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Horizon 2020 Societal challenge 5:
Climate action, environment, resource efficiency
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COP21 RIPPLES – COP21: Results and Implications for Pathways and Policies for Low Emissions European Societies

Exploring the Prospects for a Sectoral Decarbonization Club in the Steel Industry

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1. Introduction

In the Paris Agreement the world has embraced a new long-term goal in the effort to prevent dangerous climate change. In article 2.1a, Parties to the UNFCCC have agreed to "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (UNFCCC 2016, Art. 2.1a). To operationalize this goal, Parties have agreed to "reach global peaking of greenhouse gas emissions as soon as possible [...] and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (UNFCCC 2016, Art. 4.1).

The recent IPCC special report on the 1.5°C target concludes that this may not be enough to attain the temperature goal: essentially, GHG emissions need to come to net zero already by 2050 globally (IPCC 2018). While progress has been made on the power sector with an increasing role of renewable energy, much less has been achieved in energy-intensive basic materials industries in general and in the steel industry in particular. Global CO_2 emissions from the iron and steel sector (including both direct and indirect energy-related emissions as well as process emissions) were estimated at 2.41 Gigatonnes of CO_2e in 2010 (Kechichian et al. 2016). Since then, emission intensity has been reduced by about 10% between 2010 and 2017, this has been overcompensated by a substantial increase of 18% of global steel production in the same period (IEA 2019). And global steel demand is expected to increase even further. In a recent OECD report (2019), global steel production is expected to double between 2017 and 2060 in the baseline scenario. While the study finds significant potential to reduce demand through improved recycling rates, even in the improved resource efficiency scenario global production would still increase by 35% (OECD 2019). Given these trends the IEA stipulates that "Transformational change is required, and the groundwork for breakthrough technologies needs to be laid before 2030." (IEA 2019).

Time is of the essence here, because infrastructure in the energy-intensive industry is particularly long-lived. Once new fossil-fuel dependent steel making facilities are installed, they will continue to emit CO_2 for 30-40 years. Yet, the IEA concludes, in its latest World Energy Outlook, that committed global energy-related emissions, i.e. the emissions that will occur over the lifetime of the existing and currently under construction stock of energy infrastructure, already nearly consume (95%) the carbon budget assumed in the IEA's Sustainable Development Scenario. In other words, any new power plant, steel plant or any other large fossil fuel dependent infrastructure leads to emissions that move us beyond a 2°C compatible pathway. Consequently, any new infrastructure, particularly in industrialized countries, must be emission-neutral or needs to replace existing technology prematurely i.e. before the end of its technical lifetime.

For the steel industry (and many other emission-intensive industries alike), a high degree of uncertainty persists ass technologies that enable a full decarbonization of the industry still do not exist at commercial scale (Lechtenböhmer et al. 2018). What is more, the sector itself is facing substantial market uncertainty exacerbated by large oversupply resulting in a situation, where incentives to take high risk investments in innovative zero emission technologies are very low (Chalabyan, Mori, and Vercammen 2018; G20 2018). Finally, political uncertainty remains. While the Paris Agreement is clear about its ambition to decarbonize global economies in the second half of the century, significant ambiguity remains what this means specifically for emission-intensive industries and how (and whether) national governments are going to implement policies and measures to achieve that objective.

The purpose of this report is to explore what international governance can help to address this situation. Specifically, the report will explore the potential of arrangements among a limited number of actors – national and subnational governments as well as (multinational) companies – in the form of a 'transnational decarbonization club' (also see COP21 RIPPLES Deliverable 4.3c by Obergassel, Wang-Helmreich and Hermwille). We define a transnational decarbonization club as a limited grouping

- that comprises at least three country, non-state, or subnational actors from more than one country as members;
- that is formalised in terms of membership, dues, regular meetings, and tracking action;
- that delivers a club good or benefit (exclusively) to its members;
- and that significantly contributes to decarbonisation.

A previous analysis under the COP21 RIPPLES project highlighted the promise and potential for international governance in the energy-intensive industries but also found that much of this potential remains untapped by existing international institutions (Rayner et al. 2018, chap. 5). Given the dearth of international institutions specifically targeting the decarbonization energy-intensive industries, we considered that these industries would be a prime candidate to explore the potential for a sectoral decarbonization club.

We approached this question by conducting a set of explorative semi-structured conversational interviews with a total of 12 experts from national and subnational governments, academia, trade associations, and steel producing companies. In total we approached 17 experts but had only a response rate of 70%.[1]

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[1] All interviewees expressly consented to the interview and were granted anonymity. The consent was recorded by a signed consent form or through express confirmation in the audio-recorded interview. Records are available with the author.

The paper first briefly introduces the major technological pathways towards decarbonizing the steel industry (section 2.1) and synthesises the findings of our previous research on the international climate governance landscape in relation to the energy-intensive industry and related 'governance gaps' (section 2.2). In section 3 we then proceed to discuss various potential "club goods" i.e. incentives or benefits for the members of the club. Specifically we identify three areas: managing political uncertainty, sharing the risk of uncertain technologies, as well as addressing the challenge of uncertain markets. In section 4 we then dive deeper in to assess the role of different types of club members and potential membership benefits. What is in store for national and regional governments that consider joining a club, and what for companies? The role of competition is of particular relevance in this section, particularly as it may impose an important potential barrier for establishing an effective decarbonization club. In section 5 we specifically address those barriers by discussing whether and how a sectoral decarbonization club could interfere with EU competition rules, particularly on horizontal collusion and illegal state aid. Section 6 then considers the scope of a sectoral decarbonization club and weighs up whether a club should be focussed on the steel industry or cover a broader set of emission-intensive industries. Also, we discuss the pros and cons of a regional decarbonization club (e.g. focussed on the EU or even a region within it) versus one with a truly global scope. Finally section 7 summarizes the findings by recommending key features of a sectoral decarbonization club and concludes with highlighting directions for further research.

2. Study Background and Setting the Scene

2.1. Decarbonizing the steel industry

For the power sector and to some extent transportation, decarbonized alternative technologies and practices are maturing and increasingly available; the main challenge is to significantly ramp up their deployment. For many emission-intensive industries, the challenge is even more daunting: technologies of the kind that enable a full decarbonization of the steel sector are only available on lab or pilot scale and significant investment in further R&D as well as demonstration and commercialization of zero-emission technologies is required in the first place (Lechtenböhmer et al. 2016).

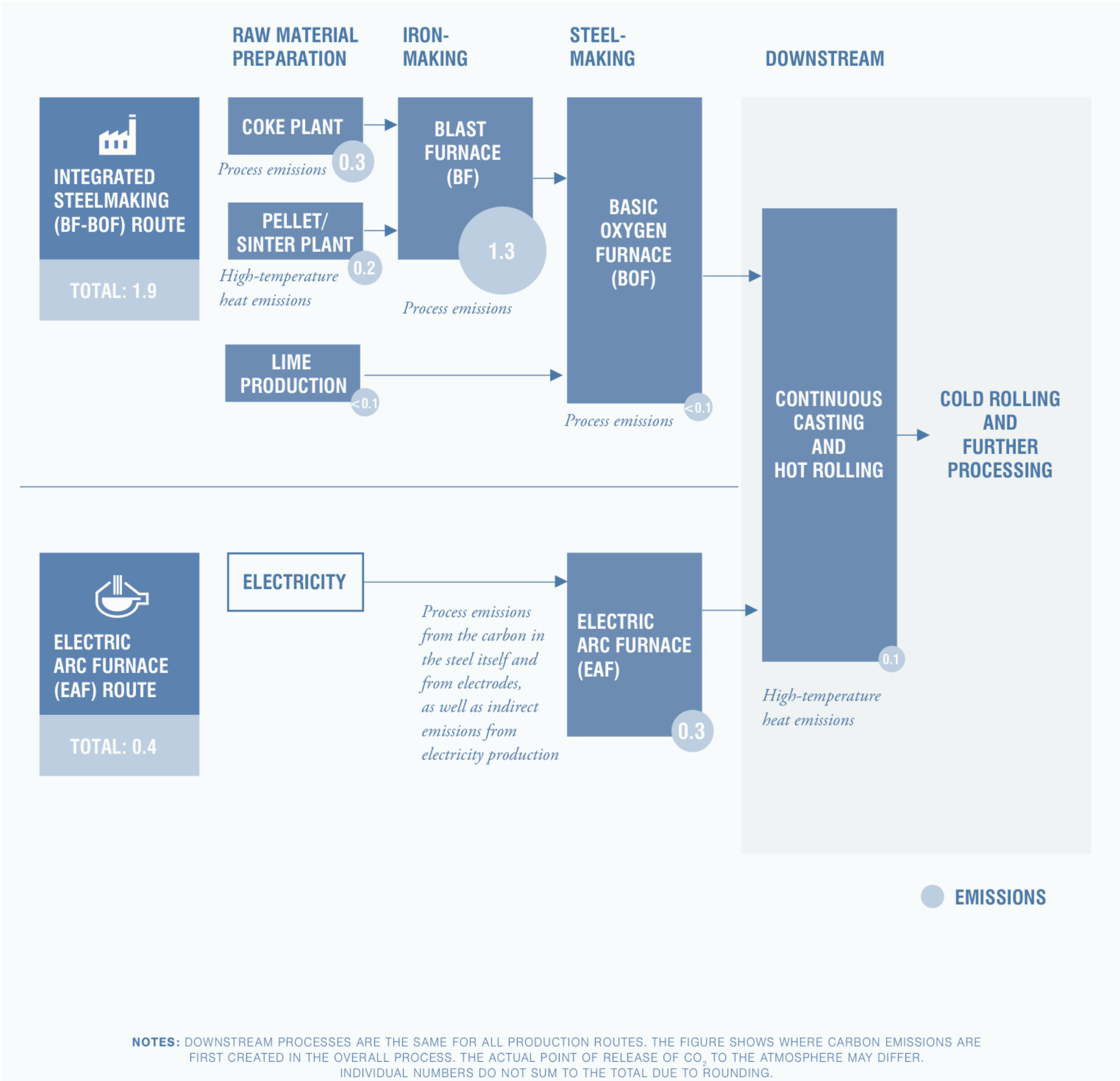

Figure 1 CO_2 Emissions from steel production; tonnes of CO_2 per tonne of steel *(Material Economics 2019, 74).*

For steel, there are in principle three types of approach that can contribute to decarbonization:

- to **reduce demand** through more lenient designs and/or alternative construction technologies requiring less steel inputs to achieve the same level of service/stability.
- to **work towards circularity** of the materials used by increasing the use of scrap and shifting supply towards using more secondary steel which can be produced in electric arc furnaces powered by renewable energy.

- and finally to develop and implement technologies that **enable zero-emission primary steel** to substitute the current highly emission-intensive product from conventional blast furnaces.

To enable a full decarbonization of the steel industry, all three strategies need to be exploited to their full potential (Material Economics 2019). But even if implementation of much more lenient product designs that rely much less on steel as a raw material is successful and near full circularity achieved, there will still be demand for virgin primary steel – be it to satisfy the growing demand in many emerging economies or for special high-grade products such as food containers or vehicle parts for which current scrap-based steel products are not suitable.[2]

International governance and cooperation may support all three of these aspects, but the focus of this paper is on the latter dimension: the supply of zero-emission primary steel. A pragmatic reason is that primary steel-making is dominated by a relatively limited number of actors. A club approach seems therefore much more manageable than working on reducing demand for steel and increasing circularity, both of which would require the involvement of a far wider range of actors across highly complex value chains. This is not to say that international governance may not be required for those aspects as well, but perhaps a club approach is not the most promising. Moreover, international spill-overs from national action on reduced demand and improved circularity are relatively fewer and therefore there is less scope and need case for international cooperation.

Now turning to technological avenues for achieving zero-emission primary steel, there are four potential pathways, none of which have proven their viability at commercial scale (Lechtenböhmer et al. 2018):

- Direct electrolysis of iron ore fines into iron (electrowinning) is perhaps least advanced technologically. The technology is currently being developed in the SIDERWIN project. Electrowinning can potentially reduce process emissions almost completely, but significantly increase the demand for electricity.
- Hydrogen direct reduction is another option being explored currently. In this technological pathway, hydrogen replaces natural gas or coal as reduction agent to produce sponge iron which, in turn, can be used as feedstock in electric arc furnaces to produce steel. If both hydrogen electrolysis and electric arc furnaces are powered with zero-carbon energy, this would decarbonize the steel making process. Various projects are currently pursuing this pathway at pilot or demo stage, *inter alia* the Swedish Hybrit project, Voestalpine in Austria and Salzgitter AG in Germany.
- Carbon capture and utilisation or storage (CCUS) is another promising pathway. In theory, this technology can be added to existing blast furnaces (if space is available on site). The concept

[2] With improved recycling and sorting practices, it may be possible to also produce high quality steel products with secondary steel making in electric arc furnaces.

foresees technologically extracting carbon from the production process. This can be done at the end of the process covering the waste gases or at various other intermediate steps covering only partially carbon emissions (Sundqvist et al. 2018). In some projects, the captured carbon is used as a feedstock for the chemical industry (e.g. Carbon2Chem or Steelanol projects).

- A final technological pathway would be to replace coking coal or natural gas in conventional steel-making processes with sustainable charcoal as fuel and reduction agent (Energy Transitions Commission 2018).

2.2. Global climate governance for the decarbonization of emission-intensive industries

Previous work in the COP21 RIPPLES project has identified a series of key transformation challenges for emission-intensive industries (cf. Rayner et al. 2018, chap. 5; also see Wesseling et al. 2017):

- **Lack of decarbonized technologies:** Deep decarbonization technologies in emission-intensive industries remain in relatively early stages of development. This is particularly true for technologies that enable a full decarbonization of production. Most of the nascent technologies would also require new and additional infrastructure if applied at industrial scale.
- **Technological inertia:** Investment cycles are particularly long in emission-intensive industries, preventing the accelerated deployment of breakthrough technologies. At the same time, R&D spending in the basic materials industry is comparatively low.
- **High CAPEX and technology risks:** Some technologies stall at the demonstration and/or commercialization stages. At these stages, very high investments are required but since the technologies are not yet proven, a high degree of uncertainty remains.
- **Competitiveness concerns:** To the extent that basic materials are traded internationally, emission-intensive industries have resisted strong climate policies so as not to compromise international competitiveness. This is particularly true where innovative decarbonized technologies produce otherwise similar raw materials at significantly higher operating costs.
- **Complex global value chains:** Deep decarbonization will require not only to decarbonize production but increase re-utilization and recycling towards an increasingly circular economy. Complex global value chains impede the tracking of the end-use of basic materials which, in turn, stands in the way of increasing rates of recycling.

But how can these transformation challenges be addressed through international governance? In the previous stages of the project we have assessed the promise and potential of international governance according to five governance functions. Synthesising the work of Khandekar et al. in Rayner et al 2019 (2018, chap. 5) international governance can support the transformation of emission-intensive industries corresponding through:

- **Guidance and Signal:** Developing and institutionalizing credible sectoral decarbonization roadmaps that help to align and shift expectations of investors in the sector.
- **Rules and Standards:** Negotiating international regulation to address competitiveness and carbon leakage concerns e.g. through carbon pricing and/or regulating embedded emissions in final products.
- **Transparency and Accountability:** Establish common monitoring, reporting and verification standards and metrics to track industrial emissions in order to enable and ensure compliance with the above-mentioned rules and standards.
- **Means of Implementation:** Facilitate international cooperation on innovative technology deployment. This includes coordinated basic R&D as well as arrangements for risk-sharing and financing of investments at the demonstration/commercialization stages.
- **Knowledge and Learning:** Co-creation and dissemination of technical knowledge, e.g. with respect to circular economy, industrial and innovation policies.

The supply of international governance was subsequently assessed by analysing the climate change regime complex including through the following institutions: UNFCCC/Paris Agreement, G20, IEA, UNEP, UNIDO, Mission Innovation, the World Bank. Collectively, these institutions do not fully address the identified governance needs. Overarching guidance and signal is provided by inter alia the UNFCCC and the Paris Agreement. Governments around the world have signed the PA, but the implications of this agreement have yet to internalized in the minds of decision makers across the economy. In order to comply with the 1.5°C target there is no place for continued production and use of 'brown steel'. A decarbonization club could help to translate the Paris objectives in a dedicated sectoral vision/roadmap thereby supporting a "mindshift" in the industry. Setting such a signal could facilitate moves to secure supply of zero-emission steel and avoid economic shocks to price premiums in developing countries later on.

International rules or regulations such as international emission limits or harmonized carbon pricing remains absent. Hence, carbon leakage remains a concern and has effectively inhibited effective regulation at the national level. Perhaps, a decarbonization club could help overcome this issue (Paroussos et al. 2019).

Transparency and accountability is very limited for most emission intensive industries. While the Cement Sustainability Initiative and the International Council of Chemicals Associations provide some transparency about the state of emissions and best available technologies for their respective industries, nothing comparable is available for the steel sector. To the contrary, assessing and comparing emissions from the industry is further complicated by the fact that process emissions and industrial energy related-emissions are reported separately in official greenhouse gas inventories. A decarbonization club could help to improve data availability not only to support enforcement of any rules and standards adopted, but to lay the very knowledge foundation to first adopt such regulations.

Means of implementation are provided by a wider range of institutions, but this engagement remains insufficient and poorly coordinated. The World Bank, UNIDO and various multilateral development banks financial support including funding for improved resource and energy efficiency. Yet, the main focus of these institutions remains on industrial development in general and consequently, "they have even supported various investments that lock-in carbon-intensive infrastructure and hence are at odds with the decarbonization imperative" (Oberthür, Khandekar, and Wyns, n.d., 14). Mission Innovation is offers another peculiarity. Mission Innovation is an international institution founded at the margins of the climate summit in Paris in 2015. It focuses on increasing funding and better aligning research and development activities of its members. As such it would be an ideal starting point to address the enormous innovation deficit in the steel industry. Still, none of Mission Innovation's activities to date focus on the steel sector.[3]

With respect to technology transfer and diffusion, several institutions are active including the UNFCCC with its technology mechanism, UNIDO, and the International Energy Agency with its Technology Collaboration Programmes (for a more detailed analysis of international cooperation on technology and innovation policies also see COP21 RIPPLES Deliverable 4.3b by Wyns, Khanderkar and Groen). But according to Oberthür et al. (n.d.) they fall far short of being adequate in view of the transformative challenges of the sector. A dedicated decarbonization club could close those gaps by leveraging financial means of implementation with an explicit focus on decarbonization. For technology cooperation as well, a decarbonization club with a truly transformative ambition could provide a leg-up to international cooperation beyond the current incrementalist approaches.

Somewhat in contrast to the gaps identified for the previous governance functions, supply of, knowledge creation and dissemination is actually relatively advanced (Oberthür, Khandekar, and Wyns, n.d.; Rayner et al. 2018). A decarbonization club focused exclusively on this governance function would therefore hardly contribute to significantly advance decarbonization.

Given this shortfall of international governance we explore in the subsequent sections, which, if any, of the identified governance gaps could be addressed by a sectoral decarbonization club?

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[3] Various approaches at the EU level were not considered in the analysis as for the purpose of this project, the EU was considered a single jurisdiction and not an international institution. Particularly noteworthy and a potential starting point for considerations of a sectoral decarbonization club are the EU's "Important Projects of Common European Interest (IPCEI)" and the Innovation Fund (EC 2019). See also discussion in section 5 below.

3. Why join a club? Assessing Potential Club Goods

As discussed in the previous section, there is ample room for a sectoral decarbonization club from an international governance perspective. But why should anyone join such a club? What is the motivation for different kinds of club members including governments, corporations or civil society organizations? In the subsequent section we will discuss potential club goods or benefits that may entice participation in a sectoral decarbonization club. We structure the discussion around three major areas of uncertainty and risks that hitherto hinder the decarbonization of the steel sector, albeit in very different realms: **political uncertainty**, **uncertainty about future technologies and the associated high-risk investments**, and **uncertainty about future markets**.[4]

3.1. Managing political uncertainty

A sectoral decarbonization club could potentially help to overcome a chicken-and-egg type problem constraining ambitious decarbonization policy. On the one hand, policymakers and legislators may hesitate to adopt stringent decarbonization targets and corresponding policies so long as domestic emission industries do not have any strategies to achieve those targets. On the other hand, companies do not have a strong incentive to develop decarbonization strategies unless there is also strong political commitment to achieve decarbonization. The case of the Hybrit project in Sweden is illustrative of this conundrum. The Swedish steel industry is already leading the world on efficiency. The blast furnaces operated by SSAB currently produce the primary steel with the lowest CO_2 footprint in the world. Yet, the company hesitated for a long time to target more radical innovation. This changed quickly with the adoption of the Paris Agreement and the announcement of the Swedish government's ambition to decarbonize the Swedish economy by 2045, after which SSAB partnered up with the utility Vattenfall and mining company LKAB both of which are state-owned to establish the Hybrit joint venture in order to develop hydrogen-based steel making (Åhman et al. 2018).

Pursuing ambitious decarbonization targets by means of a sectoral club with private companies, trade associations, and governments (subnational or national) all on board could help overcome the catch 22 noted above. Engaging with governments in a decarbonization club would allow companies to enter into conversation with governments in a balanced partnership of equals. That way companies can to some extent shape the targets and potentially also the policies that will enable and/or restrict their business in the future.

[4] Admittedly, the differentiation between the three areas are not always straight forward as some of the uncertainties are interrelated. We have tried to reduce redundancies to the greatest possible extent.

Conversely, national or subnational governance actors/ institutions could benefit by garnering broad support for their policies. Working closely with proactive members of the industry may also help to safeguard against policy reversal as subsequent elections may turn political tides.

Engaging in a sectoral decarbonization club with ambitious and credible decarbonization targets may also serve to provide guidance and signal to its members and align expectations within the various member organisations. Neither governments nor large (multinational) companies are unique actors with unique preferences. Both are large organizations with internally contested positions and very different interests at play at every point in time. Engaging in a sectoral club may help to establish the decarbonization objective as a mission for each member organization of the club and thus help mainstream it across the entire organization.

This is particularly important for companies. As one interviewee put it: “many of the basic raw materials industries are weak innovators”. This is particularly true when it comes to radical innovation as opposed to more incremental innovation, i.e. continuously improving existing processes at the margin. Given that basic raw materials are hard to differentiate and therefore product innovation is not a salient option, the basic raw materials industries “rely mostly on process innovation that tends to follow predefined technological trajectories through incremental innovation aimed at enhancing productivity“ (Wesseling et al. 2017, 1305; also see Neuhoff et al. 2014). The quest for fully decarbonized technologies would therefore require a paradigm shift for many companies involved. The signal from joining a decarbonization club could help to overcome this innovation weakness and get the companies to embrace the transformation. It is clear, that joining a club alone will not turn an innovation laggard into a leader. It may still be an important symbol of a changing corporate culture and help to challenge engineers within those countries to step out of the comfort zone of incremental innovation and engage in an innovation race with other members of the club. In the best case the establishment of a club would spur a virtuous competition for innovation among its members.

A key barrier for innovation is the motivation for investments in R&D. Typically, investment in process innovation is motivated by the anticipation of lower production cost or higher product quality and hence by the prospect of a comparative price or quality advantage. In the case of low-carbon innovation in the steel industry this is not applicable. Steel products are qualitatively very similar (at least as long as the associated emissions are not considered as part of the product’s quality) and for the production cost, the optimistic forecasts of innovation leaders within the industry indicate that operational cost of zero emission steel will exceed those of conventional primary steel by 20-30% (Material Economics 2019; Energy Transitions Commission 2018; also supported in the interviews. For more information see section 3.3 below). The usual drivers of innovation in the industry therefore do not apply. Instead, What does motivate the innovation leaders in the industry are normative objectives to contribute a fair share to the goals of the Paris Agreement as well as the anticipation of much more stringent future climate policy. A sectoral decarbonization club could support and reward this motivation.

Last but not least, the club could serve as a platform to exchange knowledge, not necessarily technological but also management knowledge and knowledge about how to change the engineering paradigm within each company. As one respondent highlighted, for the people directly involved in regular meetings or events of the club, this can be a valuable source of personal motivation and a 'treasure trove' for ideas for how to engage other people within their respective organizations. In that sense, a decarbonization club can contribute to manage political uncertainty not only at the national level, but also within companies or governments.

3.2. Sharing the risk of uncertain technologies

In the steel sector, there is no one dominant technological pathway that has proved to be viable. Instead, a variety of technological pathways are currently being explored in parallel. While each company involved in one of those pathways is taking substantial risks on their own, from a societal point of view this situation amounts to a large-scale experiment. In this context, a decarbonization club could play an important role in orchestrating these experiments. There are several ways in which this could help move the decarbonization of the sector forwards.

A first step would be to coordinate research and development programmes. That holds for research funders (both public as well as philanthropic funders) as club members as well as for private actors at the receiving end. The Mission Innovation initiative mentioned above is an effort to achieve just this, but to this day does not focus on emission-intensive industries. Coordinating research funding and research activities would help to organize the large transformation experiment in a more efficient way. It could help to avoid duplication of efforts and facilitate the exchange of lessons learned.

On a more regional level there is also scope for another dimension of coordination relating to spatial consideration. For one thing, not all regions are equally endowed to support certain pathways. For example those technological pathways that require large amounts of non-fossil electricity either as direct inputs or as a means to produce hydrogen as fuel and reduction agent may face more favourable conditions in regions where zero-emission electricity is abundant. Regions with an abundance of large hydropower or geothermal energy may have a comparative advantage over regions with less overall potential or intermittent renewable energy. On the other hand, technological pathways adopting CCS would benefit from proximity to potential storage sites for the sequestered carbon. Finally, approaches for CCU, i.e. the utilization of carbon-containing emissions as feedstock for other carbon-based products would best be placed in close proximity to regions where chemical industry or potential other partner industries are already located. Correspondingly, there may be scope to coordinate on a geographical scope focussing some regions on specific technological trajectories. To some extent such a coordination is already happening as involved organizations exploit existing proximities and infrastructures. Still, a more explicit arrangement could help to further align potential new participants and help to set strategic priorities also in research organizations and universities in the respective regions.

Finally, coordination may support the build-up of new and/or upgrade of existing infrastructures required for either technological pathway. Hydrogen-based steel making will obviously require hydrogen infrastructure – be that industrial facilities for hydrogen electrolysis, pipeline infrastructure or hydrogen shipping terminals. Likewise, the CCU/CCS route would require new ship or pipeline infrastructure and infrastructure to store carbon permanently. Finally, all technological pathways – even the most speculative ones like direct electrolysis of iron ore (electrowinning) – would require large amounts of electricity for which the current grid and generation infrastructure is not yet ready (Lechtenböhmer et al. 2016). An example for such kind of regional coordination is provided by the "Trilateral Strategy for the Chemical Industry" adopted by the governments of North Rhine-Westphalia, the Netherlands and Flanders (see Box 1)(Ministry of Economic Affairs of the Netherlands, Department of Economy, Science & Innovation of Flanders, and Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia 2017). Similar activities could also be incorporated in a sectoral decarbonization club for the steel industry.

Box 1: The "Trilateral Strategy for the Chemical Industry" of the Netherlands, Flanders and the State of North Rhine-Westphalia

In 2017, the Netherlands Ministry for Economic Affairs, the Ministry of Economic Affairs, Innovation, Digitalization & Energy of the State of North Rhine-Westphalia, and the Department of Economy, Science & Innovation of the Flemish Government have developed a joint vision and strategy to support its world-leading chemical industry cluster to become "the world ́s engine for the transition towards a sustainable and competitive chemical industry." At the core of the strategy are three pillars: coordinating and facilitating joint research and development activities, securing sustainable energy and feedstock (incl. circularity) and notably chemical industry infrastructure. For the latter, the three parties have *inter alia* agreed to develop a masterplan for chemical logistics and infrastructure, accelerate approval and construction of infrastructure and coordinate planning for new pipelines.

Orchestration of experiments could also take on an intercontinental perspective. Currently global steel markets are dealing with excessive overcapacities and this to a degree that the issue has risen to the highest political levels becoming an issue even at the G20 meetings (G20 2018). As our above analysis demonstrates, some of the most advanced technological approaches for decarbonized steel making are taking place in Europe. In the face of global overcapacities, building larger-scale demonstration plants may make most sense close to the centres of growing demand. These, however, are not in Europe but overseas, particularly in Asia. One way of internationally collaborating could be to develop a pilot activity in Europe, implement the next step (the demonstration phase), in a place with strong demand growth with a goal to mature the technology. The first commercial-scale plant could then replace existing capacities in the EU when those have reached the end of their technical lifetime. In fact, the first part of the strategy is already being applied: Tata Steel decided to built the first demonstration plant of the HIsarna technology, a technology that was successfully piloted in Ijmuiden in the Netherlands, in Jamshedpur in India (Material Economics 2019; de Waard 2018).

Experiments are by definition uncertain. While the financial risks associated with pilot-stage technological experiments may still be palatable for the private sector, up-scaling the same technologies to demonstration or even industrial scale will incur much higher investment costs. And the risk at these stages of development remain high with overall success and performance of that technology far from certain. This challenge of extremely capital-intensive investments associated with still high technological risk of failure may de-facto exclude smaller companies from attaining those technologies in the first place. But even for large multinational corporations a failed investment could mean an existential threat depending on the circumstances. Some form of risk sharing arrangement between public and private members of a club, but also among private companies, could therefore be in order.

Under current conditions, public funding for research and development is mostly targeted at earlier stages of the innovation chain (Grubb, Hourcade, and Neuhoff 2014; Mazzucato 2015). Support for innovation stages closer to commercialization are more difficult to obtain not least because in an EU-context, this kind of support might amount to illegal state aid under EU legislation (see more on this in section 5 below). One exemption to the above rule is the EU's ETS innovation fund that has been set up specifically with the mandate to support large-scale demonstration of activities in CCS, renewable energy and low-carbon innovation in energy intensive industry, including CCU. The fund is supposed grant to up to 60% of the additional capital and operational costs of innovation. A first call for applications is scheduled for 2020 (EC 2019).

Leaving this issue of illegal state-aid aside for the moment, what could risk-sharing arrangements look like in practice? Public partners of a sectoral decarbonization club could come together and set up a fund similar to the EU's innovation fund to pool resources. This could then provide grants – much like the ETS innovation fund – to strategically support different technological pathways towards the decarbonization of the steel sector. Based on Mazzucato (2015), one could go one step further and argue, that the public members of a sectoral decarbonization club could even take on a more entrepreneurial role and become active investors in joint ventures with the private members of the club. That way, the public sector actors would not only take on some of the considerable financial risk of the large transformation experiment, but also have the chance to eventually to reap some of the profits from successful experiments. As part of the National Industrial Strategy 2030 (BMWI 2019) the German Minister of Economic Affairs, Peter Altmaier, proposed the creation of a national "participation facility" that may enable the state to become a shareholder in strategic companies at risk of international takeover. In view of the goals and commitments of the Paris Agreement, wouldn't it be appropriate to use the same tool for a mission-oriented industrial policy towards decarbonization (also see Mazzucato 2018)?

A strong engagement of public members of a sectoral decarbonization club could add benefit in yet another dimension: public members could assume a role as trustees of intellectual property rights. The Programme of French "Instituts de la Transition Énergetique" provides an innovative example of how such public private partnerships can be organized in practice (see Box 2 below).

Box 2: The Programme of French Instituts de la Transition Énergétique (Energy Transition Institute)

An interesting example of a mission-oriented public-private partnership to drive innovation is provided by the French Government with its programme of so-called Energy Transition Institutes. In total, the French Government will spend EUR 1 Billion to support excellent research projects clustered on a regional level. The current selection includes Institutes on marine renewable energy, bioalgae, green chemistry, 3rd generation photovoltaics, super grid infrastructure, geothermal energy and zero-emission vehicles. The Energy Transition Institutes (ITE) are interdisciplinary platforms in the field of low-carbon energy, bringing together the skills of industry and public research in a logic of public-private co-investment and close collaboration between all the actors (competitivite.gouv.fr 2017).

As stated above, small independent steel producers may lack the financial leverage to develop decarbonized production technologies and hence would have to drop out of competition. Also, given the significant risks, not all of the large technological experiments will succeed. Some of the prospective technology pathways may end up as an impasse. In this case, the participants of less successful decarbonization experiments may want to switch onto a more successful technological pathway at a later stage. A sectoral decarbonization club could broker appropriate licensing agreements with public participants playing a fiduciary role.

Such licensing agreements could also help to mitigate second-mover advantage. This term refers to the phenomenon whereby the second industrial-scale plant implementing a novel technology is much more efficient than the first one, because it can take into account lessons learned in design and implementation. This second-mover advantage may hold back ambitions as no investor dares to take the risk of incurring high costs as a first mover. Through appropriate licensing agreements, this dilemma could be addressed by guaranteeing the first-mover licensing fees paid by those taking advantage of the lessons learned.

Public private partnerships (PPPs) that organize technology sharing in the international real are not without precedent. A series of international PPPs exist particularly in the realm of public health focusing either on the development of new drugs or health products or organizing access to drugs/products. Sampath (2018) provides an overview of the state of the art of international PPPs and their respective governance and technology sharing arrangements. The IPR arrangements of such international PPPs range from IP management-based arrangements to open innovation approaches where the technologies developed in the PPP enter the public domain (also see Reichman and Simpson 2016; Stevens et al. 2016). For the purpose of a sectoral decarbonization club approaches of "protected open innovation" (Reichman and Simpson 2016) may be most suitable. In these arrangements participating firms offer their partners a limited right to use the pre-existing patents and technologies and in return receives the right to use the outcomes of the PPP to develop its own products in the future. Of course, this arrangements cannot be used as a blueprint particularly as public health PPPs focus on product innovation whereas in the steel sector process innovation is required. However, the experience with international PPPs and their corresponding technology sharing arrangements may serve as a source of inspiration for a steel sector decarbonization club. A more detailed analysis, however, is beyond the scope of this paper.

3.3. Addressing the challenge of uncertain markets

A third dimension relates to the uncertainty about future markets. At least initially all technological options to produce carbon-neutral steel will be more costly not only regarding capital expenditures (CAPEX) but also operational expenditures (OPEX). A recent report by the Energy Transition Commission (2018) estimates that the price premium on consumer products may be as low as 1% but that each tonne of green steel could be as much as 20% more expensive than conventionally produced steel (at least in the absence of significant CO_2 prices). Even if steel makers can secure the capital to invest in a zero-emission steel production plant, they still have to recoup higher OPEX (e.g. from expensive green hydrogen). Unless they find markets that are willing to pay a premium on green steel, this seems futile.

So how could a sectoral decarbonization club take away some of the uncertainty about future markets? A first and obvious option would be to establish a credible labelling scheme that would make green steel distinguishable from otherwise identical conventional steel. Such a labelling scheme would be a precondition for a variety of further options.

Perhaps the most popular option, at least in the academic literature, seems to be to build a club around a stringent carbon price and shield the internal markets of that club by means of **border carbon adjustments** (BCA), i.e. border tax adjustments of tariffs that reflect the embedded emissions for imported steel or even imported consumer goods (Munnings et al. 2019; Dröge 2011; Sakai and Barrett 2016; Grubb 2011). Box 3 provides a back-of-the-envelope calculation on how high (or rather low) a carbon price would have to be to allow zero-emission steel to break even with steel from conventional blast furnaces.

Box 3: How high would a carbon price need to be to compensate for the additional cost of zero-emission steel?

In the European Union, the average production cost of a tonne of crude steel is ~450€ (Moya and Boulamanti 2016). The production of primary steel via the blast furnace / basic oxygen furnace route typically features a carbon intensity of 2 tonnes of CO_2 per tonne of crude steel (Hasanbeigi et al. 2016; Material Economics 2019). Finally, the operational costs for zero-emission steel are estimated to be 20-30% higher compared to conventional steel (Energy Transitions Commission 2018; Material Economics 2019; Vogl, Åhman, and Nilsson 2018).

Given these parameters, we can conduct a back-of-the-envelope calculation to identify a carbon price at which zero-emission steel would break even with conventional steel: The additional OPEX for zero-emission steel amount to 20-30% of 450€ per tonne, equalling 90-135€. One tonne of zero-emission steel avoids the emission of 2 tonnes of CO_2 . Correspondingly a carbon price of 40-60€ would suffice for zero-emission steel to break even and become competitive with conventional steel. Note, however, that this calculation only relates to operational costs and does not take into account CAPEX which are also estimated to be 30-50% higher (Vogl, Åhman, and Nilsson 2018; Fischedick et al. 2014).[5]

[5] From a macroeconomic perspective the move towards renewable energy and subsequently renewable hydrogen with zero marginal costs could lead to a situation where OPEX are largely determined by embedded CAPEX across the entire value chain. For example the main input to hydrogen steel would by H2. In turn the input for H2 would be zero carbon and zero marginal price electricity. So the cost of H2 would be the embedded CAPEX of the electrolysers and upstream the embedded CAPEX for RE production.

The combination of a stringent carbon price and some form of BCA would arguably provide the highest degree of certainty about future market conditions for prospective investors in zero-emission steel. Yet, despite the concept of BCA having been discussed extensively in academia, especially in the economic disciplines, it has yet to gain much traction in the political realm. One reason for this is the still predominant free trade paradigm. Border tax adjustments to many seem to be (illegitimate) restrictions to international trade. No one seems to be willing to risk a trade war for environmental concerns.

Mehling et al. (2019) provide an in-depth legal analysis of the commensurability of various BCA designs with international trade law. They find that significant uncertainties remain, but can be managed by designing BCAs taking into account *inter alia* the following principles:

- **Focus on emission-intensive and highly-trade exposed sectors only:** For sectors with particularly high carbon leakage risk it may be more easy that BCA is necessary in the legal sense. Also focusing on steel, aluminium and cement would be administratively more feasible than including also final good sectors. However, the risk that carbon leakage shifts from the basic materials to material intensive goods.
- **The scope should be determined sectorally and not geographically:** Differentiation of the BCA should be based on the embedded carbon content of products. This would both meet the non-discrimination clause of the WTO as well as the principle of common but differentiated responsibilities.
- **Fair and open process:** This would include open negotiations with trade partners and an opportunity to object and appeals procedure.
- **Use revenues to support decarbonization:** Using the stream of revenues from BCAs for strategic investments and or as means of implementation to assist trading partners with decarbonization.

All these requirements could well be implemented in a decarbonization club. A sectoral decarbonization club would therefore constitute a near ideal vehicle to develop and implement BCAs against all political constraints. Grubb (2011) has proposed to simply return the revenues collected at the border to the country of origin to support their low carbon development. A decarbonization club could restrict that return of revenues to its members thus creating a strong incentives for non-members to consider joining.

As an alternative approach to BACs **consumption charges on energy intensive materials** have been proposed (Neuhoff et al. 2015; Munnings et al. 2019; Pollitt, Neuhoff, and Lin 2019). The basic idea is to levy a fee on the consumption of energy intensive basic materials that is commensurate with the embedded emissions of those materials. The rate would be calculated based on benchmarks of average performance of production within the EU. The charge would be levied on all consumed materials regardless of their provenience thereby avoiding trade distortions. Pollitt et al. (2019) estimate the mitigation effect of such an approach. They assume that a consumption charge is introduced with an initial rate reflecting a carbon price of 20€ per tonne of embedded CO_2 rising to 80€ in 2050. Depending on the price elasticity of demand they calculate that such charge could reduce emissions in the iron and steel sector between about 25 and 52 per cent by 2050. And all that can be achieved at a net benefit for GDP when the revenues are reinvested appropriately. Even without such reinvestments there could be a positive effect due to fuel savings. A steel sector decarbonization club could champion this approach and exempt certified zero-emission steel from that consumption charge. Given that the required price premium is relatively low, such a consumption charge could suffice to create a market opportunity for zero-emission steel.

If approaches including some form of border adjustments remain not politically feasible in the near future, other approaches could be sought that are less contentious and hence more easily applicable. For example, **labelling** would enable manufacturers of consumer goods to source green steel and market their product accordingly to consumers. Given the relatively low price premium on consumer goods cited above, this may be an option for manufacturers to differentiate themselves from their competition and appeal to environmentally conscious consumer groups. Depending on the product and market conditions, it may even be the case that manufacturers can charge a price premium for green steel products that exceeds the additional costs.

On the other hand, it may not be straightforward to establish such a label. The challenge is that there are many different types of steel and many ways in which steel can be produced. Should the label only apply to zero-emission virgin primary steel or should it also apply for recycled steel from renewably-powered electric arc furnaces? And what about different blends of low-carbon primary steel with recycled steel? One way of addressing this would be to mandate suppliers to provide standardized environmental product declarations (EPDs) that indicate the embedded carbon emissions or global warming potential across the entire value chain. Using a (dynamic) performance benchmark one can then specify steel products that qualify as low carbon steel. A similar approach is used under the Buy Clean California Act (see Box 4 below).

Public members of a sectoral decarbonization club, national or regional governments, could also boost demand for zero-emission steel by making corresponding requirements in public procurement (also see Wyns et al. 2019). After all, the demand for steel for public buildings and infrastructure is not insignificant. For example, in the United States, 40% of steel demand stem from the construction industry (Statista 2019b). The share of construction spending of the public sector has decreased from 36 per cent in 2011 to 23 per cent in 2018 (Statista 2019a). Taking the share of construction spending as a proxy for the share of steel demand we can estimate the that steel demand for public buildings and infrastructure ranges between 9.3 – 14.4 per cent of total US steel demand.

While public demand for zero-emission steel may not suffice to support a complete transformation of the entire industry, it may still be enough to create a niche for early movers and thus reduce investment risk significantly. Unfortunately, quantifying the potential effect of public procurement on the demand for zero-emission steel in more detail is beyond the scope of this report. The argument therefore necessarily remains speculative at this point.

Box 4: The Buy Clean California Act

In October 2017 the State Assembly of California adopted Assembly Bill 262, the *Buy Clean California Act* (California Legislature 2017). It requires contractors bidding for state infrastructure and construction projects to disclose the greenhouse gas emissions for certain materials, such as concrete and steel, used in those projects by means of a standardized Environmental Product Declaration (EPD). These EPDs shall transparently report the environmental impacts including the global warming potential embedded in a particular product across the entire production process. The quantification is based on a standardized methodology. Furthermore, the bill requires the Department of General Services of California to develop a method for considering environmental impacts in the bid selection process of publicly procured infrastructure projects. As of 2021 "a maximum acceptable global warming potential for each category of eligible materials" will be determined. Products that exceed this threshold must not be used in public infrastructure construction (also see Department of General Services of California 2018).

A very different yet related aspect of uncertainty about future markets is the fact that the current situation of global overcapacities creates a situation in which, within each company, and specifically within multinational corporations, the different production sites compete for investments (see for example Jernkontoret 2018). New production facilities require investments in the order of hundreds of million of Euros. Once an investment decision has been made, the future of the selected production site is relatively certain for the next decades. Were a region to be a member of a sectoral decarbonization club, with all the potential attendant benefits, this could tip the scales towards investing in that region rather than in a different place without a mission-oriented decarbonization programme.

4. What Roles for Club Members?

In this section we will discuss the potential motivation and incentives for various actors to join a decarbonization club. I will consider four different types of members: governments (national or subnational level), companies, trade associations and civil society organizations.

Taking up some of the aspects discussed above, a key rationale for **governments** to join a sectoral decarbonization club is to drive their own decarbonization, while also maintaining a strong industrial base. A key concern is that ambitious climate policy will drive up (energy) cost for emission intensive industries which, in turn, will affect the competitiveness of those very industries. In the worst case, these industries will be relocated to places without such stringent policies ("carbon leakage") (De Cian et al. 2017; Neuhoff et al. 2014; Branger and Quirion 2014). Especially for regions with a strong industrial base, decarbonization therefore has to take place under the constraint that industrial production is not displaced. Not considering this constraint would undermine the economic foundation of the affected regions. It would mean a loss of typically well-paid jobs and could threaten the chances of the responsible governments of re-election. Worse still, if the demand for raw materials were then to be met through imported high-carbon supply, no benefit for the climate would have been achieved.

If a sectoral decarbonization club could bridge the two objectives of decarbonization and maintaining a strong industrial base, this would be a strong motivation for governments to join. Drawing on the above analysis, governments would want to engage in a decarbonization club as a means to:

- signal to its companies that they take decarbonization seriously and hence challenge the industries' innovation capacities. Doing this as part of an international decarbonization club could underline that the respective governments are not pursuing the decarbonization goal in isolation and an internationally binding commitment would to some extent also bind subsequent governments. Also, the backing of an international decarbonization club could help improve leverage of subnational governments to confront large multinational corporations.
- support its domestic industries in their innovation efforts through targeted R&D programmes and/or mission-oriented investment. Here an international decarbonization club could help with coordination and create opportunities for learning and exchange hence increasing the effectiveness of R&D programmes overall.
- create lead markets for zero-emission raw materials through public procurement. In this case a decarbonization club could increase the market size thus improving liquidity of markets as well as decreasing dependence on business cycles in one region.

As discussed above, another motivation for governments is to try "future-proofing" their policies by closely engaging powerful stakeholders. That way, it is less likely that future governments would want to roll back current policies.

The rationale for **private companies** to join is very different. For them, joining a sectoral decarbonization club makes sense if they can gain a competitive edge over their peers. They can achieve this on several levels. Preferential access to R&D funding and/or venture capital for high-risk investments in demonstration and commercial scale production installations is clearly a strong incentive. Joining a decarbonization club may be particularly attractive for small companies if they can access zero-emission technology which they would be otherwise unable to obtain e.g. through a dedicated IPR hub (see discussion and Box 2 above).

However, competition can also be a barrier to participation in a club as companies do not want to give away their technology, and do not want to give up their leading position in an innovation race. From a competition point of view there may therefore be a misalignment of incentives, in the sense that technologically advanced companies do not want to join a club but technological laggards do. With respect to competition as a barrier/incentive for joining a club it is at least as relevant who is NOT in the club as it is who is in. By joining, companies may give up a competitive edge over the other members of the club but may gain by getting ahead of those competitors who are not part of the club. In practical terms, an example could be if the European steel industry joined forces with Japanese and/or Korean steel makers to gain an advantage over the strongly growing and increasingly export-oriented Chinese steel industry. By providing each other access to technologies and sharing lessons learned in the "decarbonization experiments", the club members could increase their own innovation capacities and gain an advantage over those companies that do not participate in the knowledge pooling and exchange activities of a decarbonization club.

Last but not least, a decarbonization club would be attractive for companies if it were to offer some form of protection from competition. If a club were to include a scheme for stringent carbon prices with some form carbon tariff adjustments companies may opt to join the club and pay the carbon price instead of being subjected to external levies, fees or tariffs they have much less control over. Similarly, getting access to lead markets for zero-emission steel established through public procurement (see discussion above) could be an incentive to join, at least for innovation leaders in an early phase of the club.

Another important incentive for companies to join a sectoral club would be to increase the ability to access and influence political processes. That may be achieved through strong joint positions that club members put forward to influence external policy processes e.g. within the European Union. In the case of strong participation of governments in the decarbonization club, the direct access afforded companies would be perhaps even more attractive. It would provide companies the opportunity to shape the policies that govern the decarbonization for those jurisdictions represented in the club. For technological leaders it may be particularly interesting to drive up ambition in order to exploit their advantage over those competitors that are less technologically advanced.

To summarize, the key incentives for companies to join a club are:

- to get (preferential) access to R&D funding, venture capital and zero-emission technologies
- to gain a competitive advantage over companies that are outside of the club
- to shield their domestic/main market from international competition
- to access and influence policy processes.

5. Is a Sectoral Decarbonization Club Compatible with Competition Rules?

In this section we will discuss a set of potential challenges and/or barriers to establishing an effective sectoral decarbonization club. In section 4 we have already discussed the role of competition and how it creates incentives and disincentives for companies to join a decarbonization club. Beyond these individual incentives, a major concern of the interviewed experts was that a club with strong involvement of companies may infringe competition rules on two important aspects: (1) engaging in a club which entails close cooperation on technology development and innovation may be considered 'horizontal collusion' (Baumol 1992) among the participating companies , and (2) that cooperation between private companies and national or subnational governments could be considered a form of illegal state aid. An exhaustive legal analysis of those aspects is beyond the scope of this report. Yet we will shed some light on the matter in order to highlight potential pitfalls and outline some questions for further (legal) analysis. The subsequent analysis focuses on EU rules on competition.

What is the purpose of rules on competition? According to the European "rules on competition are designed to ensure fair and equal conditions for businesses, while leaving space for innovation, unified standards, and the development of small businesses" (European Union 2019). As we have outlined above, the current situation in the steel sector features a low rate of innovation, at least of the kind of disruptive innovation that is required to meet the goals of the Paris Agreement, and the enormous investment needs for demonstration plants may effectively exclude smaller companies from innovating zero-emission production processes and consequently may exclude them from competition if and when eventually stricter climate policy rules out conventional steel making. In that sense, a sectoral decarbonization club should be well-aligned with the purpose of the EU's rules on competition.

The core of the EU's common rules on competition are laid out in Article 101 §1 of the Treaty on the Functioning of the European Union (2008) according to which agreements, decisions and practices are prohibited that

(a) directly or indirectly fix purchase or selling prices or any other trading conditions;

(b) limit or control production, markets, technical development, or investment;

(c) share markets or sources of supply;

(d) apply dissimilar conditions to equivalent transactions with other trading parties, thereby placing them at a competitive disadvantage;

(e) make the conclusion of contracts subject to acceptance by the other parties of supplementary obligations which, by their nature or according to commercial usage, have no connection with the subject of such contracts.

As discussed above, a proposed decarbonization club should among other things focus on collaborating on innovation as described in section 3.2. This would not relate to selling prices or trading conditions nor would it include sharing markets or sources of supply, nor would it include "dissimilar conditions" i.e. discriminate against trading partners. The most pertinent provision is related to §1b. However, quite explicitly the purpose of a decarbonization club would not be to "limit and control" technological development and investment, but the opposite – to spur innovation and foster investment in low-carbon technology. §3 of Article 101 even provides exemptions from the prohibition of measures cited above which contribute "to improving the production or distribution of goods or to promoting technical or economic progress ..." (European Union 2008, Art. 101 §3). The economic literature on innovation cooperation also seems to suggest that close cooperation in R&D may be beneficial to competition and to overall social welfare. Petit and Tolwinski conclude their study on the effect of technology cooperation by stating that "antitrust legislation should be flexible towards technological cooperation since it may produce social benefits and even reduce the incentives for industrial concentration" (Petit and Tolwinski 1999, 207; also see Baumol 1992; Miyagiwa 2009).

Even if the above discussion seems to suggest that a sectoral decarbonization club may conform with competition rules, a further way to address concerns about infringing competition would be to include a clear process and conditions for joining the club. This would make sure that the decarbonization club is not an exclusive approach focussed on gaining and maintaining a competitive advantage, but a mission-oriented endeavour that is open for new members on the condition that they adopt the same ambitious targets and contribute their part to the objectives of the club.

The second major concern mentioned in the interviews conducted for this report was the fear that the involvement of public members – national or subnational governments – and in particular their active involvement in public-private partnership joint ventures with the industry as outlined in section 3.2 above, may constitute a form of illegal state aid, defined as "an advantage in any form whatsoever conferred on a selective basis to undertakings by national public authorities." (European Commission 2019). Explicitly excluded from this are subsidies and support schemes provided to all actors by means of an open and transparent process. Hence, including a clear process and conditions for membership in the decarbonization club may also conciliate concerns over illegal state aid.

But even beyond the generic provisions on illegal state aid, there may be room to explore a sectoral decarbonization club with strong involvement of public actors. One current policy process is particularly relevant in this regard: the "Strategic Forum for Important Projects of Common European Interest (IPCEI)". Under this initiative a set of "value chains of strategic interest" will be defined. For these, Member States are encouraged "to channel public funding towards such integrated projects which have clear spill-over effects for a wider part of the Union such as on Key Enabling Technologies: KETs are knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly-skilled employment" (European Commission 2019). A sectoral decarbonization club in the steel industry with the express objective to meet a key objective of the EU – decarbonization – would resonate well with these provisions and arguably could be considered such an Important Project of Common European Interest.

To conclude, the challenges of collusion and illegal state aid are relevant considerations to be taken seriously when designing a sectoral decarbonization club. However, the analysis suggests that these concerns should not be an impenetrable barrier.

6. Scope of the Club

A final consideration to be made is the appropriate scope of the club. This question can be discussed on at least three dimensions: the type of members, the sectoral scope, and the geographical scope. We have implicitly addressed the first aspect already in section 3 and 4. Given the previous discussion, we can conclude that a sectoral decarbonization club can be most meaningful if it includes both private companies as well as public actors – national and/or subnational governments.

In terms of the sectoral scope we have already discussed that a club approach may be most useful in a situation where a relatively limited number of actors can already achieve a meaningful impact in terms of changing the course not only of those involved but of the industry as a whole. On those grounds, we have discarded the idea of proposing a club approach to facilitate and support an increasingly circular economy, as it would require involvement of too large a number of actors across a highly complex value chain.

Similar arguments hold when considering to incorporate a wider set of emission-intensive industries. It is certainly more easy to align the interest of a critical mass of actors from one single industry than with a much wider group. On the other hand, some of the challenges are similar across a range of different industries. For instance most emission-intensive raw material industries face high challenges in developing and promoting radical innovation (Wesseling et al. 2017). Also, they have in common that electrification as well as the use of hydrogen are major strategies for decarbonization. If implemented this would entail much larger demand for electricity, which would have to be generated from renewable energy sources and integrated into existing grid infrastructure. Finally, some industries are closely linked at earlier stages of the value chain. In particular, this is the case for steel and cement which both supply the construction industry. Any policies that address steel demand in the construction industry could therefore also affect the cement industry.

It is also worth noting that different sectoral scopes may favour different technological pathways. E.g. carbon capture and use (CCU) would greatly benefit from inclusion of petrochemical industry (as a potential source of demand), whereas hydrogen-based steel-making would be “happy” in a steel-only club, presumably. With respect to coordination of infrastructure, a broader scope would also be beneficial. Including all industries that will utilize hydrogen/CO_2 infrastructure would be required anyway.

One way to address this issue would be to govern several emission-intensive industries under a common umbrella decarbonization club with specific chapters for the individual industries. This would also allow to incorporate chapters for important sectors located further down the value chain such as building and construction industry, automotive industry and packaging industry and hence enable cross-cutting inter-sectoral policies. Following this approach would allow to initially focus on a reduced number of actors in one sector and then subsequently develop new chapters and start addressing cross-cutting issues as the club increases. This way, there is no need to engage all relevant sectors at the same time which could be too complicated and cumbersome to start a decarbonization club in the first place.

As regards geographical scope, the question is whether a more regionally restricted decarbonization club e.g. at the European level would be more appropriate or a truly global transnational decarbonization club. Some of the potential club goods discussed in section 3 above particularly lend themselves to a more regionally-focused club. This is particularly true for all issues regarding the coordination of physical infrastructure. Other aspects may be relevant internationally. For example coordinated or combined emissions trading schemes, border tariff adjustments and coordination of R&D programmes could be highly beneficial if discussed in a more international setting.

A more international club approach beyond the confines of the European Union would also make sense as future demand growth will occur elsewhere (Rozenberg and Fay 2019). If this growing demand is not ultimately also met with low-carbon raw materials, the objectives of the Paris Agreement cannot be achieved. India is a particularly relevant country in this regard. Not only are Indian steel makers, notably Tata Steel and ArcelorMittal already heavily engaged in the European steel market, but also India will be a major centre of demand for steel in the future. India's steel production is estimated to quadruple by 2050 (Levi 2019)While China's demand for new infrastructure development seems to have peaked (*The Economist* 2018), India still experiences a dramatic shortfall in public infrastructure. In fact, industrial emissions are one of the key remaining challenges for deep decarbonization in India. While the country is making significant progress in the power and transport sector (Spencer and Awasthy 2019; Pachouri, Spencer, and Renjith 2019), Indian industrial emissions are expected to experience significant growth.

From a geopolitical perspective, including China could be desired from an EU point of view. Building a decarbonization axis with China would set a bold example against the US administration's stance on climate and energy policy. Moreover, the Chinese Belt and Road Initiative will likely also be an important driver of global steel demand in the coming decades. However, while including China would be politically appealing, from an (European) industry perspective, it might be more difficult to welcome Chinese steelmakers joining the club early on. In the light of the discussion of the competitiveness issue, someone needs to be outside of the club for members to gain a competitive advantage over, at least initially (see also discussion in section 4 above).

While it may be initially more easy to start a club with a regional focus and include a limited set of actors, ultimately what is required is the decarbonization of the entire industry. The rationale for a club approach is precisely to kick-start ambition with a smaller group of actors, but once the transformation gathers speed, the same approaches and technologies should be distributed much more widely to achieve the decarbonization of emission intensive industries everywhere across the globe.

7. Design Elements: Cornerstones for a Sectoral Decarbonization Club

This section will summarize the previous analysis towards outlining key features for a proposed decarbonization club. This proposal should not be considered as the definitive approach but instead serve as a discussion starter. After all, as highlighted in the introduction, the decarbonization of emission-intensive industries still has tremendous challenges and at the same time has received scant attention from international institutions, policy makers and academics alike. With this proposal we hope to contribute to a constructive discussion to bring about the required transformation.

7.1. Objectives

It is clear that a true decarbonization club must not be a club to promote 'green washing'. It must not portray business-as-usual activities of the industry as innovative contributions to climate change mitigation, thereby only simulating real climate action. A fundamental precondition for an effective decarbonization club therefore is a transformational ambition in that it goes significantly beyond marginal performance improvements (see Mersmann and Wehnert 2014 for a discussion of transformational change a concept describing the intensity or degree of changes).

To meet this criterion, a decarbonization club should require its members to commit to exactly this: a full decarbonization of the production process. The term "decarbonization" has been contested since it could also imply the ruling out of *any* carbon-based materials. What is intended here is that all members agree to phase out the use of coal, oil and gas for combustion as well as eliminate any industrial process emissions.

Parties to the Paris Agreement have committed to "aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (UNFCCC 2016, Art. 4.1). In line with this commitment a membership condition for a sectoral decarbonization club should be **a commitment to achieve decarbonization by 2050.**

Complementary to this long-term target, club members should also set intermediate targets. **A moratorium on new unabated conventional blast furnaces** would be a straight forward commitment. To meet the objectives of the Paris Agreement, a recent analysis carried out under the REINVENT project suggests that after 2030 no new investments in unabated conventional blast furnaces (greenfield or retrofit) should be allowed to achieve a climate neutral steel sector by 2050 (the operational life of a blast furnace can be up to 20 years) (van Sluisveld et al. 2018). Given the current overcapacities in the steel sector and developed countries' responsibility take the lead in combating climate change (United Nations 1992, Art. 3.1), it might be even more appropriate for developed countries to install the moratorium as of 2025. Developed countries should than follow that example as of 2030.

7.2. Club goods

Corresponding to our analysis there are three areas in which a decarbonization club could contribute significantly to advance decarbonization of its members relating to (1) innovation activities, (2) infrastructure, and (3) securing markets for zero emission steel.

The **innovation component** of a decarbonization club should focus on supporting the development of demonstration and industrial-scale production plants for the various technological pathways outlined in section 2.1. Setting up a significant fund for strategic investment in public-private partnership joint ventures to develop demonstration and eventually industrial scale plants would be a bold approach.

The role of national and subnational governance in such a club would not only be to contribute financially to this fund but also act as a fiduciary for the intellectual property rights developed within the joint ventures, i.e. secure access to technologies for members of the club that are not members of the consortium developing the technology under pre-determined conditions. Correspondingly, the decarbonization club should establish an IPR-hub to make available in a coordinated way the technologies that will be developed under the PPP joint ventures. The French Energy Transition Institutes could serve as a model (see Box 2). Experiences with international PPPs in the public health domain may inspire innovative ways for technology sharing and handling of intellectual property rights.

Finally, the club should engage in coordinating R&D activities by specifying regional experiments selecting some regions to try out and focus on selected technological pathways. In accordance with these specialization strategies, the **infrastructure component** of the club should coordinate the build up of required infrastructure. This kind of activity clearly is most relevant at the regional level and would not require the inclusion of a more global set of actors. We therefore suggest that the decarbonization club should launch a set of regional initiatives that can be facilitated and supported by the club secretariat (see below). A salient starting point could be the region between Dunkirk (France), Antwerp (Flanders), Amsterdam (Netherlands), and Duisburg (North Rhine-Westphalia). The trilateral strategy already in place for the chemical industry of North Rhine-Westphalia, Netherlands, Flanders could serve as a blueprint for this component (Ministry of Economic Affairs of the Netherlands, Department of Economy, Science & Innovation of Flanders, and Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia 2017, see also Box 1 above). This would require to involve national governments and large corporations who can pay for the infrastructure investments but also subnational governments who typically oversee planning and planning regulations.

Finally, the club should include a **market component**. It should establish a label for zero emission steel to help club members to differentiate their product from competitors not in the club. Such a green steel label could be modelled after the “Buy Clean California Act” which mandates a standardized environmental product declaration and sets a threshold for “maximum acceptable global warming potential” for different types of steel products (see Box 4).

Such a label would be a prerequisite for establishing a dedicated market for zero-emission steel. The decarbonization club could create a lead market if public members of the club would mandate an increasing quota of zero-emission steel in all public infrastructure and buildings constructions. Doing so could at least initially create a small premium market that could help early investors to recoup the expected higher operational costs compared to conventional steel.

Border carbon adjustments do not seem to be politically feasible in the short term. Material consumption charges may avert some of the international trade implications that have hampered the uptake of BCAs, but the concept is relatively recent and has not been taken up prominently in the political debate. Furthermore, subnational governments (and national governments in the EU context) may not have the legal competence to impose such measures. While such measures could be the ultimate purpose of the sectoral club, the political and legal challenges should not delay the launch of a decarbonization club as this would arguably delay the decarbonization of the industry. We suggest there is enough potential for cooperation already without these instruments to motivate the foundation of a sectoral decarbonization club. Ideally, the members of the club would agree to work towards developing appropriate tools to eventually shield a larger market for zero-emission steel, whether that is through carbon pricing and complementary BCAs, through a materials consumption charge or through any hybrid form combining aspects of the two approaches.

7.3. Scope and membership

We have discussed the potential sectoral scope of a decarbonization club above. Pragmatically it seems to be most practical to begin to build a club for the steel industry. This way it may be easier to bring together a critical mass of actors, from which momentum for further development can potentially be gathered. In the longer term, this steel sector club could become a chapter of a cross-sectoral umbrella decarbonization club alongside other sectoral chapters. To enable later expansion of the club, particular care should be taken to design the club in such a way that it does not favour some technological pathways over others. Doing so may alienate some of the actors and negatively affect the required innovation race.

The next question regarding the scope concerns the type of actors involved. Throughout the report we have assumed that there are important roles to be played by public as well as private actors. The advantages of having national governments on board are quite obvious, given their legislative competencies. But also subnational governments can play an important part, particularly because the effects of an unmanaged structural change in response to the decarbonization of fossil fuel-dependent industries will mostly be felt on the regional level. Ambitious regional governments may therefore be particularly motivated to challenge the industries they host in their region to innovate and proactively seek to decarbonize their operations in order to ensure the industrial production and corresponding jobs remain at the same location. Finally, the involvement of the EU may be particularly important when it comes to exploring border tax adjustments because Member States have transferred the competency to negotiate trade agreements and trade-related policies to the supranational level. Also involving the EU, the European Commission in particular, may help to align the decarbonization club and its activities with other EU initiatives like the Important Projects of Common European Interest, European research programmes as well as the Energy Union. Moreover involving the European Commission may help to ensure compatibility of the decarbonization club with competition rules by carefully designing the club's structure in accordance with existing rules and/or by altering or creating exemptions within them.

As regards the companies, the decarbonization club should certainly include the technological leaders of the industry. Outstanding examples include the Swedish Hybrit project, Voestalpine from Austria as well as ThyssenKrupp and Salzgitter from Germany. Alongside these comparatively smaller steel makers multinational corporations such as ArcelorMittal and Tata Steel are carrying out promising technological projects. But their global purview may have additional leverage to advance decarbonization at the global level. After all the decarbonization of the steel industry is a global challenge, and including multinational corporations may help to disseminate and transfer zero emission steel making technologies to places that are not as technologically advanced.

A lot speaks in favour of a European decarbonization club – not least the importance of the infrastructure component mentioned above. Many of the most advanced low or zero emission technologies are currently being developed in Europe. But as stated above, decarbonization of the steel industry is a global challenge. The decarbonization club therefore should not be limited to EU members. From an international perspective it should be avoided that the decarbonization club is perceived as a means to protect and unduly support European industry at the expense of international competition. If the decarbonization club is eventually to have a global impact, it should be made clear from the outset that it is a cooperative approach motivated by the need to mitigate climate change and not a protectionist instrument.

Partnering up with India could be a natural starting point, not least because two of the most important multinational corporations that are active in Europe are either based in India (Tata Steel) or have close connections (ArcelorMittal). Moreover, India's increasing demand for public infrastructure and the corresponding steel demand not only makes the country particularly important from a global climate change mitigation perspective, but it also provides a lot of opportunity to experiment with innovative technologies in a market that is less constrained by existing overcapacities. In fact, this is already happening as illustrated by the example of the HIsarna demonstration plant being developed in India instead of Ijmuiden, where the first pilot plant had been installed (see above). From a geopolitical point of view, China would be also a desirable partner for establishing a decarbonization club, but from an industry perspective competitiveness concerns may prove to be a challenge. Noting the the complexity of the economic and political landscape, the EU should work with all potentially willing governments to help design a club with the right properties, that ideally could attract both India and China as well as some of the established OECD producers.

Most importantly, though, is that the decarbonization club is conceptualized as an open club with a clear pathway to membership. It may be necessary initially that the club provides a competitive advantage for its members over non-member companies to incentivize companies to join the club. But in the long run the objective of the club needs to be to decarbonize the entire industry. Therefore all companies and jurisdictions that commit to the same objectives and that comply with the rules of the club including the provision of the club goods as described above, should be welcomed.

Doing so would also align well with overarching international governance. The Paris Agreement explicitly encourages "voluntary cooperation in the implementation of their nationally determined contributions to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity" (UNFCCC 2016, Art. 6). A sectoral decarbonization club would well fit into this kind of voluntary international cooperation. Similarly, the Sustainable Development Goals call for enhanced international cooperation. Specifically, SDG 17.17 calls countries to "encourage and promote effective public, public- private, and civil society partnerships, building on the experience and resourcing strategies of partnerships" (United Nations 2015). Again, a sectoral decarbonization club could well a practical example of such an effective partnership.

Finally, something that has not been discussed in detail in the previous sections but was highlighted by various experts in the interviews is a strong and well-resourced secretariat to support the activities of the club with permanent staff and resident experts. According to the experience of those exports this kind of support is critical in driving the implementation of the club and its activities. This also resonates with the academic literature that has highlighted the role of international bureaucracies and treaty secretariats as policy entrepreneurs (Biermann and Siebenhüner 2009).

8. Conclusions

In this report we have discussed and analysed various different potential policies or instruments that could serve as club goods for a sectoral decarbonization club. Many of the proposed instruments make sense in their own right and do not need to be implemented in the context of a decarbonization club. But we would like to argue that in combination these instruments can serve as a package that is attractive with ambitious companies as well as governments (national and subnational). Implementing them in the form of an open decarbonization club with the clear aim of expanding the collaboration beyond Europe could fill important governance gaps and help to advance the decarbonization of the steel industry globally.

As stated already in the title of this report, we did not set out to provide a definitive proposal for a sectoral decarbonization club but to explore its promise and potential. Needless to say that not all questions and open issues could be sufficiently addressed in the scope of this report. Further research should inter alia address in more detail the legal implications of a decarbonization club, particularly with regard to competition rules and how it could be set up to avoid allegations of both horizontal collusion as well as illegal state aid. Another question that we could not fully address in this report, at least not in a representative way, is whether and under what conditions such a decarbonization club would be attractive and acceptable for steel companies. Would they welcome the financial involvement of public club members in PPP joint ventures? A broader survey of industry representatives could yield some answers. On the technological level, further research could help to provide insights into the required cost and investment requirements to indicate what kind of financial commitment would be required from the public actors to effectively kick start the transformation of the sector. Moreover, more detailed research on decarbonization timelines and roadmaps for the industry could help to underpin the commitments of a prospective decarbonization club. And finally, further research could try to assess the implications of a (successful) decarbonization club by integrating it into global climate and energy models. First attempts have been made also in this project specifically on the impacts of trade and competitiveness (##refer to work from Ramiro Parrado in WP3.4), but further research would be required e.g. to assess the implications for decarbonization pathways both within the club as well as globally.

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