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This report is the first output from DIW and Climate Strategies' ongoing project on Policy Design for a Climate-Friendly Materials Sector.

More information at www.climatestrategies.org

About Climate Strategies

Climate Strategies is an international organisation that convenes networks of leading academic experts around specific climate change policy challenges. From this it offers rigorous, independent research to governments and the full range of stakeholders, in Europe and beyond. We provide a bridge between research and international policy challenges. Our aim is to help government decision makers manage the complexities both of assessing the options, and of securing stakeholder and public consensus around them. Our reports and publications have a record of major impact with policy-makers and business.

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Summary for policy makers

Basic materials like steel, cement or aluminium are important inputs for the construction of infrastructure and buildings as well as manufacturing of industrial products. Their primary production is however carbon intensive and in Europe responsible for the dominant share of industrial emissions and for 16% of overall greenhouse gas emissions.

Emission reductions have been in the past achieved primarily with efficiency improvements of primary material production, but remaining efficiency potentials with best available technologies are modest. Therefore the focus is now on expanding action to new climate friendly options:

- Innovative material production with electricity from wind and solar, biomass or Carbon Capture Storage/Carbon Capture and Use (CCS/CCU).
- More efficient use of materials and extended product life time.
- Substitution with higher value or different materials reducing overall carbon intensity.
- Increasing re-use and recycling rates and avoiding loss of material quality with recycling.

A portfolio of these climate friendly options is required to achieve the European Union's 80-95% emission reduction target for 2050 or climate neutrality as agreed in the Paris Agreement on climate change. Understanding the precise benefits and costs as well as possible scale of individual options will only become clear as these options are being explored in practice. Therefore an early development of this broad portfolio is essential to achieve the climate objectives with cost efficient technologies and practices.

However, activities towards unlocking the portfolio are so far largely constrained to scientific analysis, laboratories and very few early demonstration projects. The current developments in the material sector are inconsistent with longer-term policy objectives. How will governments respond by 2030 if no further progress is achieved? This uncertainty is of increasing concern for all investment decisions in conventional material production.

To attract investment and create job opportunities, the European and national policy frameworks needs to be consistent with the longer-term policy objectives. Therefore there is a need for an integrated perspective on innovation and use of the portfolio of climate friendly options.

A policies framework for the large scale use of climate friendly options comprises a set of elements to address barriers, overcome inertia and internalize climate externalities, as outlined in Section 4. Together they not only support investments in existing options, but also give incentives to private actors to develop technologies, practices and business models. In the current debate four aspects are particularly time critical:

- **aligning the EU ETS cap and linear reduction factor with long term climate objectives**, including timely response to accumulated allowance surplus with market stability reserve.

- **ensuring full carbon price pass through** to include in the policy framework all actors that can take forward climate friendly options and to ensure incremental costs can be recovered.
- **refining sector roadmaps in public-private cooperation** to reflect technology learning, as basis for innovation funding decisions and to facilitate developments of policies and codes.
- **providing training and funding arrangements to support public procurement authorities** in considering climate externalities – so as to create lead markets for climate friendly choices.

Many climate friendly technologies and practices are, however, not yet fully developed and commercial viable. Therefore a policy framework for innovation is also needed to address financing constraints, to compensate for limited appropriation of benefits by the innovator, and to demonstrate commitment to climate policy. This may involve (more detail in Section 4):

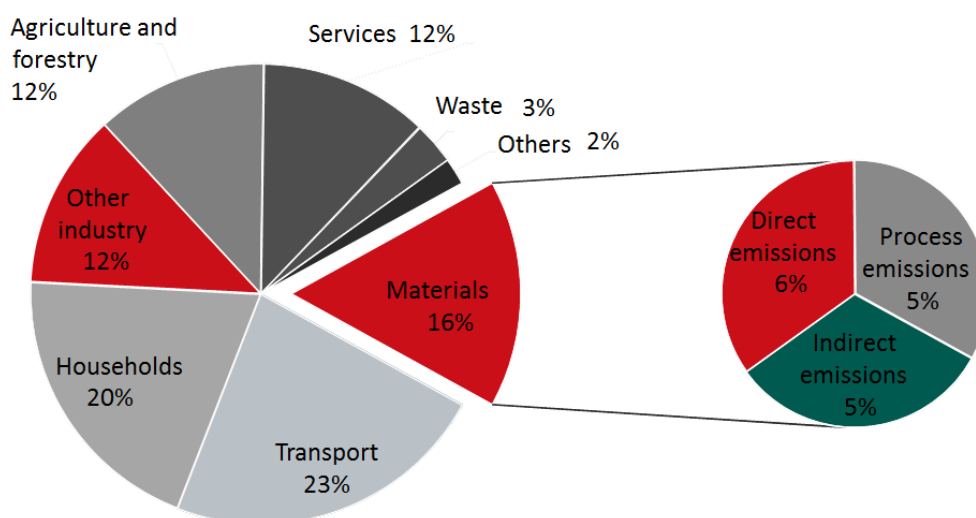
- **Integration across funding channels:** there are a variety of funding channels with climate policy, industrial policy or regional development policy objectives at local, national, and European level that can in principle support innovation in climate-friendly materials. Thus, it is important for each channel to focus on strengths and to identify complementarities.
- **Project-based carbon price guarantees** can complement investment grants and insure investors in climate-friendly production process and material options against regulatory risks over the life time of projects. This facilitates access to lower-cost finance for projects and firms while enhancing overall credibility of the climate regime.
- **Competition between projects for innovation support:** a sufficiently broad portfolio of technologies and practices combined with iterative up-scaling can create competition and thus incentives to increase and accelerate efforts. Factors like market readiness and likely spill overs need to be considered in granting support.
- **Facilitate learning and transparent review:** There is a need for continuous learning about technology, cost and social performance of climate-friendly material options. This should be the basis for a transparent review of the portfolio of mitigation opportunities benefiting from public support to limit regulatory uncertainty about funding decisions.

The interlinkages between innovation and large scale adoption are central to the success of corporate strategy and industrial climate policy. Accounting for them will signal that the public and the private sector have a shared long term vision for climate friendly materials so as to support sustainable investments in jobs in Europe.

1. Introduction

Basic materials like steel, cement or aluminium are important inputs for the construction of infrastructure and buildings as well as manufacturing of industrial products. Their primary production is, however, very carbon-intensive and in Europe responsible for 16% of greenhouse gas emissions (Figure 1). To limit the risks from climate change, emissions need to decline drastically in order to achieve 80-95% emission reductions by 2050 and climate neutrality by the second half the century as agreed by EU and UNFCCC Paris Agreement. This requires a portfolio of new technologies and business models for the production and the use of basic materials.

Figure 1: Basic Materials contribute to 16% of EU green-house gas emissions (EEA, UNFCCC 2010)



In this report, we discuss a policy framework for the industry to achieve the EU's climate objective and to participate successfully in a global low-carbon transition. Therefore, this report addresses the following three questions:

- I. A low-carbon transformation of the material sector requires a portfolio of mitigation options for climate friendly material production and use. **How broad should this portfolio be in order to support a learning experience for a transparent review of the policy framework?**
- II. Many options for climate friendly material production and use will be economically viable only if carbon intensive alternatives are exposed to the full carbon price, if regulation and norms tailored to traditional technologies are adjusted, and if regulatory risks are contained. **What policy design enables a large-scale use of these climate friendly options?**
- III. The success of climate friendly options depends on their integration into complex production processes and value chains. This requires private sector involvement and initiative. However, private firms are concerned about the scale of investments and regulatory uncertainty, knowledge spill over and the time lag

before commercial success. **What are the implications of these concerns for public innovation support?**

With this report, we aim to contribute to the debate by providing an integrated perspective across these three questions, in order to

- support the emerging vision for technologies, business models and policies that characterize the transformation of the material sector; a shared vision or roadmap helps to coordinate the public and private sector's choices for investment in the materials sector,
- explore complementarities and potential discrepancies in and between new production processes, new materials, efficient material use, recycling and re-use to gather political support for a low-carbon transformation from actors involved in any option and ensure policies address the needs of all options,
- integrate the often distinct debates on policies for innovation and for large scale use of climate friendly material options and to recognize that private actors will not invest in innovation without prospects for large-scale use.

This policy summary is structured along the three main questions raised above and explores emerging implications for policy design.

2. Portfolio of climate friendly options possible and necessary

Most emission reductions in the material sectors have to date been achieved through efficiency improvements and a switch to less CO₂ intensive fuels (mainly natural gas). Additional emissions reductions through efficiency improvements with existing process technologies will be modest and not sufficient to achieve the EU 2050 emission reduction targets. Accordingly, further emissions reductions channels need to be activated.

- **Climate friendly production processes:** Radical innovation can include hydrogen based steel making using renewable electricity, bio-based chemicals for material production or capture and use or storage of CO₂. The maturity of the different options varies – some are to be explored in laboratories, while others are to be explored next in larger scale demonstrations. Climate friendly production processes often improve several of the three mitigation clusters energy efficiency, fuels switch and carbon-capture and storage.
- **More efficient use of materials:** For decades, declining material costs and increasing labour costs limited the attention dedicated to material efficiency. Climate and resource efficiency objectives could provide the necessary attention to identify and realize efficiency potentials estimated for example in construction in the range of 20-30%.
- **Substitution with higher value or different materials:** Consumers review materials choices when performance requirements (fuel efficiency and weight of car) or preferences (design) changes. An increasing price of carbon intensive

materials can result in different material choices, and thus offer market opportunities for alternative or more tailored materials.

- **Increased reuse and recycling rates:** In the construction and automotive industry recycling rates are already high, but need to be increased for example in packaging. For all material use it is increasingly important to design products that facilitate later recycling without a loss of material quality, for example by avoiding compound material use, or to even allow for reuse.

While the role of these opportunities may differ across materials and is difficult to predict, it is clear that a deep decarbonisation of the industry sectors will depend on all of these mitigation opportunities. Despite these uncertainties, two major principles for policy design can be determined:

- **A broad portfolio** of technologies and practices needs to be developed and explored to limit the risk that cost effective opportunities are ignored and climate policy objectives are achieved in an unnecessarily expensive manner. The portfolio most likely needs to consist of innovative climate friendly production processes as well as solutions down the value chain including material efficiency and substitution.
- **Multiple projects** for the exploration of technologies and practices are required to reduce the risk that execution failures preclude follow-up projects.

2.1. Potential for climate friendly production of materials

The possible portfolio of low-carbon technologies for materials production to achieve ambitious long-term reduction goals is substantially more diverse than it is in other sectors such as transport, buildings or electricity generation. At the same time, it is also less researched. Scholars mostly assess the impact of existing available technologies and energy efficiency improvements in the mid-term (Brunke und Blesl 2014a, 2014b; Fleiter et al. 2012). In contrast, assessments of ambitious transition paths until 2050 including innovative break-through technologies are scarce.

Still, several relevant studies are available and provide valuable input for mitigation options and potentials. Table 1 provides a typology of reduction options ranging from energy efficiency in the production process to material efficiency and substitution downstream at the end-user of the material. For each cluster of mitigation options example technologies are included for illustration. These are drawn from both today's best available technologies and future technology (best not available technology).

Table 1: A typology of GHG reduction options in basic materials industry. Examples selected for illustration purposes only.

	Clusters of mitigation options	BAT	BNAT
Materials industry	Energy Efficiency	<ul style="list-style-type: none"> • Oxy-fuel burners • Use of waste heat • Shoe press in paper dewatering 	<ul style="list-style-type: none"> • Primary aluminium: inert anodes • Low-carbon cement
	Fuel switch	<ul style="list-style-type: none"> • Clinker: Lignite -> waste/biomass • Steam: Coal -> natural gas/ biomass • Natural gas DRI-EAF 	<ul style="list-style-type: none"> • Steel: RES-H2 DRI-EAF
	End-of-pipe (CCS)	<ul style="list-style-type: none"> • CCS cement • CCS steel 	<ul style="list-style-type: none"> • CCS steel with TRT
	Recycling and re-use	<ul style="list-style-type: none"> • Paper recycling • Electric steel • NFM-recycling 	<ul style="list-style-type: none"> • Cement/concrete recycling (to replace virgin clinker)
downstream	Material efficiency	<ul style="list-style-type: none"> • Construction: less over-dimensioning • Longer living products 	<ul style="list-style-type: none"> • Carbon reinforced concrete • Longer living products
	Material substitution	<ul style="list-style-type: none"> • Construction: Wood, clay and straw replacing concrete and steel 	<ul style="list-style-type: none"> • Low-carbon cement

(**BAT**: best available technologies; **BNAT**: best not available technologies; **CCS**: Carbon capture and storage; **NFM**: non-ferrous metals; **RES H2 DRI-EAF**: steelmaking with direct reduced iron and electric arc furnace using hydrogen from renewable energy sources; **TRT**: top gas recovery pressure turbine)

The iron and steel industry is among the most intensively assessed sub-sectors. Studies focussing on the use of energy-efficient technologies in the global steel industry date back to the 1990s (Beer et al. 1998). More recent studies assess the steel industry in Japan (Gielen und Moriguchi 2002), China (Wang et al. 2007), the EU (Pardo und Moya 2013) or from a global perspective (Oda et al. 2007). Similarly, a huge focus was on the cement industry with studies investigating energy-efficiency potentials in the US (Worrell et al. 2000), Thailand (Hasanbeigi et al. 2010), China (Xu et al. 2014) and the EU (Moya et al. 2011; Pardo et al. 2011). Other sectors have been less studied, but a few assessments are available for the global chemical industry (Saygin et al. 2011) or the global aluminium industry (Kermeli et al. 2014).

In recent years, the sector roadmaps that were published by industrial sector organizations at EU level explore mitigation potentials until 2050 often including innovative process technologies (BCG 2013: Steel's contribution to low-carbon Europe, EUROFER 2013: steel low-carbon roadmap, CEMBUREAU 2013: Cement low-carbon roadmap). A few technology examples are given in the following. For the petro-chemical industry, it is proposed to replace fossil fuel feedstock with biomass waste¹. However, biomass availability is limited. Ammonia production could be electrified through solid state synthesis². The cement industry considers a specific type of CCS technology

¹ CEFIC, 2013, p. 112

² Amar et al., 2011, p. 1860

(calcium looping), which comes with important co-benefits³. In the steel sector a new type of blast furnace that would eliminate the need for coking and sintering in hot iron production is currently being tested. While reducing construction and operation costs compared to conventional technologies, emissions could be reduced by 20%. Over longer time scales, hydrogen based ore reduction is under investigation, reducing emissions to almost zero (Jerkontortet, 2016). With a shift to CCS both construction and operational costs would increase but emission reductions of to 80% are possible⁴⁵.

These few examples show that there are potentially significant new production technologies under development. These technologies are in very different stages in the innovation cycle and it is certainly yet uncertain, if they will successfully enter the market.

2.2. Potential for substitution of carbon intensive materials

Innovative products will also have to play a key role in the industrial low-carbon transition. In the chemical sector development of new high-performing chemical compounds that can easily be assembled from bio-based feedstock will be essential⁶. The new products would facilitate the transition from a petro- to bio-chemical industry. For the cement sector most important low-carbon product innovations will need to occur in the design of new types of concrete. It is in theory possible to produce high quality concrete that only requires half of the amount of Portland cement as binding agent. This would lead to an emission reduction of 50%⁷, at current production levels. Advanced material science leading to high performance and lightweight steel can open a high value added market for steel producers, which targets downstream consumers in need of these types of steel for low-carbon performance of their products.

2.3. Potential for efficient use of materials

A paradigm shift towards higher levels of resource efficiency and a circular economy in the EU also matches well the industrial transitions mentioned in this report. Both the steel and the chemical sector have ample potential to increase re-usage and recycling of products⁸ and need to realize options to increase value added at lower sales volumes⁹.

There is now considerable evidence that products comprising carbon intensive materials could be manufactured efficiently and their lifetime extended to minimise replacement rates. In analysing the 'reach' of EU-wide collective corporate action,

³ Global CCS Institute, 2014

⁴ Ulcoss, 2016b

⁵ Croezen and Koreland, 2010, p. 32-33

⁶ Werpy & Petersen, 2004

⁷ Garcia, 2008

⁸ Bureau of International Recycling (2015)

⁹ Allwood and Cullen, 2012, pp. 53-54

Skelton (2013) identifies that the EU has influence over additional (non-traded) emissions in the region of 1 Gt CO₂, amounting to nearly a third of EU industry production emissions, by addressing company supply chains.

Barrett and Scott (2012) identify a range of measures that affect the design and consumption of different products showing that material use could be reduced by 40% while still delivering the same service provided by the products. This is further supported by analysis from Girod et al (2014) who demonstrates substantial material efficiency gains in shelter, travel and food provision. Strategies include product longevity (Bakker et al., 2014), material substitution (Gieseckam et al., 2014), design and urban planning (Müller et al., 2013) as well as product-service systems (Reim et al., 2015, Roelich et al., 2015).

It is clear that there is not one simple option that delivers material efficiency across the whole economy but a range of options for each “material service demand”. They often question fundamental business models, re-thinking design and the inefficiency of consumption by households, firms and governments. However, if there is a willingness to address the broad range of options, the reductions in material use could be significant.

3. Policy framework required for use of climate friendly options

The challenge for climate policy and corporate strategy is to create a credible and shared perspective to turn these opportunities into reality.

Ensure the internalization of climate externalities in the decision processes: A multitude of materials with a variety of production processes can deliver the services required in products and construction. It is therefore virtually impossible to provide generic recommendations for the type or scale of material used for specific applications, even more so in the context of evolving material properties. Exposing all decision makers to a carbon price provides a common basis to facilitate climate friendly material choices. If climate friendly materials options have incremental costs, then the climate friendly option will only be used if production and use decisions are exposed to climate externalities. If climate friendly options deliver cost savings, then they will be used at larger scale if carbon prices result in higher cost savings and more incentives for use of climate friendly options. For the structural reform this requires

- **alignment of EU Emissions Trading Scheme (ETS) cap and linear reduction factor with long-term climate objectives** to create a realistic carbon price for low-carbon options. The market stability reserve needs to provide a timely response to accumulated surplus of allowances in EU ETS (Schopp et al. 2015);
- **reflection of the carbon price in the materials price** to support efficient material use, higher value and low-carbon materials and as well as a business case for low-carbon production processes. This can be achieved through the inclusion of consumption of carbon intensive materials in the EU ETS, were international developments do not result in global pass-through of carbon prices.

Enabling environment including standards and codes: A shift to climate friendly material use requires adjustments to a variety of planning and permitting regimes, building codes, certification or various security requirements as well as appropriate training and certification of the work force and consumer engagement. To overcome barriers, the low carbon transformation of the materials sector requires:

- **roadmaps for sectors** to identify needs and to manage adjustment processes, and
- **a governance structure** that allows for learning about the requirements and the implementation of suitable solutions to enhance public acceptance and a positive business response.

Including carbon externalities in public procurement: Getting “value for money” is the primary objective of public procurement procedures. Public procurement based on environmental parameters can play an essential role to (i) to create markets for climate friendly options (ii) aggregate demand and to allow for economies of scale, and (iii) to support the public awareness for climate friendly materials and producers.

Realizing such potential for public procurement requires **incentives for local authorities and procurement officials** to adopt environmental criteria in procurement. Based on the green public procurement directive best practice examples, training of procurement teams needs to be further advanced and there is a need for a clear governance structure. This will help to make the overarching climate objectives relevant for individual procurement choices. Alternatively funding arrangements could address incremental costs that may result when implementing green public procurement.

3.1. Effective carbon pricing in the ETS

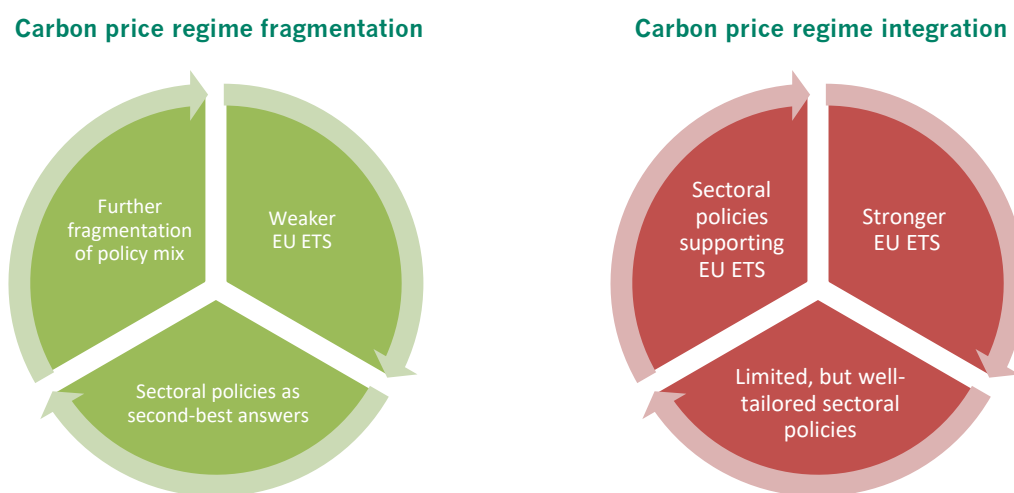
The evolution of a carbon-pricing regime in the EU is the key determinant for the prospects of adoption of climate friendly materials. Currently, it is at the crossroads between moving towards a unification of the price signal based on the reformed EU ETS and further fragmentation along sectoral lines (e.g. RES, energy efficiency, industry, transport, buildings) (CECILIA 2050/ENTRACTE 2015).

An assessment of policy instruments designed to promote low-carbon material choices should take into account that sectoral and overarching carbon pricing policy choices are interconnected.

Ambitious EU ETS reform resulting in a higher and more predictable carbon price signal decrease the need for dedicated instruments focused on industry, but also may lower their impact on the broader European Emission Allowances (EUA) market through weakening the supply/demand channel (e.g. through introduction of a carbon price floor). The inclusion of material consumption in the EU ETS may be a catalyst for such reforms by addressing industrial competitiveness concerns. Furthermore, the higher the EUA price, the more effective will consumption charges linked to the EU ETS be in driving climate friendly material choices. Expectations about future carbon prices are also crucial for innovation-related investments that pay off in the longer term

A lack of the EU ETS reform will result in a weak overarching carbon price signal. If a high carbon lock-in is to be avoided, broad national and/or sectoral instruments dedicated to the promotion of low-carbon material innovation should be adopted. This, in turn, will further undermine the role of the EU ETS in the policy mix for decarbonisation, at least in the short and mid-term. Low EUA prices will also mean that the inclusion of consumption will have a limited impact on the material efficiency and substitution further down the value chain, unless the carbon charge on consumption will be set higher than the EU ETS price. That, however, will further contribute to a fragmentation of the carbon-pricing regime.

Figure 2: Policy feedback loops in two indicative scenarios



While the fragmentation of the carbon price regime may be a less efficient policy option than a regime integration, it remains a probable option. Thus, the assessment of policy options for climate friendly materials should cover both scenarios, highlighting consequences of each policy choice from the perspective of the whole climate policy mix.

3.2. Inclusion of Consumption

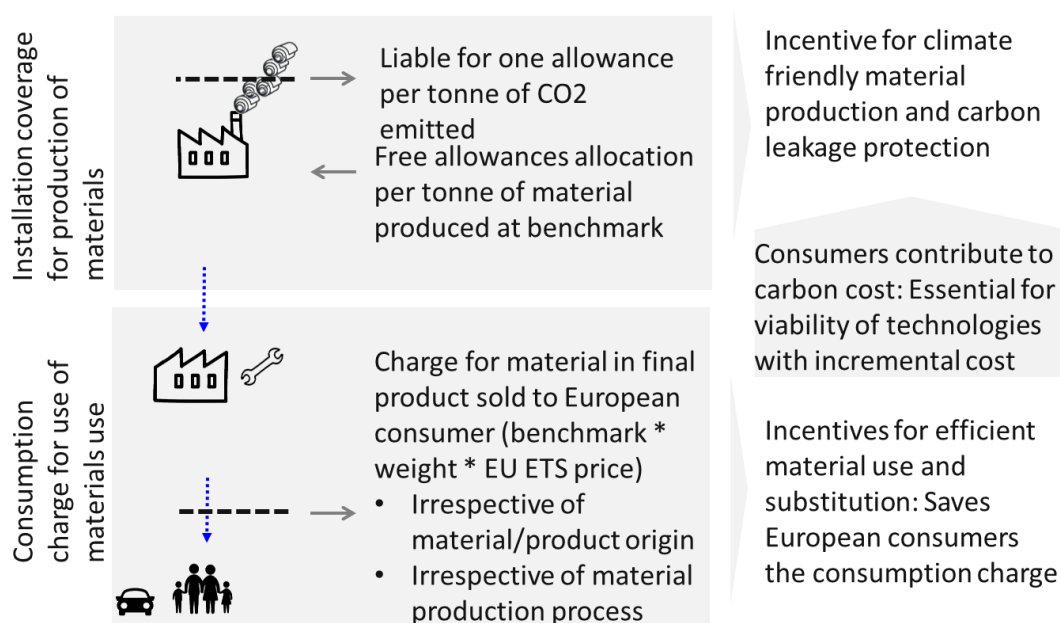
Initially, the EU expected that its ETS would be copied and integrated with similar schemes around the world. However, while some countries have implemented emission trading systems, their stringency and prices differ (Kossoy et al. 2015). Therefore, it is not possible to fully pass the carbon cost onto product prices of carbon intensive materials when they are traded internationally. This creates concerns regarding a relocation of production and associated carbon emissions (“carbon leakage”) outside the EU’s territory if carbon pricing puts a competitive disadvantage to European producers. To avoid higher costs for industry that could trigger such “carbon leakage”, allowances are allocated free of charge to industrial emitters. This further reduces carbon price pass-through.

Full carbon price pass-through is however crucial for the application of climate friendly technologies and practices in the material sector. It allows for example low-carbon cement to compete on a level playing field with traditional cement that bears the full carbon price. It allows the construction industry to dedicate more resources to planning and quality control as the savings from efficient material use increase. It also allows steel producers to invest in more expensive low-carbon steel making technologies, as incremental costs are passed with the carbon price to downstream purchasers and consumers.

The EU Parliament’s draft ETS reform text (as of January 2017, following a vote in the environment committee in December 2016) established the principle of full carbon-price pass through to material prices. It aims to achieve full carbon price pass through by including imports of selected materials into EU ETS while no longer granting free allowances to European producers of these materials. Thus producers will pass the full carbon price to product prices. The additional cost is adjusted for imports (and possibly exports) at the level of the benchmark that was previously used for free allocation to European producers. This also ensures full carbon leakage protection.

The full carbon price pass-through could be better achieved by “inclusion of consumption” instead of “inclusion of imports” of selected basic materials into EU ETS. Inclusion of consumption is politically less controversial than import adjustments and other trade related approaches, as it replicates uncontroversial consumption charges well established for alcohol, tobacco or excise on fuels. Inclusion of consumption has first been implemented in Korean and Chinese emission trading systems in the context of electricity (Munnings et al., 2016). It has been shown to be technically and administratively feasible (Ismer et al., 2016), legally viable as part of EU ETS (Ismer and Haussner, 2016) and discussed in the context of cement (Neuhoff et al., 2014), steel (Neuhoff et al., 2014) and pulp&paper (Roth et al., 2016).

Figure 3: How does Inclusion of Consumption in EU ETS work?



The system works by providing carbon-intensive materials producers free allowance allocation according to a benchmark and tightly linked to recent production volumes. This gives materials producers the full incentives for climate friendly production of materials while providing full protection against carbon leakage. The tight link of allocation to recent production volumes inhibits the carbon price pass through. Carbon price pass-through is instead re-established with an additional consumption charge for European consumers at the benchmark for carbon intensity of primary production of the material. Thus industrial and final consumers have the full incentives for efficient and alternative material use and producers a business case for climate friendly material production processes with incremental costs.

Materials that are close substitutes and carbon intensive should be jointly covered. In cement, steel and aluminum for example a €30/tCO₂ would already trigger price increases of 10%, 20% and 30%. Cambridge Econometrics simulated the macro-economic impacts for a scenario with EU ETS prices increasing to €80/tCO₂ by 2050. If demand is responsive (elasticity -1) CO₂ emissions from materials decline by up to 50% while overall economic performance increases by a quarter percent by 2050 (<http://www.carboncap.eu/>).

3.3. Enabling environment for technology adoption

Climate friendly technologies and practices may not be selected, even where they seem economical rational. This points to the importance of a broader consideration of decision criteria and processes that can support or inhibit climate friendly material choices – the enabling environment.

Adoption of technologies or innovations is linked by marketing and management literature primarily to technology and adopter characteristics of firms (Frambach and Schillewaert, 2002) or consumers (Arts et al., 2011). Technologies have frequently not been implemented because example pay-back periods exceed internal amortization requirements of about 2 years. Despite the evidence that firms with sustainable initiatives perform better (Judge and Douglas, 1998; Nakao et al., 2007) adoption of sustainable technologies remains slow. Institutional pressures of customers, competitors, and other stakeholders may accelerate adoption in the future (Srinivasan et al., 2002).

However, innovation in and adoption of material and production technologies in isolated firms at individual supply chain levels is insufficient. Business ecosystems need to combine value network structures and integrated technological knowledge-oriented education systems (Barnett, 2006). Thus supply chain barriers could be bridged in development and adoption of technologies. Value network structures could also help supply chain reconfigurations and reformulations of business models and customer value propositions and facilitated systemic innovation in related technologies. For example, changing from steel carbon fibres in making cars requires new coating processes to replace electrostatic systems.

Governments also have an important role in improving sustainable development of the firm (Wolf, 2013). The Dutch Environmental Law for example urges firms that use moderate energy levels to implement all sustainable technologies with pay back periods up to five years to overcome the constraint implied by 2 year amortisation. The “Vehicle Emissions Performance Standards” have improved the operational efficiency of car use by 20% between 1990 and 2011. Electrical appliances have also demonstrated significant improvements in efficiency driven by the Eco-Design Directive. The same can be said for improvement in building efficiency under the Energy Performance of Buildings Directive (Scott et al. 2017). Beyond the local impacts, there is also evidence of “trading up effects” (Vogel, 2009; Crippa et al., 2016). Crippa et al. (2016) found the implementation of regulatory standards for emissions and engine efficiencies in cars in Europe and America had a ‘trading up effect’ through economic integration where suppliers, use improved standards in their home country and support the implementation of similar standards to benefits from economies of scale.

The enabling environment is also important for efforts dedicated to development of sustainable technologies. This may involve the importance attributed to such development by stakeholders (Wolf, 2013), the nature of governance policies, e.g. international agreements on energy (De Coninck, Fischer, Newell, and Ueno, 2008), or

other external factors such as regulatory requirements, energy costs and customer demand (Rosen, 2013).

Coordination across the different stages of the value chain and across public and private actors is essential for such a transition. The EU 2050 roadmap remains however rather unspecific (COM 2011: Low carbon roadmap and impact assessment), while road maps developed by sector organizations are primarily focused on new material production processes. This points the importance of **further development and refinement roadmaps for the material sectors**.

Also standardization of technologies and avoiding institutional voids in regulatory frameworks is necessary. It needs to be complemented with an educational system directed at technological knowledge development from lower to the highest level of professions feeds the development, implementation and use of technologies. **Governance structures need to allow for** learning about the emerging requirements and timely adjustments of standards, regulation and training.

3.4. Use of Public Procurement

In the EU, governments spend the equivalent of 15% of the gross domestic product via public procurement in areas such as infrastructures, buildings, information technology, office equipment, and vehicles. In these areas, public procurement can create lead markets for climate friendly choices, providing some certainty to private sector suppliers on the uptake of innovations, and scaling up production to bring costs down (Edquist and Zabala-Iturriagagoitia, 2012). Like other 'demand-side innovation' tools (regulations and standards), procurement can spur innovation without engaging new spending, a plus in times of fiscal consolidation (Lember et al., 2015).

Many EU countries have launched sustainable public procurement programs of various kinds and scopes. The 2014 EU Directives on public procurement accommodates many innovations in this space, including the possibility to reflect the cost of externalities in public tenders, the use of life-cycle cost analysis or total cost of ownership. At international level, public procurement is governed by the Revised Agreement on Government Procurement. This agreement also includes the option to evaluate bids according to environmental characteristics.

Thus green public procurement can overcome the barrier created by the traditional "lowest bidder" approach to public procurement, which can be in blatant contradiction with the interest of procuring agency (e.g. when acquiring cheap equipment with energy expenditures that would more than offset the original price difference with a more efficient equipment).

In the Netherlands, Rijkswaterstaat, the public works administration, provides a Sustainable Building Calculator (DuboCalc) to tenderers to assess the environmental impacts of the use of materials in the contract (van Geldermalsen 2014). It allows contractors to 'optimise' on the basis of various environmental costs derived from a life-cycle analysis of materials, including CO₂. The environmental impacts are

translated into a monetary value, which is combined with the tender price to award the contract. Thus the cost of carbon is reflected, with all materials accounted for with their actual carbon and other environmental footprints. The level of the carbon price need not reflect the current EU ETS price, but may reflect the future carbon constraint.

The Norwegian Ministry of Transport launched in 2010 a competition for an energy efficient and low-emission car ferry to link two villages in the Sognefjord. The successful bidder would be awarded a 10-year concession contract. The Norwegian Public Roads Administration, in charge of the competition, required a minimum 15-20% improvement in energy efficiency over that of the existing diesel-powered ferry. Bids were evaluated on the basis of the price (60%), energy use per passenger car-km (18%), total energy use per year (6%), tons of CO₂ emitted per year (6%), kilograms of NO_x emitted per year (4%) and innovation (6%). The winning consortium offered the world's first electric car ferry.¹⁰

A well-known challenge of sustainable public procurement is the ability of procurement officers to design tenders that best drive sustainable and innovative approaches, without overly restricting competition for example by prescribing specific technology solutions. **This is being addressed with green public procurement directive and guidelines, best practice examples, and training of procurement teams.**

Furthermore, procurement officials may require a mandate to implement procurement procedures that may result in incremental costs. **This requires a clear governance structure to make the overarching climate objectives relevant for individual procurement choices, or funding arrangements to address incremental costs.**

¹⁰ References to other sustainable public procurement efforts can be found in Baron (2016).

4. Innovation strategy required for many climate friendly options

The potential of climate-friendly options will only be fully realized if integrated in complex production processes and value chains. This requires a strong engagement and initiative from the private sector. However, the following concerns may hinder private firms' incentives to invest in climate friendly options:

- The scale of investments required for innovation in green products and processes is large compared to the available financial resources of companies, and the time to bridge before commercial success long. Hence, firms will struggle to finance the investment.
- Appropriation of the benefits by innovators in the material sector may be limited, as engineering innovation is difficult to protect with patents, and the attribution of scarcity rents in a fragmented value chain is uncertain.
- Regulatory risks can remain significant where commercial success of an innovative process or product depends for example on a fully effective carbon price.

Public innovation support therefore needs to address financing constraints, to compensate for limited appropriation of benefits by the innovator, and to demonstrate commitment to climate policy.

Project-based carbon price guarantees can insure investors in climate-friendly production process and material options against regulatory risks and thus facilitate access to lower-cost finance for projects and firms while enhancing overall credibility of the climate regime.

Competition between projects for innovation support: Diversity of technologies and iterative up-scaling create competition and thus incentives to increase and accelerate efforts. Competition through new entrants can encourage incumbents to innovate, or to allow new entrants to capture market shares as in wind and solar power. For different stages of technology development, the policy framework, needs to considerate the level of market readiness, the level of appropriability by private actors, and the likeliness of spill-overs of innovation to develop a sufficiently broad technology portfolio.

Facilitate learning and transparent review: Continuous learning about technology, cost and social performance of climate-friendly material options is needed. This should be the basis for a transparent review of the portfolio of mitigation opportunities benefiting from public support to limit regulatory uncertainty about funding decisions.

Integrate across funding channels: A variety of funding channels with climate policy, industrial policy or regional development policy objectives at local, national, and European exist that can in principle support innovation in climate-friendly materials. Thus, it is important for each channel to focus on strengths and to identify complementarities.

4.1. Innovation support for large-scale demonstration projects

The notion of the technology valley of death is that technologies at the demonstration stage face particular challenges that lead to under-investment (Murphy and Edwards, 2003; Watson, 2008; Weyant, 2011). Private sector involvement is essential for experiential learning (Hendry et al., 2010) and to ensure technologies are explored as part of value chains and consumer markets (Macey and Brown, 1990).

However, private actors will struggle to fully fund innovation activities and in particular demonstration projects in break-through material technologies (Hurmelinna-Laukkanen et al., 2008). This is, because also other firms will benefit from knowledge about outcomes of demonstration projects. The radical innovation is inherently linked to uncertainty about performance, which typically requires a hedging strategy across a multitude of projects. However, the scale of investment required limits the ability of even the largest firms to afford such a portfolio. Furthermore, the regulatory risk about future market opportunities – e.g. linked to stringency of emission targets will impact all climate friendly innovation projects of a firm.

Hence, sharing of risks and rewards between public and private is essential (Baer et al., 1976; Markusson et al., 2011). Nemet et al. (2016) find in a study of 511 demonstration projects for capital intensive technologies a median public contribution of 64% with a 25-75th percentile range of 29% and 80%. The following policy recommendations follow from their analysis:

Prioritizing learning and tolerating failures: Selection of demonstration projects should focus on maximizing learning or minimizing cost per learning. Production and costs are useful indicators of progress but should not be the only project selection criteria. Otherwise technology risk will be avoided, technical diversity minimized, both of which are crucial for learning (Anadon et al., 2016). Instead demonstrations should be seen as experiments (Lefevre, 1984), part of a process of continuous experimentation (Hellsmark, 2010).

Disseminating knowledge: Management of knowledge produced, codification, stored, and transmission is central (Grubler and Nemet, 2014). Performance review of demonstrations projects (Frishammar et al., 2015) and reporting of results (Gallagher et al., 2006) is helpful. For example, UK CCS plant design benefitted from access to the engineering plans in previous rounds (Reiner 2016). These benefits need to be balanced with private claims of proprietary access to knowledge created.

Iterative upscaling: Learning is enhanced with a sequence iterating technical, organizational and market demonstration (Bossink, 2015). Demonstration plants are tools for upscaling (Frishammar et al., 2015), which takes time, and requires passing through a formative phase' of experimentation (Wilson, 2012). Building to full commercial size immediately is asking for trouble, as we've seen in wind (Garud and Karnoe, 2003) and to some extent in CCS (Lupion and Herzog, 2013).

Supporting diversity Strong scale economies imply a need for diversity support (Markusson et al., 2012) to avoid lock in (Shackley and Thompson, 2012). Given multiple pathways available for large scale low carbon technologies, premature focus can be risky (Nemet et al., 2013). This creates a need to support variety while evolutionary mechanisms impose selection pressure (Kemp et al., 1998).

The proposed Innovation Fund for the period 2020-2030 can become an important tool to enable a timely commercialisation of new material technologies. Linked to a milestone-based reward system can reduce the risk for both the public and private sector. Close integration with further funding channels and instruments is essential for the required scale of innovation.

4.2. Project based carbon contracts

For pilot plants and subsequent commercialization of climate-friendly production processes and new materials, large-scale investments are required. Climate-friendly technologies typically require higher investment costs than conventional technologies or refurbishment of existing assets to achieve better energy efficiency (insulation, heat recovery) or for additional processes to reduce emissions, like in the case of carbon capture and use for other applications. They may also imply higher operational cost with a shift from coal to low-carbon energy carriers like biomass or renewable electricity.

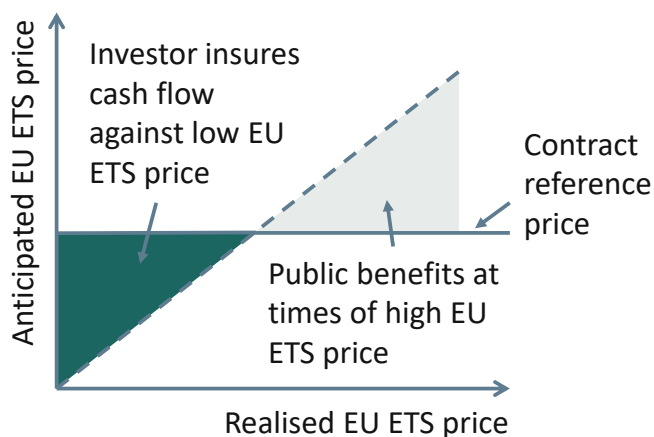
Firms will consider additional investment and operational costs against savings on CO₂ emissions monetized at the anticipated CO₂ price during the initial 10-15 years of plant operation. Large uncertainty about the trajectory of the CO₂ price (i) can put at risk the operation of technologies with incremental operational costs and (ii) diminish the contribution of such savings to the refinancing of investment cost. Thus it can stop the progress of new technologies or increase the required scale of public co-funding for innovation.

Of particular concern for investors is, that the price risk associated with the EU ETS is not purely market driven, but consists also of a general credibility problem of governments and a time horizon problem of carbon markets (Helm and Hepburn, 2005). The general credibility problem is due to governments' incentive to renege on their policy position and, for example, supply additional allowances to deliver short-term price reductions for consumers and industry at the expense of longer-term investment incentives. The time horizon problem arises since the investment timescales for the assets and infrastructure needed in the materials sector often exceed the periods for which for example benchmarks, or the emission trajectory under the EU ETS are defined (Nemet et al., 2017).

Building on the general idea of carbon contract (Helm and Hepburn, 2005) and commitments by governments through financial options (Ismer and Neuhoff, 2006), national governments could offer long-term carbon contracts for differences (CCfD) on the carbon price, linked to innovative projects with the potential for deep emissions reductions. Thus they could provide a commitment to a reference carbon price and

benchmark and thus make the cost savings from emission reductions predictable and bankable for investors. Thus additional financing structures and sources can be accessible and financing costs reduced, facilitating implementation of additional projects or reducing the required public investment support for such projects.

Figure 4: Project based carbon contracts insure investors against low carbon prices and consumers against high ones



Several design elements need to be considered. The first is the qualification for recipients of CCfDs. As the objective is progress with new climate-friendly materials or production processes, an ex-ante assessment needs to confirm a sufficiently deep emission reduction.

Second, the contract reference price and contract duration could result from a competitive bidding process, or be set ex-ante by governments while projects bid for example on the additional innovation support required. In this case, the reference price could (i) reflect current expectations of price developments (ii) anticipate future CO₂ price increases (iii) be based on the social cost of carbon (iv) include a mark-up to provide incentives for innovative technologies.

Third, the monitoring mechanism on the CCfD could build on existing monitoring mechanisms of the EU ETS, for example, to ensure the continued linkage to an active project.

4.3. Legal aspects

Public funding can support innovation processes. However, it also can distort the market and discriminate against a group of competitors. It is thus essential to frame public funding schemes in a transparent and non-discriminatory manner.

From an EU law perspective, public funding through EU institutions is not subject to State Aid rules. These rules only apply where public funding takes place through Member States. According to Art. 107 TFEU, any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favoring certain undertakings or the production of certain goods is, in so far as it affects trade between Member States, incompatible with the internal market and thus prohibited. Nevertheless, this does not constitute an absolute prohibition on state aid. Rather, the Commission can grant approval for state aid schemes under the EU rules on state aid (Art. 107:III TFEU). If the commission has not approved a funding scheme qualifying as state aid, undertakings that received aid would have to pay back the financial resources that were granted by Member States.

From an international law perspective, public funding schemes have to comply with the General Agreement on Subsidies and Countervailing Measures. This Agreement applies where a financial contribution that constitutes a benefit was granted to undertakings within the territory of a Member to the Agreement by the government. Financial contributions do comprise not only a direct transfer of funds (e.g. grants, loans and equity infusion), but also government revenue forgone that is otherwise due (e.g. tax credits).

The agreement distinguishes between two types of subsidies: Prohibited subsidies and actionable subsidies. Prohibited subsidies comprise financial contributions that are specifically designed to distort international trade. In contrast, actionable subsidies are financial contributions with an adverse effect to the domestic industry of other Members. Both kinds of subsidies have to be withdrawn. Otherwise, Members can impose countervailing duties.

Due to the consequence of illegal state aid, it is essential to draft public funding schemes on innovation within the framework of EU and WTO law.

5. Conclusion – linking up policies for innovation and use

In conclusion, a consistent perspective for a climate-friendly transition of the materials sectors requires the fulfilment of the following three needs:

First, the need to develop a shared vision or roadmap for technologies, business models and policies, which supports the coordination of public and private sector's choices for investment in the materials sector. This shared perspective should be based on the portfolio of technological options, should structure the enabling environment, and should work as a basis for decisions on public co-funding. Successful realization needs to attract both industry interest and be based on broad public engagement.

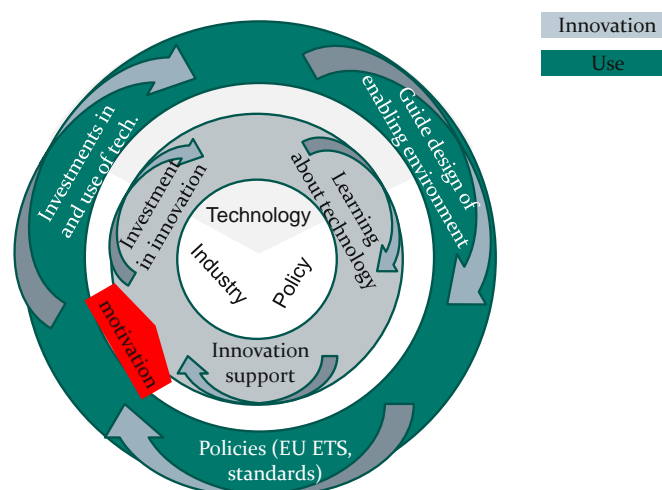
Second, to jointly consider new production processes, new materials, efficient material use, and recycling and reuse of materials for the structure of road maps and design of policies. This ensures consistency across technologies and materials, engages all actors to jointly support a policy framework, and allows for incentives for fast and cost efficient technology development from competing between technologies and business models.

Third, the need for an integrated design of policies for innovation and a large-scale use of climate-friendly material options, recognizing that private actors will not invest in innovation without prospects for large-scale use. This creates interlinkages between innovation and large-scale use, which can be summarized as follows:

- private firms will only dedicate their own resources to innovation if this opens future business opportunities. Thus, a credible perspective of large-scale use is necessary to motivate and structure innovation by private firms.
- a credible vision for the large scale use of technologies depends on the policy framework, both with respect to the enabling environment (standards and codes, training and certification of work force) and with respect to the internalization of carbon externalities by carbon prices.
- while private identification and selection of promising options and initiative in their realization is essential, public support for innovation including pilot projects will also be critical as together, it is a strong business case.

The interlinkages between innovation and large-scale adoption are central for the success of corporate strategy and industrial climate policy. Accounting for them will signal that the public and the private sector have a shared long-term vision for climate friendly materials.

Figure 5: Link policies for innovation and use of climate friendly materials



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