i) and (ii), EU industry has started to move in the right direction with a number of R&D projects, pilot plants and up-coming demonstration projects targeting zero emission in the pipeline. Most projects are undertaken in the EU, but other regions are preparing to follow (Bataille 2019**,** ETC 2018). The crucial aspect of reshaping or creating niche markets, pillar (iii), for green materials is still lacking in industrial decarbonisation policy around the world. Green public procurement, labelling, or/and specific support schemes resembling the support schemes deployed for renewable electricity could create niche markets for "green" materials (Vogl et al. 2020) and this is currently discussed within the EU (EC 2019). Pillar V: International coherence, addresses the issues discussed in this paper as trade policy always is a central part of any industrial policy and pillar (vi) is currently discussed under the label of "just transition" in the EU (EC 2019). A just transition for EII differs from the power sector in that it is mainly concerned with industrial restructuring rather than phase-outs and plant closures. A pathway towards a decarbonised industry is a long term endeavour that requires a sequencing of different policy measures over time (Pierson 2000; Meckling et al. 2017). These 6 pillars are of varying importance in the different stages of a transition.

4. Traded commodities and embedded carbon

The effect of unilateral climate policy on trade and carbon leakage will depend on the carbon intensity of the traded commodities, the volumes traded and the trade partners. The risk of carbon leakage is not equal for all commodities. Typically, it is energy intensive commodities that are being targeted for BCAs or other interventions. The value of embedded carbon in end-use goods is typically below 1% of the sales value (Rootzén and Johnsson 2016a, Rootzén and Johnsson 2016b), whereas the embedded carbon value for basic materials (steel, cement etc.) can be anything from 20 to more than 100 % of the sales value. The production of steel, chemicals & petrochemicals, non-ferrous metals, pulp and paper as well as non-metallic minerals accounts for more than 80% of industrial energy use as well as more than 90%

of non-fuel combustion related greenhouse gas emissions of the sectors under the European Emission Trading System (Fraunhofer ISI and ICF, 2019).

This section analyses the trade flows of embedded carbon and the impact of carbon costs for steel, cement, chemicals and aluminium in the EU. In Table 1 the share of imports/exports related to overall EU production is given and in Table 2, the top three trading partners for each commodity are displayed. As shown in Table 1, cement trade is limited due to high transport cost compared to its low sales value. In contrast, nearly all aluminium (high value product with low weight) used in Europe is imported from regions with access to low cost electricity. Imports and exports of steel and chemicals range between 13% and 24% of European production in 2018.

Table 1: Share of mass export from and import to the EU-28 on production in EU-28, 2018 (Sources: EC 2020b: MAD, CEFIC 2020, EUROFER 2019, European Aluminum 2020, Cembureau 2020)

2018	Share of export	Share of import
Cement	9%	2%
Steel	13%	17%
Chemicals	20%	24%
Aluminum	19%	659%

Table 2. Top-3 importing and exporting countries by selected products (CN-classification); total traded amount in million tons (Mt), and share of top-3 countries on total traded amount, 2018 (Sources: EC 2020b: MAD)

2018		Top 1	Top 2	Top 3	Total (Mt)	Share top3
Cement (2523)	Export	United States	Ghana	Cameroon	14,56	0,381
	Import	Turkey	Ukraine	Belarus	3,34	0,5012
Semi-finished steel (7207)	Export	Turkey	Morocco	United States	1,40	0,5811
	Import	Russian Fed.	Ukraine	Brazil	9,30	0,8984
Flat steel products (7208)	Export	Turkey	United States	Egypt	3,22	0,4552
	Import	Turkey	Russian Federation	India	10,37	0,5827
Flat steel products (7210)	Export	United States	Turkey	Mexico	3,38	0,3785
	Import	China, PR	Korea, Republic of	Taiwan	6,54	0,6136
Long steel products (7213)	Export	Switzerland	United States	Turkey	2,01	0,473
	Import	Turkey	Russian Federation	Switzerland	2,51	0,6105
Inorganic Chemicals (28)	Export	United States	Brazil	Norway	15,10	0,2839
	Import	Turkey	Russian Federation	Countries *	16,72	0,3621
Organic Chemicals (29)	Export	United States	Turkey	China, PR	11,71	0,4101
	Import	United States	Russian Federation	China, PR	25,44	0,3946
Fertilizers (31)	Export	Brazil	Countries*	United States	12,88	0,3515
	Import	Russian Fed.	Egypt	Belarus	17,98	0,5356
Plastics (39)	Export	Turkey	China, PR	United States	20,83	0,3059
	Import	China, PR	Saudi Arabia	United States	17,63	0,4215
Aluminium (7601)	Export	Switzerland	Japan	Serbia	0,31	0,6136
	Import	Norway	Russian Federation	Iceland	6,36	0,5307

Countries* = Countries and territories not specified for commercial or military reasons in the framework of trade with third countries For a more detailed analysis sub-categories of steel and chemicals were chosen, i.e. semi-finished -, flat-rolled -, and long rolled steel as well as inorganic and organic chemicals, fertilizers and plastics.

As can be seen from Table 2, the Russian Federation and the United States stand out as countries with which the EU-28 trades a large variety of basic materials. These two countries are seven and nine times, respectively, among the top-3 trading countries with the EU-28 in 2018 followed by Turkey. It is important to note that all these countries are defined as Annex 1 countries in the UNFCCC and should thus in theory strive for similar climate policy ambitions as the EU.

The majority of import countries lie within the vicinity of the European Union. Exemptions are the US, as mentioned above, imports of chemicals from China and steel imports from Brazil and India. Certain high value steel products (CN 7210) are also imported foremost from China, South Korea and Taiwan. Key export destinations for basic materials are neighbour countries such as Turkey, Morocco or Egypt. While some steel and chemical products are imported from overseas, mainly chemicals are exported to far away countries like Brazil and China. Mexico and the US are transatlantic importers of European steel in primary forms (World Steel Association 2019**)**.

While most of the analysed trade is unidirectional, i.e. that a product is either imported or exported from and to another country, this is not the case for organic chemicals and plastics that are both intensely exported and imported with the US and China.

In Figure 1, the embedded carbon in basic materials exported from or imported into the EU-28 are shown. Steel stands out with 60 Mt of embedded carbon imported. The carbon balance is especially uneven for semi-finished and flat-rolled steel. Increasing the imports of semi-finished steel could be one example of carbon leakage, as the energy-intensive step (iron ore reduction) is done in regions with less strict climate policy and the intermediate product is then imported to regions with ambitious climate legislation, e.g. the EU-28. On the other side, some imports are beneficial from a climate point of view. The EU-28 imports the majority of its aluminium from regions with lower CO_2 intensities of the electricity such as Norway and Iceland. Moving the production of energy- and CO_2-intensive materials to regions with access to low-carbon energy is one way to mitigate global CO_2 emissions.

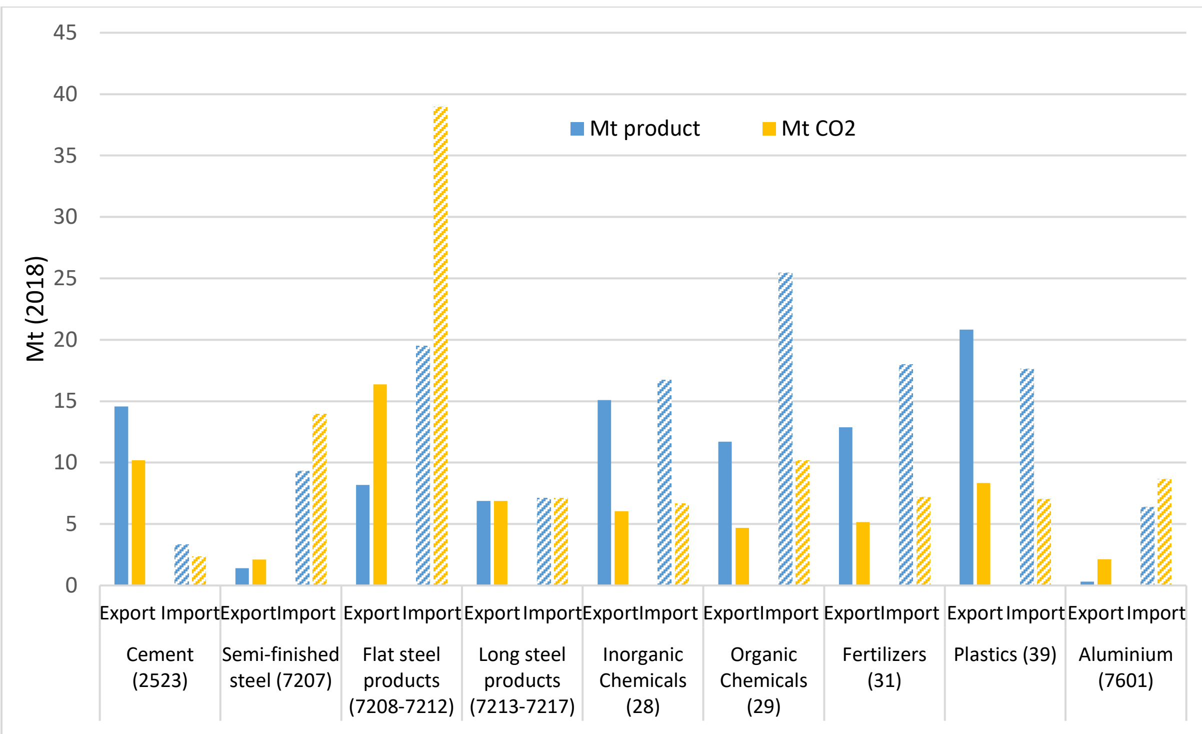

Figure 1 Import to and export from EU-28 in Million tons (Mt) by 2018 and respective associated CO_2 emissions by selected product categories (Combined Nomenclature) (sources: EU 2020b: Market Access Databased; assumptions on specific CO_2 emission factors by product in Annex)

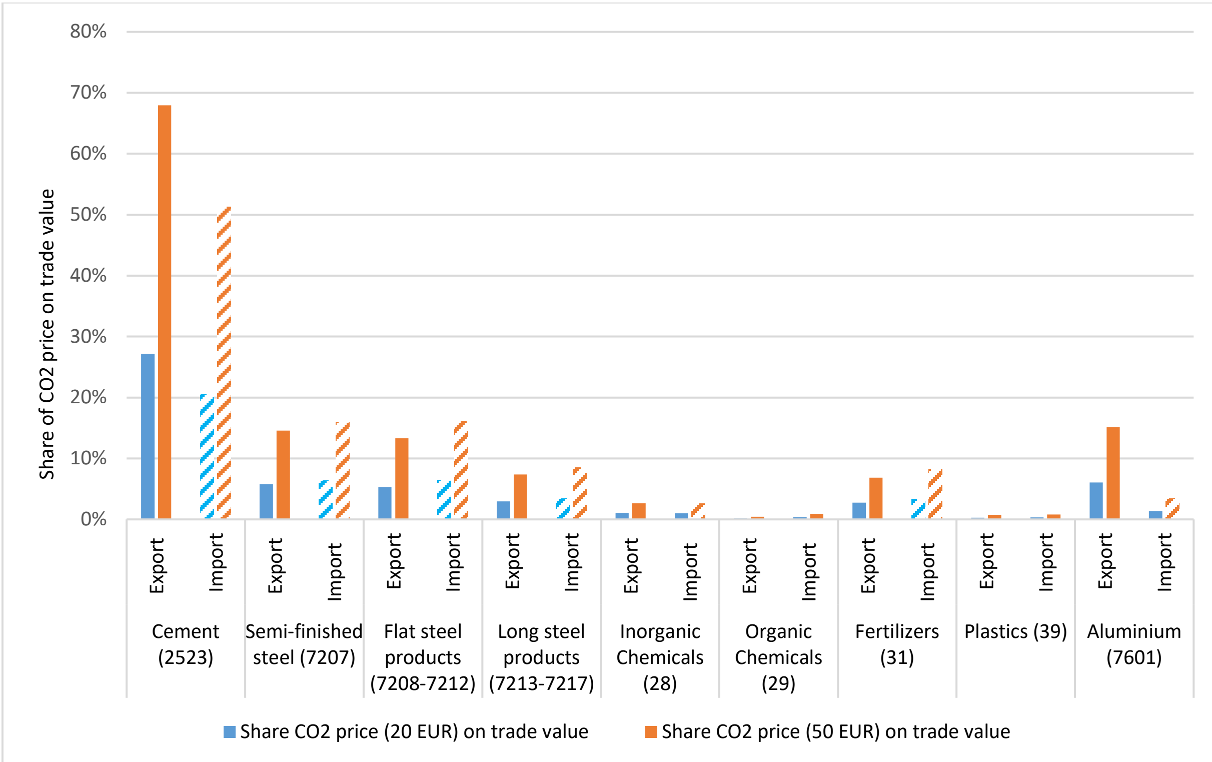

Figure 2. Impact of a CO_2 price of 20 / 50 Euros per ton of emitted CO_2 on selected products (CN classification) on trade value by 2018 (source: EC 2020b: MAD, assumption on specific CO_2 emission factors by product in Annex).

In Figure 2 the effect of an assumed carbon price compared to the sales value for basic materials are illustrated. It shows that these materials are exposed to carbon prices to varying degrees. Chemicals, with the exception of fertilizers, should be invariant against carbon pricing due to the higher value of their products. The same accounts for imported aluminum as it comes from regions with low CO_2 intensities of the electricity grid. On the contrary, cement is highly affected by pricing CO_2 as its value is comparably low. However, cement is not traded as intensively as steel, chemicals or aluminum (see Figure 1 and Table 1 and 2). Among the selected products, steel, especially flat-rolled steel that is more CO_2-intensive than long rolled steel, is the material that is most sensitive to carbon prices according to our analysis. Current prices of about 20 Euro per ton of CO_2 make up 5% to 6% of its value. A carbon price of 50 Euro would have an impact of 13% to 16% of its current value.

The EU-28 imports more embedded carbon in basic materials than it exports, 102 Mt CO_2 versus 61 Mt CO_2 respectively (see Figure 1). Compared to EUs overall emissions of 4,294 $MtCO_2eq$ in 2018, the net-import of embedded carbon in basic materials is relatively marginal. The main imports of embedded carbon comes from consumer goods that are not as sensitive to increasing carbon costs. The EU estimates that EU-27 avoids ca. 400 $MtCO_2eq$/year by our total import of goods for our consumption from outside the union (Eurostat 2020).

The different basic materials face different challenges as they are not equally exposed o international competition. Steel and aluminum are both highly traded on a global market and a carbon price will have a substantial effect compared to the sales value. For cement a carbon cost would have an even greater effect compared to sales value. However, cement is traded only in limited amounts and only with EU neighboring EU countries. Chemicals are a special case when it comes to trade and the risk of carbon leakage – crude oil can be replaced with natural gas (already happening) but otherwise a relatively domestic industry with limited trade and low carbon to value risk.

4.1 Future trade of low carbon commodities

Access to renewable electricity will be a key resource for deep decarbonisation of EIIs (Lechtenböhmer et al 2016, IRENA 2019). As a consequence, this could change the comparative advantage between countries. Countries and regions with favourable conditions for developing low-cost renewable electricity are, for example, Australia, Saudi Arabia, Northern Africa, Chile (Bogdanov et al. 2019; IRENA 2019). These countries might from an industrial policy perspective want to move up the value chain rather than exporting renewable electricity or biomass but also intermediate basic materials products that have a higher value.

Shifting the production geographically due to climate change mitigation policy is thus not always bad for climate but can in certain cases be motivated as earlier in the case of aluminium production in Iceland and Norway. In a long term perspective, moving production to countries with higher potentials for biomass or renewable electricity could be beneficial for GHG mitigation. Old industrial regions have often been developed around certain strategic resources such as access to coal that needs to be abandoned to avoid dangerous climate change.

New intermediary products based on access to renewable electricity can emerge as a consequence. An example would be to trade DRI (direct reduced iron) from countries with good renewable resources to countries with downstream processing (e.g. rolling). Gielen et al. (2020) make the case for Australia to shift from exporting iron ore to exporting DRI (sponge iron) produced with renewable electricity. Renewable ammonia or hydrogen as feedstock for fertilizers and petrochemicals might also become future commodities. Gidey et al. (2017) and Armijo and Philibert (2019) argue for green ammonia production based on renewable hydrogen that could compete with fossil alternatives in scenarios with low electricity prices. Natural gas as a feedstock for petrochemicals and DRI and ammonia based on natural gas are traded in smaller quantities already today. A challenge in the future will be to allow trade in cases where relocation and geographic change can be positive for the climate and to privilege future green commodities such as green ammonia and DRI from “brown” ammonia and DRI.

5. Energy intensive industry: what has been tried in negotiations so far?

5.1 Pre-Paris: Burden sharing and carbon trading

Global greenhouse gas emissions from the energy intensive industries have seen a steady increase the past 20 years despite existing climate targets (Crippa et al. 2019). In the EU and the US, emissions from energy intensive industries have been declining slowly, partly due to increasing energy efficiency but also partly due to structural changes (Lapillone et al. 2012, Arens et al. 2012).

Several initiatives in the negotiations were put forward on how to deal with these industries in the time period when the post-Kyoto architecture was discussed (around 2005 to 2009). These initiatives had in common targeting only specific sectors instead of the whole economy, so called “sectoral approaches”. In Table 3 below an overview of the various approaches tried in the negotiations is given. The sectoral approaches are grouped after whether they were primarily linked to the adotion of *carbon trading*, *technology development*, or a set of wider *policies and programs* and how the issue of differentiated responsibility was dealt with in the proposals.

Table 3. Summary of proposals and initiatives with a sectoral focus pre-COP 15. Adapted from Åhman et al. (2017)

Sectoral Approaches linked to :	Proposals	Differentiated responsibility (art 3 CBDR)	Status
Carbon trading	EU-sectoral crediting	Efforts required by developing countries (15-30% below BAU)	Failed
	New Market Mechanisms (NMMs)	Undefined – varying and voluntary	Survived partly via the NDC concept
	Sectoral-CDM	All responsibility on industrialized countries (Kyoto-style)	Failed at the time but discussed again
Technology development	Japanese sectoral approach ("carve out model")	No differentiation at all	Failed
	Asia Pacific Partnership (APP)	No differentiation as no targets (only information sharing)	Abandoned, but never part of UNFCCC process
Policies and programs	SD-PAMs (Sustainable Development – Policies and Measures)	All responsibility on industrialized countries (Kyoto-style)	Not accepted by Annex-1 but resembles NAMAs and NDCs
	National Appropriate Mitigation Actions (NAMAs)	Undefined / varying and voluntary	A part of NDC concept

For more details on the various approaches, see Åhman et al. (2017), Meckling and Chung (2011) or Schmidt et al. (2008).

Some industrialized countries (EU, Japan and the US) suggested several sectoral approaches that meant that developing countries should shoulder some, or even equal, mitigation responsibility compared to industrialized countries for decarbonizing the targeted sectors. The EU based their suggestions mostly on linking sectoral approaches to carbon trading with some differentiation between Annex 1 and non-Annex 1 countries whereas both Japan and the US favored sectoral approaches linked to technology development and with no differentiation such as the Japanese "carve out model" and Asia Pacific Partnership (APP). Developing countries (non-Annex 1) put forward suggestions (mostly via South Africa) that focused on broader development issues and increasing opportunities for identifying and attracting international climate financing (SD-PAMs, then later NAMAs).

All proposals had their own interpretation of how respective "*differentiated responsibilities*" should be viewed in the post-2012 agreement. The Japanese technology oriented carve out model or the EU's ideas of a sectoral crediting mechanism with "*no lose targets*" for non-Annex 1 were never accepted by the relevant parties as the sensitive issue of what is a fair distribution of responsibilities and costs was not resolved. In the negotiations up to Copenhagen 2009, non-Annex 1 countries at the time could not accept any share of the mitigation responsibility as was suggested both by the EU, Japan and the United States and all sectoral approaches for levelling the playing field (e.g. equalizing the carbon cost) were rejected in the post-Kyoto negotiations (Åhman et al. 2017). Approaches linked to policies and programs have survived in various forms in the Paris Agreement as the voluntary effort sharing principle resembles the bottom-up approach in the Paris Agreement.

5.2 Paris Agreement and global cooperation

When the Paris Agreement was signed in December 2015 this marked a shift to abandon the top-down architecture[4] from the Kyoto-protocol and instead opt for a bottom–up and voluntary architecture. The Paris Agreement sets the overarching goal (1.5 to 2 °C) but leaves up to each country to set their own

[4] Top-down architecture: CO_2-targets and timetables set centrally by the COP for all parties; bottom-up architecture: parties defines their own CO_2-targets and timetables based on their "respective capabilities"

targets with the overarching idea that they should respect the principles of the convention. The architecture of the Paris Agreement relies more on deeper cooperation among parties and puts less emphasis on “burden sharing” compared to the period with the Kyoto protocol (Keohane and Victor 2016).

After the failed Copenhagen meeting (COP 15) in 2009, there was a surge in activity by individual countries and organizations for developing “new market mechanisms” and “NAMAs” as they seemed most acceptable to all countries. Several pilot programs were launched exploring new ways to cooperate around climate mitigation and to make countries “carbon market ready” or “climate finance ready”. These projects, mostly in energy and waste sectors, have helped in building institutional capacity in data collection, creating an awareness of mitigation options and climate financing options in recipient countries (ADB 2018, Climate Focus 2019).

In the Paris Agreement, the discussion on global cooperation for advancing mitigation is taking place within the scope of article 6. The details of how to operationalize the Paris Agreement including article 6 is negotiated and will be deliberated in a rule book that was set to be finalised by December 2019. The final details are still pending (at the time of writing, December 2020) and one of the contentious issues still not resolved is related to article 6 and especially carbon trading and accountability.

Article 6 establishes three different strands of cooperation on mitigation. First, the cooperative approach (Art. 6.2) that allows governments to work together and thereafter exchange “ITMOs[5]” to meet their stated NDCs. Cooperative approaches within art. 6.2 should focus on ITMO trade between governments. The second established mechanism in Article 6.4, coined Sustainable Development Mechanism (SDM). It is project-oriented and represents a continuation of the programmatic-CDM schemes. Here, the focus is on creating a carbon market based on credits and open to strong participation from the private sector. The SDM, strongly resembling earlier ideas of SD-PAMs, requires UNFCCC oversight and government involvement even though it is oriented towards the private sector. The last mechanism (art. 6.8) is based on supporting “non-market” approaches. This approach is still undeveloped but could include technology cooperation and information sharing. The Paris Agreement also includes a technology mechanism (art.10) that sets a foundation for technology cooperation. So far, this mechanism has worked with technology transfer in terms of information sharing and building capacity via e.g. technology needs assessments (TNAs) and not focused on more R&D oriented novel developments (Glachant and Dechezlepretre 2016).

6. Towards a Green Materials Club

In the context of the Paris Agreement, a variety of voluntary sectoral approaches based on the concepts of climate clubs and focussed on innovation have been suggested as a possible way forward by e.g. Åhman et al. (2017), Hermwille (2019) and Victor et al. (2019). Below we outline how a “green materials club” could develop through deliberately creating path dependency on a low-carbon pathway for the EIIs. The idea of a green materials club is to create a “winning coalition” among nations willing to implement a green industrial policy with the aim to decarbonise the EIIs as outlined by e.g. Nilsson et al. 2020. A green materials club can be developed as a part of article 6.2 on cooperative approaches between a select number of parties within the UNFCCC. However, a club does not necessarily need to be formally attached to the UNFCCC in order to be effective.

[5] ITMO: International Tradable Mitigation Outcomes

6.1 The functions of a green materials club

We base our assessment on the functions of a green materials club on the framework put forward by Levin et al. (2012), who argues that climate policies should be designed so that they stick immediately, entrench support and expand their reach over time. In an international climate club context, stickiness refers to the ability of a policy intervention to attract and lock-in the support of the first members to a club by providing an immediate benefit and avoiding short-term costs. Entrenchment refers to a logic in the design of a club that produces increasing member support over time and the start of a low-carbon lock-in. Finally, expansion means that it must be in the club members' interests to expand the club further, and in the interest of non-members to join the club.

A club would need to start with a small number of parties that already have the ambition to decarbonise EIIs and that want to become green industrial leaders. The presence of such initiatives already today points to the direction that such interest exists, see e.g. LeadIT[6] (UN 2019), Mission Innovation and the Energy Transition Commission (ETC 2018) that have several country and business members committed to net-zero emission to 2050 and beyond. *Stickiness* for these already ambitious countries can be achieved committing to presenting roadmaps and visions to showcase ambition and opportunities. These can be developed jointly by policy makers, industry and other relevant stakeholders. A vision of how to technically decarbonise EIIs regarding the respective local contexts provides the needed directionality for industry and a shared basic understanding of the level and forms of public support needed to reduce policy risk. To join the club and to develop and publicly communicate these visions can be considered a "no lose" option for ambitious countries and a start of a wider discussion of how to formulate the content of a future green industrial policy. Reversal will still be possible but unlikely and difficult as the first members will want to appear as leaders.

Entrenchment is achieved when the visions are followed by real investments in R&DD such as water electrolysis or heat pumps, or investing into collaborative pilot and demonstration projects. Investments into low-carbon technologies in industry can produce stickiness, as industries with sunk costs on their balance sheets will hold their governments accountable for the promised pathway. A club member can enjoy "climate finance readiness" status for multi- or bilateral climate support. Entrenchment is also achieved when the planning and future investments of infrastructures (power grids, pipelines) are aligned to support a low-carbon pathway.

For *expansion*, a club need to be increasingly attractive for more countries and industries to join. The "carrot" in most suggested climate clubs so far have been the avoidance of BCAs. However, in our case we see the biggest carrot being (i) access to finance (via e.g. multilateral banks or bilateral funds) for key infrastructures in line with industrial decarbonisation and (ii) access to policy-created green niche markets. Creating (or re-shaping) niche markets to favour "green" materials is a key component in a green industrial policy for reducing risks for industrial leaders and to learning for reducing costs further. Niche markets for green materials do not yet exist[7] but are being discussed in the EU by methods of e.g.

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[6] The Leadership Group for Industry Transition was founded by the Indian and Swedish governments at the 2019 UN Climate Action Summit. see www.industrytransition.org

[7] Early developments can however be seen such as the setting up of a market place for "green aluminium" at the London Metal Exchange, see https://www.ft.com/content/e11cdc46-fda3-445d-a323-69e4f9c6012b?sharetype=blocked

green public procurement, contract for difference, quota obligations, or a materials tax (Vogl et al. 2020; Bataille 2019; EC 2019). Green niche markets are an example that can enable both entrenchment and expansion. As more members take part in supply and demand of green materials, the benefit for members grows and the disadvantages of staying outside the club increase. Although the inclusion of new members intensifies the competition for club producers, also the size of the green markets increases, allowing for trade of more a diversified selection of goods. By expanding the reach of the club, countries should be able to put the comparative advantage earned through early membership to use.

These anticipated dynamics mean that a green materials club would need to adopt a strategic sequential framework, i.e. that the club and its policy initiatives will have to evolve over time both in strength and in form. A sequential framework would allow the club to strengthen their ambitions following the logic of the Paris Agreement. As an example, access to green niche markets could only be available once these are implemented and functioning. Another example would be how to address future BCAs in this context. Agreement on BCAs or other trade measures could be a part of a green materials club but would not be intended to be the prime motivator for joining. However, as momentum builds and the need for deep decarbonising of the EIIs is more widely seen as both possible and inevitable, BCAs could be used as could be used as a "last leverage point". BCAs might also ease the separation of "brown" versus "green" energy intensive intermediates in global trade that are likely to increase such as ammonia, hydrogen and reduced iron (DRI/HBI).

6.2 Risks and factors determining success

The long-term success of a green materials club depend on if technical development and investments in infrastructures will reduce the costs of low-carbon options and thus if it will become increasingly attractive to join the club over time. An underlying assumption to this is the emergence of a globally growing awareness and demand for green basic materials that will strengthen this positive trend. These factor will, if successful, create increasing returns towards net-zero basic materials that eventually can break the existing fossil based carbon lock-in.

There is always a risk of prematurely "picking winners" when governments adopt a technology policy that supports a development path that is not ambitious enough and will instead lead to a premature carbon lock-in or entrench existing carbon lock-ins. An effective green industrial policy must adopt a strategic view on near-term actions that will give directionality and enable future developments aligned with the Paris Agreement. A transparent vision in form of a roadmap that outlines the pathways possible to reach net-zero emission within the stated time frame will disqualify some technical options that will lead to a premature carbon lock-in. A difficult choice here will thus be on how to define what a "green development pathways" looks like and make it ambitious enough so just not to support incremental change and further lock-in into carbon intensive structures. Vogl and Åhman (2019) present an example of how this assessment can be done for green steel in the EU.

A green materials club will still need to overcome the always present issues of fairness in global climate negotiations. A club must have an understanding of "fair trade" that includes each member's right to industrial development and industrial policy. Agreeing on a "common but differentiated" green industrial policy will involve several sensitive issues such as trade, domestic direct or indirect subsidies, privileging national champions in public procurement etc. Several developing countries give advantages to their industries as part of an industrialization strategy but e.g. in India, industry rather support other social objectives such as agriculture. With regards to the debate of avoiding relocation and carbon leakage, a club needs to consider that in the future there could be several cases of relocation of EIIs to regions with better access to e.g. renewable electricity that will have a climate benefit.

6.3 Membership qualifications

There are at least two minimum requirements that are needed for a membership in order for a green materials club to become effective and help countries reach the goals set out in the Paris Agreement. The first requirement is a commitment to the long-term target of developing EIIs with a net zero carbon footprint that is compatible with the Paris Agreement. This ambition will need to reflect that net-zero emission in EIIs will not be achieved over night but that it takes time to prepare, develop, test and demonstrate before being implemented and that there will be a variety of options for each material as well as large difference between different materials.

The second requirement is a commitment to jointly work on openness and accountability rules for data and carbon footprints from the targeted sectors. This can be a sensitive issue but is important for international credibility. Access to data will also have the effect to empower stakeholders such as NGOs and academia outside the formal membership to influence the direction of policy (Dai 2010). For the same reason, the transparency of visions and roadmaps is important for increasing credibility for government support as well.

Club membership is foremost directed toward nations/parties to the convention as they have the competence to implement the wide scope of interventions needed in a green industrial policy. However, a green materials club should also welcome industries and multilateral institutions as members. Both are needed and can play different parts as enablers for financing, technology expertise to the negotiations, and technology transfer.

7. Conclusions

The global policy response for mitigating greenhouse gas emissions in energy intensive industries have so far been weak. EIIs are stuck in a “carbon leakage trap”: One the one hand, ambitious national climate policies are needed to spur action, on the other hand, fears of losing competitiveness in global markets scare away these very policies. The dominant suggestion for how to exit the trap has been to implement border carbon adjustments. This could reduce the carbon leakage risk and thus enable higher domestic climate ambitions, but both the practical effectiveness and the acceptability of BCAs in the negotiations is still unclear. BCAs will not be a panacea for these sectors but risk being a relatively blunt instrument if implemented. The architecture of the Paris Agreement emphasizes and puts more hope on global cooperation for innovation compared to only recommending various ways of pricing carbon. For the EIIs to be compliant with the ambitions set out in the Paris Agreement, the current fossil lock-in of the EIIs needs to be broken and a new path pathway towards future net-zero for EIIs must be established. This will require a green industrial policy with the specific aim of decarbonising EIIs. Such a green industrial policy will include a comprehensive set of sequentially adopted policies.

In this context, we propose Green Material Clubs especially designed for deep decarbonisation of the EIIs as a part of a voluntary cooperative sectoral approach in global climate policy. The idea of a green materials club is to create a “winning coalition” of member countries that will implement green industrial policies. The activities of such a club would be to start relatively easy with developing and adopting long-term deep decarbonisation visions or roadmaps for EIIs that are grounded in the respective local contexts. After that, the support of these pathways for deep decarbonisation of EIIs would be entrenched with dedicated support for R&DD and e.g. infrastructure planning. In order to be effective towards the Paris target, a green materials club would need to expand beyond the first enthusiastic members. The “carrot” for joining the club (and thus adopting a green industrial policy) would be to get access to future niche markets for green basic materials. A green materials club has the potential to create a *positive path dependency* towards deep decarbonisation of EIIs. This could be a viable way to ease the current short-term conflicts and mitigate the need for a carbon tariff. However, a green materials club would still be a part of a wider discussion around what is considered fair trade practices under the UNFCCC and how this relates to national interest and industrial policy for the decarbonisation of basic materials production.

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Annex to Figures 1 and 2

product	Trade	Mt product	Mio EUR value	EUR value/t product	t CO2/t product	Mt CO2
Cement (2523)	Export	14,56	750	52	0,70	10
	Import	3,34	228	68	0,70	2
Semi-finished steel (7207)	Export	1,40	724	516	1,50	2
	Import	9,30	4370	470	1,50	14
Flat steel products (7208-7212)	Export	8,19	6152	751	2,00	16
	Import	19,48	12072	620	2,00	39
Long steel products (7213-7217)	Export	6,89	4681	679	1,00	7
	Import	7,13	4188	587	1,00	7
Inorganic Chemicals (28)	Export	15,10	11409	755	0,40	6
	Import	16,72	13034	780	0,40	7
Organic Chemicals (29)	Export	11,71	55365	4729	0,40	5
	Import	25,44	57065	2243	0,40	10
Fertilizers (31)	Export	12,88	3772	293	0,40	5
	Import	17,98	4365	243	0,40	7
Plastics (39)	Export	20,83	57320	2751	0,40	8
	Import	17,63	44062	2500	0,40	7
Aluminium (7601)	Export	0,31	703	2247	6,80	2
	Import	6,36	12649	1988	1,36	9