Accelerating the Climate Transition

Key Messages from Mistra Carbon Exit

MISTRA
CARBON
EXIT

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PREFACE

We need to dramatically accelerate the climate transition

The IPCC has shown that climate change is occurring faster than expected and that extreme weather events, such as the floods, extreme temperatures and fires witnessed in 2021, can be linked to human activities. If we are to achieve the objectives of the Paris Agreement, to keep the global average temperature increase well below 2°C, deep cuts will have to be made in global emissions of greenhouse gases (GHGs), not only on the long term but also in the run up to Year 2030. Thereafter, the goal of zero emissions must be reached by the middle of this century.

Sweden has committed to achieving net-zero emissions by Year 2045, and many other countries have made similar commitments. The EU Commission has recently proposed that the EU should be climate-neutral by Year 2050. These targets will require transformative pathways that involve completely new processes in many industries, as well as a complete overhaul of the value chains from basic materials to end-products and services. Thus, incremental reductions in emissions will not suffice.

Several positive developments

Transforming the society to near-zero emissions within 25 years may seem like an overwhelming task. Nevertheless, there have been several positive developments. The price for wind and solar power has dropped dramatically, sales of electric vehicles are increasing faster than expected, and we are seeing several industrial initiatives to produce zero-carbon steel, with car manufacturers committing to buy these materials. In Sweden, key industrial sectors, including the building and construction sector, have developed roadmaps within the Fossil Free Sweden initiative. Although the roadmaps are conceptual in nature, they indicate that there is a consensus that the Swedish climate targets must be reached.

In addition, the cost of emitting carbon in the EU ETS has increased 12-fold in 4 years, from 5 EUR per tonne of CO_2 in 2017 to 60 EUR in September 2021. While these are all highly positive developments, they are not enough. We need to accelerate dramatically the climate transition. Emissions need to be reduced by several percentage points per year. We do not have time to pick only the low-hanging fruits; we need to start picking all the fruits. The whole of society needs to engage, in all sectors and at all levels, including policymakers, firms, municipalities and citizens. The decisions and actions taken this decade will have a critical impact on our ability to reach zero emissions in Year 2045.

Analyzing opportunities and challenges

So how can we accelerate the climate transition? The objectives of the research program Mistra Carbon Exit are to identify and analyze the technical, economic and political opportunities and challenges for Sweden to reach the target of net-zero GHG emissions by Year 2045. We adopt a novel approach to address this problem from the supply chain perspective: from the input of raw materials, through the primary and secondary activities, to the final products and services demanded by the end-user. We focus on the supply chains of buildings, transport infrastructures, and transport systems. The program, which started in 2017, is being carried out by 10 research organizations from 4 countries, in co-operation with 23 Swedish companies, authorities and NGOs.

In this publication, we present the main findings from the first four years of Mistra Carbon Exit, distilled down into 29 key messages in the following chapters.

Chapter 1 *Buildings and Transport Infrastructure* presents the key results from our technical assessments of the materials production processes, energy systems, buildings, and infrastructure. We have identified the technologies that will pave the way towards a low-carbon economy, and most of these technologies can start to be implemented in the next 5–10 years.

Chapter 2 *Transportation* focuses on transportation and the impacts that different policies and measures are expected to have on decarbonization, such as a ban on combustion engines, the fostering of policies regarding electric vehicles, and increased car sharing.

Chapter 3 *Governance and Behavior* describes how attitudes towards climate action have changed globally and discusses the factors that drive firms and consumers to engage in climate

In this publication, we present the main findings from the first four years of Mistra Carbon Exit, distilled down into 29 key messages in five chapters

action, as well as the ways in which they respond to different policies. We also show that Sweden can play an important role in shaping the EU climate policy.

Chapter 4 *Policy Design* focuses on policy design for industry, energy, buildings and infrastructure. In this context, carbon pricing through the EU ETS is a centerpiece of EU climate policy, although further reform is needed. It is also clear that carbon pricing needs to be complemented by other policies, for instance standards, investment support through carbon contacts for differences, and public procurement. We present how financial funds can be raised to support investments in low-carbon technologies. While negative emissions are a central component of global scenarios to reach net-zero emissions in Year 2050, there are few incentives for producing them. We show how incentives and financing can be created for technologies that facilitate negative emissions.

Chapter 5 Sustainable Climate Transition. The climate transition which should unfold in the next 10-20 years, will have implications for other sustainability goals. Zero-carbon materials, electric vehicles, and renewable energy will become the new normal. These are likely to impose stress on other development goals, such as biodiversity. Some traditional jobs will disappear, with potential social impacts. But it's likely that the transition also will bring ancillary benefits, such as improved air quality and new jobs. Swedish industry developing new technologies may win market shares and create export opportunities. These implications will entail challenging compromises and need to be understood. This work has started, and in this chapter, we present some initial conclusions.

We hope that you will find this publication interesting and thought-provoking!

Lars Zetterberg, Filip Johnsson,
Program management Mistra Carbon Exit

1. Buildings and Transport Infrastructure

Recent estimates indicate that the construction sector accounts for approximately one-quarter of global CO_2 emissions.

We have assessed the potential for reducing the climate impacts of both infrastructure projects (road construction) and the construction of buildings. In assessing the energy supply, we show how future steel production can contribute with flexibility within the electricity system, thereby supporting the efficient integration of wind and solar power.

The results indicate that it is technically possible to decrease by 40–50 percent the CO_2 emissions from road and building construction projects, through applying current best-available technologies and practices. Moreover, it will be possible to achieve close to net-zero emissions by Year 2045. The latter would require transformative technologies such as CCS being applied to cement production and electrification.

Paying the full price of basic materials

JOHAN ROOTZÉN AND FILIP JOHNSSON

A shift to new low-CO_2 cement- and steel-making processes would substantially increase the cost of cement and steel. However, the increase in price for the end-products, such as buildings and cars, would be marginal. This insight opens up possibilities for innovative ways to fund a technical shift in the basic materials industry.

Primary production processes for basic materials, such as steel and cement, are among the most energy- and CO_2-emission-intensive industrial activities globally. Reducing emissions in line with the goals set out in the Paris Agreement implies a drastic deviation from the historical trend and will require the implementation of profound changes across the entire supply chains: This will involve measures to reduce the carbon and energy intensities of primary production, while concurrently improving material efficiency in the further processing and use of basic materials.

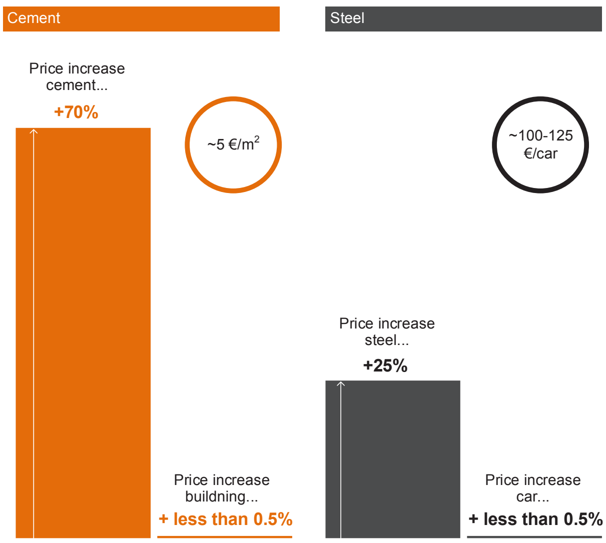

Figure 1. Investing in new low-CO_2 cement- and cement-making processes would require substantial increases in the selling prices of cement and steel, although the price increases facing a procurer of a building or the buyer of a car would be marginal.

Allocating the costs along the supply chain

In tracking the material and value flows involved in the supply chain for steel and cement, we have assessed how the costs of CO_2 abatement could be allocated along the supply chains of cement and steel. We show that while covering the costs of investing in new low-CO_2 steel- and cement-making processes would require substantial increases in the selling prices of steel and cement, such price increases would neither significantly alter the cost structure nor dramatically increase the price to be paid by end-users, e.g., a car buyer or a procurer of a building or an infrastructure project. Moreover, the (marginally) increased costs could be further reduced by efforts on the demand side to optimize, curb and reduce the consumption of cement and steel.

We conclude that a transformation of traditional cement- and steel-making processes to utilize zero/low-carbon materials will not constitute a major cost for society but will instead be a distributional issue. This should also open up avenues to alternative support and business models for funding the transition, as discussed in, for example, *EU ETS is not the only show in town - Industrial decarbonization requires policy packages and A transition fund to foster deep emissions cuts in the basic material industry.*

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A concrete change: Decarbonizing cement production

JOHAN ROOTZÉN, IDA KARLSSON, AND FILIP JOHNSSON

Decarbonization of the cement industry will involve two parallel activities: investments in zero-emission production processes, such as Carbon Capture and Storage (CCS); and investments in measures to reduce cement and concrete use.

Both activities require complementary policy interventions and/or private initiatives, to secure financing and lessen the risk for investments in zero-emissions production processes, as well as to incentivize changes in building and construction practices.

It is obvious that concrete has had, and continues to have, important roles to play as a structural material in the buildings and infrastructure that provide shelter from the elements and mobility for people and goods, including the infrastructures for the supply of water, electricity, and heat. However, global annual production of close to 30 Gt of concrete contributes to around 8% of global CO_2 emissions. The production of cement, which acts as a binding material, accounts for the majority of these emissions. Thus, it is important to find ways to reduce and, in the longer term, eliminate CO_2 emissions from the production of cement.

Biofuels, electrified kilns and CCS

As part of the Mistra Carbon Exit research program, we have developed a series of roadmaps that explore how different choices, with respect to technological development in the Swedish cement industry, influence material flows, energy use, CO_2 emissions and cost over time. The analysis illustrates how CO_2 emissions can be reduced to a level close to zero, and proposes different technological options for achieving this, such as increased biofuel use, electrified cement kilns and CCS. However, the different technical choices will have very different impacts on the surrounding energy system.

The results give an indication of the rate and scale at which the support infrastructure would need to be rolled out in terms of a renewable electricity supply, electricity grid expansion, CCS infrastructure, and sustainable biofuel supply. Since the lead times related to planning, permitting and construction of both the support infrastructure and the piloting and upscaling to commercial scale of the actual production units are long, initiation of strategic planning will need totake place as soon as possible. Successful decarbonization of the cement industry will also involve complementary policy interventions and/or private initiatives to secure financing and lessen the risk associated with investments in zero-emissions production processes.

Since more than half of the emissions from cement production arise from the calcination of limestone, the application of CCS technology is more or less inevitable to achieve deep emissions cuts in cement manufacturing.

Public procurements can incentivize circular practices and efficiency

Whereas the emphasis of this work has been on options to reduce the direct on-site energy-related and process-related CO_2 emissions from cement plants, it is also important to increase efforts on the demand side, to optimize, curb and reduce the consumption of cement and concrete.

This will not necessarily come at the expense of reduced profitability for concrete products. Since most of the cement and concrete produced in Sweden is used within the country, there is a clear link between measures to reduce the use of cement and concrete and the possibility to reduce emissions from domestic cement production. Here, public procurers in governmental agencies, municipalities, and county councils, by virtue of their significant purchasing power, play important roles in reducing the risks associated with material innovation and incentivizing circular practices and material efficiency. In addition, private actors can help to increase the volume of demand and to legitimize public strategies.

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Reaching net-zero emissions require best available technologies and transformative shifts

JOHAN ROOTZÉN, IDA KARLSSON, AND FILIP JOHNSSON

CO_2 emissions from the construction of buildings and transportation infrastructure can be cut by 40-50 percent by applying best-available technologies and measures.

However, reaching close-to-zero CO_2 emissions would require the inclusion of transformative technological shifts, including the electrification of machinery/transports and electrification of and/or implementation of carbon capture and storage in the basic industry.

Research in Mistra Carbon Exit shows how key priorities to unlock the potential for emissions reductions that exist already today include efforts to upscale the use of sustainable biofuels, optimization of material use and mass handling, increased recycling of steel, asphalt and aggregates, and increased use of alternative binders in concrete.

However, reducing CO_2 emissions to a level close to zero would require the inclusion of transformative technological shifts, including the electrification of machinery/transports and the electrification of and/or implementation of carbon capture and storage (CCS) in basic industry. While these technologies are to a large extent known, they need to be demonstrated at large scale.

From the work, it is clear that a decarbonization of the building construction will also require efforts to identify and manage "soft" measures (organization, knowledge sharing, competences), in addition to the handling of cost barriers.

New ways of cooperating, coordinating and sharing information must be devised and implemented

Unlocking the full abatement potential of these emission reduction measures will involve not only technological innovations, but also innovations in the policy arena combined with new ways of cooperating, coordinating and sharing information between actors.

These will include:

• Legislators and regulators realizing their power (and responsibility) to contribute towards reducing the CO_2 emissions from infrastructure construction. This will not only have to include environmental economic policy instruments and regulations, but also the making of decisions as to what and how much new transport infrastructure is to be built.

• Providing policy coordination and clear responsibility for monitoring and follow-up of progress. Establishment of a clear division of responsibility for national and sector-wide follow-up of progress aligned to national goals, sector goals and industry roadmaps.

• Overcoming compartmentalization in traditional organizational structures, so as to encourage coordination and collaboration within and between projects and across the supply chain.

• De-risking material innovation and incentivizing circular practices, material efficiency and material substitution measures in permit issuing and procurement requirements.

• Engaging stakeholders in the supply chains for basic materials, such as steel and cement, to work collectively towards securing financing and de-risking investments in low-, zero- or negative-emissions technologies.

It is worth noting that while building and infrastructure construction obviously have much in common when it comes to routines, equipment and key materials and products – concrete and steel in particular – there are also major differences with respect to the networks of stakeholders involved and the possibilities to carry out substitution of materials and adaptations of practices.

However, for a successful transition to zero-carbon emissions in both building and infrastructure construction, it is important that picking 'low-hanging fruits', such as material substitution and efficiency measures, is not used as an excuse for not laying the foundation for higher-cost, deep decarbonization measures in terms of transformative technologies such as CCS and electrification in steel- and cement production. Conversely, it is also vital not to allow possibilities for such future technologies to become an excuse for failing to unlock the potential of lower-cost measures that already exist today.

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Hydrogen-mediated direct reduction of steel and the electricity system – a win-win combination

ALLA TOKTAROVA, IDA KARLSSON, LISA GÖRANSSON, JOHAN ROOTZÉN, MIKAEL ODENBERGER, AND FILIP JOHNSSON

The European steel industry must achieve deep reductions in CO_2 emissions to meet the targets set out in the Paris Agreement. Options for reducing CO_2 emissions include electrification, carbon capture and storage (CCS), and the use of biomass. The plummeting cost of renewable electricity makes expanded electrification an attractive option for eliminating the current dependence of the steel industry on coal.

In Mistra Carbon Exit, we have investigated how electrification of the steel industry using a hydrogen-mediated direct reduction steelmaking process can interact with the electricity system towards achieving zero CO_2 emissions from both the steel industry and electricity sector.

Techno-economic pathways to assess electrification of the steel industry

The concept of techno-economic pathways is used to investigate the potential implementation of CO_2 abatement measures over time, towards the goal of zero-emissions steel production in Sweden. Two different techno-economic optimization models are used. The first model investigates the impacts of electricity price variations on investments and the operation of steel production. The second model is applied to study the interaction between an electrified steel industry and the future electricity system of northern Europe.

Sweden can help to decarbonize the European steel industry

The results reveal that for Sweden, it will be feasible to reach close-to-zero CO_2 emissions from steel production by Year 2045 using electrification via a hydrogen direct reduction process. We also show that increased production of hot briquetted iron (HBI) pellets could lead to decarbonization of the steel industry outside Sweden, assuming that the exported HBI will be converted via an electric arc furnace (EAF) and that the receiving country has a decarbonized electricity generation system.

The results also indicate that the cost-optimal design of the steelmaking process is strongly dependent upon the electricity system composition. It is found to be cost-efficient to invest in overcapacity for steel production units [electrolyzer, direct reduction shaft (DR shaft) furnace and EAF] and in storage units for hydrogen and HBI, so as to allow the operation of the steel production capacity to follow the variations in electricity price.

Electrification of the European steel industry will increase electricity demand

The modeling shows that an electrified steel industry could increase the electricity demand of northern Europe by around 180 TWh (i.e., 11 percent), and that the geographic placement of the electrified steel production capacity might differ from the current allocation of steel plants. Certain factors, such as the availability of low-cost electricity generation and access to iron ore, significantly influence the allocation of electrified steel plants. The modeling results show that the additional electricity demand from an electrified steel industry can be met primarily by increasing the wind and solar power outputs.

Achieving a transition of the steel industry as described above will obviously present major challenges for society. There will be strong pressure on the transition of the electricity supply system to include flexibility on the demand side and the application of hydrogen storage systems.

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An electricity system based on renewables that addresses the future power demand

LISA GÖRANSSON

In a climate-neutral society, electricity is expected to be a crucial energy carrier. There are multiple technological options to generate electricity without emitting carbon dioxide, and several of these options offer electricity at a relatively low cost.

As a consequence, sectors that today rely heavily on fossil fuels for their energy supply, such as the transport and industry sectors, are seeking possibilities to replace these fuels with electricity. The possibility to use electricity to derive fuels (e.g., hydrogen and electrofuels), in order to replace a fossil fuel-based feedstock, is also considered.

One important enabler of the ongoing electrification is the phenomenon whereby the costs of wind and solar power have decreased steadily over the past two decades. Dedicated policies that stimulate investments in modular wind turbines and solar panels have cut costs to the extent that these technologies are currently competitive without subsidies in many parts of the world. Scenarios reported by the European Commission indicate that by Year 2050, more than 80 percent of electricity will be generated from renewable energy sources.

Variability in supply managed by storage or demand-side management

Electricity generation from wind turbines and solar panels relies on varying wind speeds and levels of solar irradiation. Thus, these methods of electricity generation introduce variability into the electricity system. Historically, variability in the electricity system was introduced primarily by the electricity demand and was mitigated by a dispatchable supply side, mainly involving thermal generation and hydropower. In an electricity system in which the dispatchable supply is small relative to the variable supply, variability must instead be managed by demand-side management of the variations or by using dedicated storage systems.

Electrification of the transport, industry and heating sectors can offer flexibility to various extents through applying different strategies that can be supported by electricity price incentives. Energy can be stored as hydrogen, as heat or in vehicle batteries.

Results from the work conducted in Mistra Carbon Exit show that, based on cost structure and flexibility constraints, it is cost- and resource-efficient to adjust electric vehicle charging and hydrogen production to the net load in the electricity system. In particular, it is found to be strategic to charge electric vehicles during periods of high availability of solar power and to avoid hydrogen production during hours of low wind power production. (We have found that this mode of strategic consumption of electricity reduces the need for stationary batteries for variation management within the electricity system. Strategic consumption of electricity also implies a lower cost of electricity for the flexible consumer. Naturally, the electricity demand of a strategic consumer is supplied to a greater extent by wind and solar power, as compared to a case in which the consumer does not adjust their consumption pattern to the availability of wind and solar power.

Higher initial cost of the charging infrastructure and electrolyzers

The strategic consumption of electricity requires a higher level of investment in electricity-consuming equipment compared to a situation in which electricity consumption is governed exclusively by the consumption side. Thus, a higher initial cost for the hydrogen production equipment (i.e., electrolyzers), electric vehicle charging infrastructure, or heat pumps needs to be absorbed to enable flexibility. These investments may need to be made before the full variability of the electricity prices is manifested i.e., before volatility in electricity prices makes the investments competitive.

Clear communication between the supply and demand

Given the high capital costs and long lifetimes of many investments associated with electrification, clear communication between the supply-side and demand-side is needed in the planning for electrification, so that the future value of potential flexibility contributions is accounted for when investment decisions regarding electricity-consuming equipment are taken. Furthermore, successful implementation of the abovementioned flexibility strategies will require the implementation of smart communication systems.

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Three types of barrries to overcome for successful implementation of abatement measures in the construction sector

MARCUS ERIKSSON AND STEFAN UPPENBERG

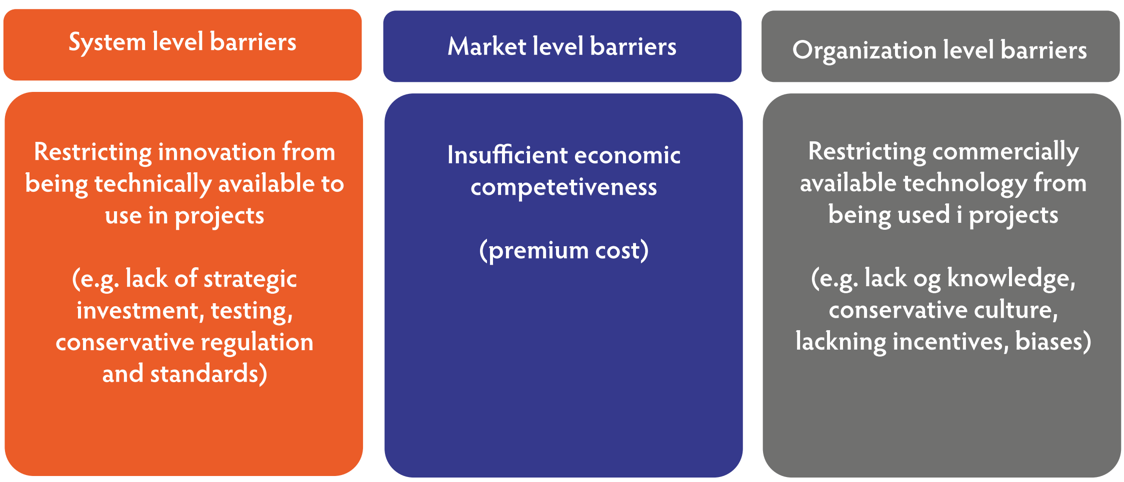
Based on an assessment of the different technical measures needed to decarbonize the building and construction sector, we identify barriers on the levels of the system, market and organization. This three-level barrier structure calls for a holistic approach to finding solutions and orienting construction projects on a trajectory towards climate neutrality.

We have analyzed the barriers that need to be overcome to implement successfully the technical abatement measures identified by Karlsson and colleagues (2020) as part of the Mistra Carbon Exit Programme. The aim was to use the barrier assessment as a starting point for formulating solutions and policies towards an efficient transition of the building and construction sector, although here we focus on the construction sector.

The barriers to abatement can be broadly characterized as obstacles that occur at the system level, market level, and organization level (Figure 2). This categorization is based on where in the construction process the barriers occur and at what level they can be solved. Typically, system-level barriers and market-level barriers need to be overcome for an abatement measure to become available for use in projects, after which organization-level barriers become relevant.

System level

It is clear that certain abatement measures need to occur in conjunction with significant developments before they become available on the market and, subsequently, available to use in construction projects. These developments include further investments in research and development, further testing and validation of the technical capabilities of an innovation, and steps to ensure that the innovation is compatible with the applicable legislation and is included in the relevant technical standards.



Market level

Once an abatement measure becomes technically available, the level of economic competitiveness needs to be such that there are incentives to choose the low-carbon solution.

This is particularly important for the innovation to penetrate the market and become the default choice. The absence of economic competitiveness is a market barrier, and is governed by factors such as supply, demand, and economic policy.

Organization level

Whether or not available and viable abatement measures are eventually implemented depends on decisions made by the construction project stakeholders – the clients, designers, contractors and suppliers. Regardless of economic competitiveness, someone, at some point, needs to decide to use a less-carbon-intensive product, material or process in place of the conventional solution. The factors that influence the choices and decisions of individual designers, engineers or planners include the workplace culture, norms, expectations, and incentives for the person or team. The barriers within this category can exist within organizations, as well as within specific project groups, which do not always align with each other.

Three of the most-important organization level barriers identified were: lack of reliable reference cases; lack of incentives for project managers to try new solutions; and lack of knowledge regarding the properties and cost reduction potentials of low-carbon materials.

Holistic approach

The abovementioned barriers call for a holistic approach to work out how available mitigation measures can best be implemented over time. An example is the introduction of calcinated clays as a large-scale alternative to Portland cement: on the system level, cement standards have to be adapted to allow the use of such binders; on the market level, the possibility to obtain permits for clay mining has to be enabled; and on the organization level, designers, contractors and suppliers have to learn about the properties of the materials and how to adapt their design parameters and construction methods.

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2. Transportation

The greenhouse gas (GHG) emissions from the passenger transport sector in Sweden corresponds to about 10 $MtCO_2$-eqv per year, which corresponds to about one-fifth of total Swedish GHG emissions. If we also include emissions that are incurred higher up in the supply chain of fuels and materials used in the vehicles, the emissions that can be associated with passenger car transport increase to about 15 $MtCO_2$-eqv per year.

Thus, it is critical to understand how these emissions, occurring both in Sweden and through the supply chain also in other countries, will be affected by ongoing trends in the passenger car transport sector, such as electrification, automation, and car- and ride-sharing. Given the overall goal of net-zero GHG emissions, we also need to understand how these trends can be steered in directions that enable a fast transition to supply chains that are low in GHG emissions.

In Mistra Carbon Exit, this work has started in Phase 1 and has included: studies on supply chain emissions during a transition to electric vehicles; a policy analysis for the adoption and use of low-emitting vehicles; and an analysis of the actors involved in the introduction of shared and/or self-driving vehicles.

Swedish phase out of internal combustion engines – enabling decarbonization or relocating emissions to battery manufacturing?

JOHANNES MORFELDT AND DANIEL JOHANSSON

Phasing out internal combustion engines for sales of new cars results in net benefits for the decarbonization of Swedish passenger car travel, despite the high CO_2 intensity of battery manufacturing.

Electrification of passenger cars is one of the main strategies for decarbonizing transportation. To promote and accelerate such a pathway, several countries and companies are considering to ban or phase out internal combustion engines in sales of new cars.

A Swedish ban on internal combustion engines in new cars for sale presents the possibility to enable long-term decarbonization and zero tailpipe emissions by mid-century. The main alternative considered in Sweden is to increase the use of biofuels. Biofuel use is, however, largely constrained by a limited supply of sustainably produced bioenergy and demands for biomass in other sectors.

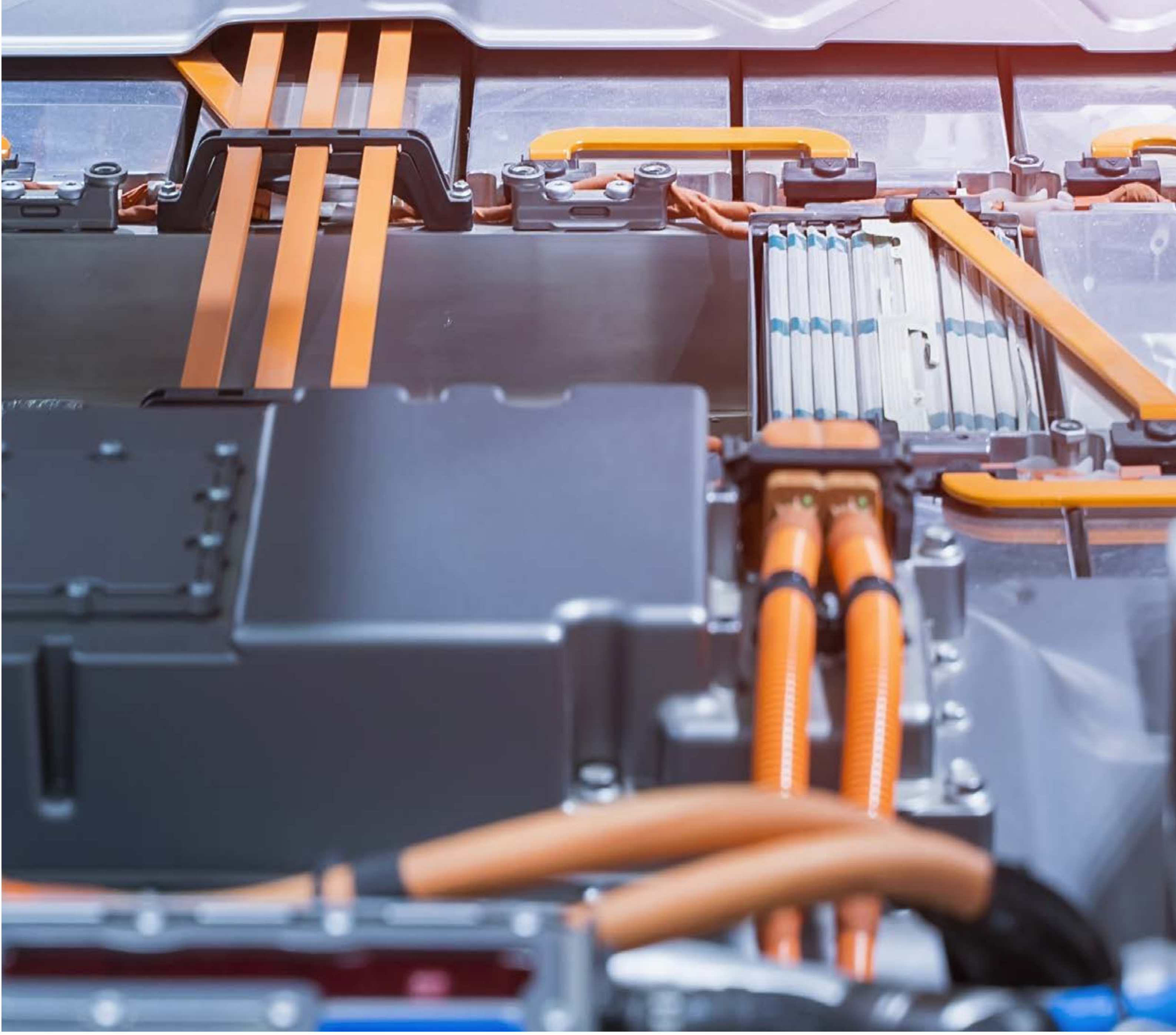
The actual climate benefit of biofuel use is largely determined by the type of biofuel used, which is regulated in Swedish biofuel policy so as to promote biofuels with low lifecycle greenhouse gas emissions. Further research is needed to clarify how the increased use of different types of biofuels will influence the carbon cycle for the coming decades and the related levels of warming.

The full effect of a ban becomes apparent 20 years later

In order to analyze consequences of different pathways for the future Swedish passenger car transport system a model that takes into account different demand patterns, vehicle stock turnover as well as supply chain emissions for different energy carriers, materials and batteries have been developed. The model can be used to analyze carbon footprints and material flow impacts of different pathways with respect to, for example, car and ride sharing, autonomous vehicles, electrification etc. So far in Mistra Carbon Exit the analysis have been focused on carbon footprint consequences of a ban of the internal combustion engine in new passenger cars.

Using this model, our analysis of the carbon footprints of strategies to achieve zero tailpipe emissions of CO_2 from cars in Sweden reveals that approximately 20 years elapses after the introduction of a ban on internal combustion engines before the full effect is observed in terms of reaching near-zero tailpipe emissions. This is a consequence of the fact that the average passenger car lifetime is about 17 years, which means that cars with internal combustion engines will be present in the system at least until Year 2050. Consequently, the introduction of a ban of internal combustion engines for sales of new cars from Year 2030 will, if implemented in isolation from other policies, not be sufficient to ensure zero tailpipe emissions of $CO_2$from passenger cars by Year 2045. Various types of biofuels are needed to enable a decarbonization of car passenger transport by Year 2045. However, the levels of biofuels are expected to be lower than what will be needed to meet the climate target for the Swedish transport sector by Year 2030.

The analyses show that the accrued carbon benefits of a ban are substantial. The carbon footprint of Swedish passenger car travel (tailpipe and fuel- and vehicle-related emissions, including CO_2emissions from battery production) is significantly reduced when implementing a ban, since emissions related to the electricity used for charging are low in Sweden. In this case, the low emissions during the use-phase of an electric car compensate for the currently CO_2-intensive battery manufacturing. However, there is a risk that this policy-driven phaseout of internal combustion



engines will result in increased emissions outside Sweden's borders, as a consequence of the increased demand for batteries and its manufacturing-related emissions.

Full carbon footprint regulations may be needed

The potential for reducing CO_2-emissions linked to battery manufacturing is significant. We estimate that for the global manufacturing industry, the average emissions per produced kWh of battery capacity can be reduced to one-third by Year 2050 if the industries decarbonize their production systems in line with the levels necessary to reach the temperature targets of the Paris Agreement. However, these potentials may not be realized if the manufacturing sites are located in countries with less-ambitious climate policies and targets.

Policy interventions that contribute to reducing carbon leakage and incentivizing emissions reductions in manufacturing processes may, therefore, be warranted. Regulation of the full carbon footprint of new cars and sustainable batteries (in terms of both their environmental and social aspects) are currently being discussed within the European Union.

Furthermore, concerns have been raised regarding the mining of materials used in batteries, as this creates substantial social and environmental problems in the mining country. Future research should focus on measures to reduce the demand for virgin battery materials, including car- and ride-sharing, battery downsizing in response to new charging options (such as electric roads), and battery recycling.

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Tradeable performance standards represent a promising tool in the transportation sector

SONIA YEH, DALLAS BURTRAW, THOMAS STERNER, AND DAVID GREENE

New research as part of the Mistra Carbon Exit project has revealed the effectiveness of credit trading for several programs that were designed to promote the advancement of clean technologies in the transportation sector.

As global temperatures continue to rise, policymakers are working to find ways to promote technology development and cut emissions in the transportation sector, which is responsible for 24 percent of direct CO_2 emissions from fuel combustion.

Four different performance programs examined and compared

A performance standard is a policy that promotes innovation by setting a performance goal (such as fuel economy standards) without specifying how it should be achieved. Rather than requiring every company to reach this goal, a tradeable standard allows companies to over-perform and sell credits to companies that incur higher costs for reaching the goals, thereby making the policy more flexible and cost-effective.

We have examined four tradeable performance standard (TPS) programs and policies in the US transportation sector: regulations for vehicle greenhouse gas emissions, the state-level Zero Emission Vehicle Program, the Renewable Fuel Standard, and California's Low Carbon Fuel Standard.

We have made the following observations:

• Performance standards set policy targets while leaving technology choices to producers.

• Since their implementation, TPS programs have provided billions of US dollars in the form of credits to companies that perform at levels above the standards.

• Compared with carbon pricing programs, existing TPS programs contain greater incentives for technology switching and innovations but have lower price impacts and, therefore, weaker incentives to reduce consumption.

• TPS combines effectively with carbon pricing to foster innovation and economic transition.

Politically attractive and successful

Carbon pricing through taxes or tradeable permits is generally considered to be the overall superior instrument. However, in circumstances in which carbon pricing (at a sufficiently high level) is not feasible politically, TPS programs offer a very attractive alternative. TPS programs have been prominent in the US electricity sector, exemplified in 29 states' renewable portfolio standards and in the Obama Administration's proposed Clean Power Plan. Recently, China announced its intent to implement the largest rate-based emissions trading program in the world for its electricity sector.

Even in the EU and in Sweden, we see political limits to carbon pricing. To resolve this, TPS could be applied more broadly to various sectors (e.g., industry), especially where significant cost heterogeneity exists. Sweden is already increasingly using a Performance Standard approach (Reduktionsplikten) for the transport sectors. Policymakers might consider increasing the tradeability feature to make this a TPS. They might also consider coupling in a more-systematic way TPS with carbon pricing, to foster greater technology innovation.

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Reducing vehicle ownership while maintaining mobility: The case for car sharing

FRANCES SPREI

Car sharing can play a role in enabling more sustainable mobility. It has the potential to reduce vehicle ownership, the number of vehicle kilometers traveled, and the need for parking spaces. It can also enable a more efficient use of resources through reducing the number of vehicles. However, the membership and usage levels of car sharing services remain low. To make car sharing more attractive, improvements in pricing models and better information are needed

Car sharing is a membership service that allows members to rent vehicles for shorter time periods. Compared to traditional car rental, the vehicles are distributed over a larger urban area and all bookings are handled online.

While the adoption levels of car sharing have been increasing in Sweden over the last 10 years, they are still less than 1 percent of the population, and active users are most probably even fewer. Therefore, there is a need to understand more clearly the characteristics of car sharing users compared to other car users, and to develop ideas as to how car sharing can be made a more attractive option.

What drives car sharing usage?

The aims of this work have been to elucidate the factors that drive car sharing usage, and to characterize car sharing users compared to other car drivers. Previous research has either simply looked at car sharing members or compared them with the general population, generating biases and irrelevant comparisons with, for example, people who do not even have access to car sharing.

We surveyed the residents of apartment buildings with access to car sharing in Gothenburg and Malmö, to capture data form both the car sharing members and non-members living in the same residential area. Thus, the groups had similar mobility conditions, such as access to car sharing, public transport, and biking infrastructure. We compared three different groups: car sharing users; car owners; and drivers who neither owned a car nor were members of a car sharing service.

Car sharing members are younger and have higher education levels than car owners

We find that car sharing members generally are younger than car owners and more often live with a partner, as compared to other car users (those who neither are car sharing members nor own a car). Car sharing members have the highest education level of the three groups, with almost 90 percent having a university degree. We also find that more highly educated people find it easier to use car sharing and, thus, also are more likely to use the service. Therefore, improvements are needed related to the levels of information and education concerning the usability of car sharing services.

Income-wise, car sharing members were in the middle, i.e., they had a lower income than car owners but a higher income than other car users. This is reflected in the fact that car sharing users often cite economic reasons for using the service, whereas those that do not use the service perceive it to be too expensive. The degree to which car sharing is perceived to be expensive is also related to how often and for what type of trips one uses car sharing. In general, car sharing members rarely commute by car, in contrast to car owners. They also tend to live closer to their workplace than car owners, even if we do not find any statistically significant difference in this respect.

Car sharing must be presented as a viable option to more people

When transitioning to a more sustainable transport system that is less reliant on privately owned vehicles it is important to ensure that car sharing is a viable option for as many persons as possible, so as to shift more people from vehicle ownership to car sharing. Our research shows that better pricing models and improved information and education programs regarding car sharing can play an important role in this shift.

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Policies for electric vehicles must target not only adoption but also (sustainable) use

WOLFGANG HABLA

Current policies aimed at the electrification of passenger transport mainly target the adoption of electric vehicles (EVs). It is equally important that these policies address the actual use of EVs.

In many countries, the transport sector is the largest contributor to CO_2 emissions. Therefore, decarbonizing this sector represents a critical component to strategies to achieve national climate objectives. One way of accomplishing this is electrification. However, as electrification is associated with several challenges and controversies, additional policies are warranted.

First, rates of adoption of EVs are still low in most countries, despite generous subsidies and 'eco bonuses'. This hints at the possibility that EVs are not (yet) perceived to be viable or attractive substitutes for their gasoline-guzzling counterparts.

Second, controversy surrounds the issue of the CO_2 impact of EVs as compared to vehicles with internal combustion engines (ICEVs). The relative advantage of EVs in this regard largely depends upon the emissions intensity of electricity generation, as well as the ways in which EVs are actually being used. Research conducted within the Mistra Carbon Exit project shows that battery electric vehicles (BEVs) are, on average, driven fewer kilometers per year than ICEVs.

Low mileage of EVs implies an inefficient policy

One might be tempted to think that the lower mileage of EVs is good news, since fewer kilometers mean lower CO_2 emissions. However, the low mileage of EVs also implies that the subsidies paid on their purchase have very high abatement costs per tonne of avoided CO_2, indicating an inefficient policy.

Furthermore, more plug-in hybrid electric vehicles (PHEVs) were sold in Sweden in Year 2020 than BEVs. This is probably linked to the ability of PHEVs to cover longer distances without recharging, which alleviates what is generally referred to as "range anxiety" among EV users. However, the share of the distance traveled in electric mode is typically very low for PHEVs (and much lower than official statistics by car manufacturers suggest). Even if we consider PHEVs a transition technology to a largely electrified transport sector, these vehicles will be on the roads for 10 years or more. Thus, their unsustainable use can have consequences over a long period.

Higher carbon price is desirable

Which policies can remedy the issues raised above? From the economic point-of-view, it would be desirable to have a high carbon price, to make EVs more attractive than ICEVs. This would induce consumers to buy EVs, although it would also cause PHEV owners to recharge their vehicles more frequently rather than refuel them. If carbon prices are not sufficiently high, policies that are complementary to purchase subsidies and charging infrastructure expansion are needed to drive electrification of the transport sector in the right direction. Such policies must target not only the adoption of EVs, but also their use.

Cheaper access to rental cars or alternative modes of transport for traveling long distances

To address range anxiety, more information could be provided on the real-world cruising ranges of EVs, and more opportunities to gain first-hand experience with EVs could be offered. Furthermore, the very few days per year when there is a demand for a long range, e.g., during a vacation, are likely to be perceived by households as a substantial barrier to EV adoption.

To alleviate this concern, car manufacturers and firms that offer company cars to their employees could make cheaper ICEV rentals or cheaper access to long-distance trains available to EV owners, e.g., in the form of vouchers. Such policies could significantly speed up EV adoption. In addition, policies can be introduced to encourage PHEV owners to charge their vehicles more frequently, entailing either financial incentives (e.g., subsidies to promote charging) or "nudges" that motivate people to use their PHEV in a more eco-friendly way (e.g., by creating habits to recharge rather than refuel these cars). Finally, a smart charging infrastructure and higher shares of renewables in electricity generation would help to reduce further the CO_2 emissions linked to EVs.

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How are cities driving connected and autonomous vehicles?

ELLA REBALSKI AND CECILIA HULT

Connected and Autonomous vehicles (CAVs) could transform the mobility landscape and the roles and responsibilities of the companies and actors involved. However, the current degree of uncertainty related to CAVs calls for increased cooperation between the public and private sectors.

Swedish authorities are aware that the CAV technology could induce substantial changes in our cities, and while they are generally uncertain as to how the future will play out, they are starting to prepare for it.

Digital infrastructure must be further developed

Interviews conducted with multiple actors from both the industry and the public sector revealed an expectation that the digital infrastructure must be expanded. Furthermore, cooperation between public actors at local, regional, and national levels will be important. Local and national bodies act as road authorities, so they must work together to ensure a coherent and integrated digital infrastructure. Although legislation is primarily decided upon at the national level in Sweden, the law must also consider the needs of local areas where non-motorized road users are seen more common.

Respondents considered pilot projects to be a good way of building knowledge and increasing societal readiness for CAV adoption. Pilot projects allow for the testing of and exposure to new methods of transportation, without having to solicit public buy-in or build an expensive, permanent infrastructure.

Dialogue and cooperation between public and private stakeholders

It is also crucial to prioritize dialogue and cooperation between the actors from the public and private sectors, as this enhances understanding of the needs and challenges faced by each sector. In particular in the public sector, stakeholders perceive autonomous vehicles to be associated with both opportunities and risks. A common concern among the interviewees was that that Swedish cities would be designed around CAVs, as they were once designed around cars, as opposed to putting the interests of people in focus. In addition, many stakeholders mentioned the need for improved knowledge with regard to CAV policy planning within the public sector, as well as a unified strategy among political parties and across national, regional and local governance systems.

Policy measures must ensure traffic safety, efficient land-use and low-carbon transport

Safety was a major concern for the interviewees, which is unsurprising given that it is a top priority within the Swedish transportation field. It was clear from the interviews and survey that AVs are not unconditionally regarded as positive, but rather that the regulation and use of the technology (as opposed to the technology itself) are major concerns. Our findings indicate that there exists fear amongst stakeholders that the impact of CAVs on the overall energy demand could counteract the potential impacts of increasing the energy efficiency of the individual vehicle. This perceived worst-case scenario would affect land-use in and around cities, as well as the transport demand, energy consumption levels, and related greenhouse gas emissions.

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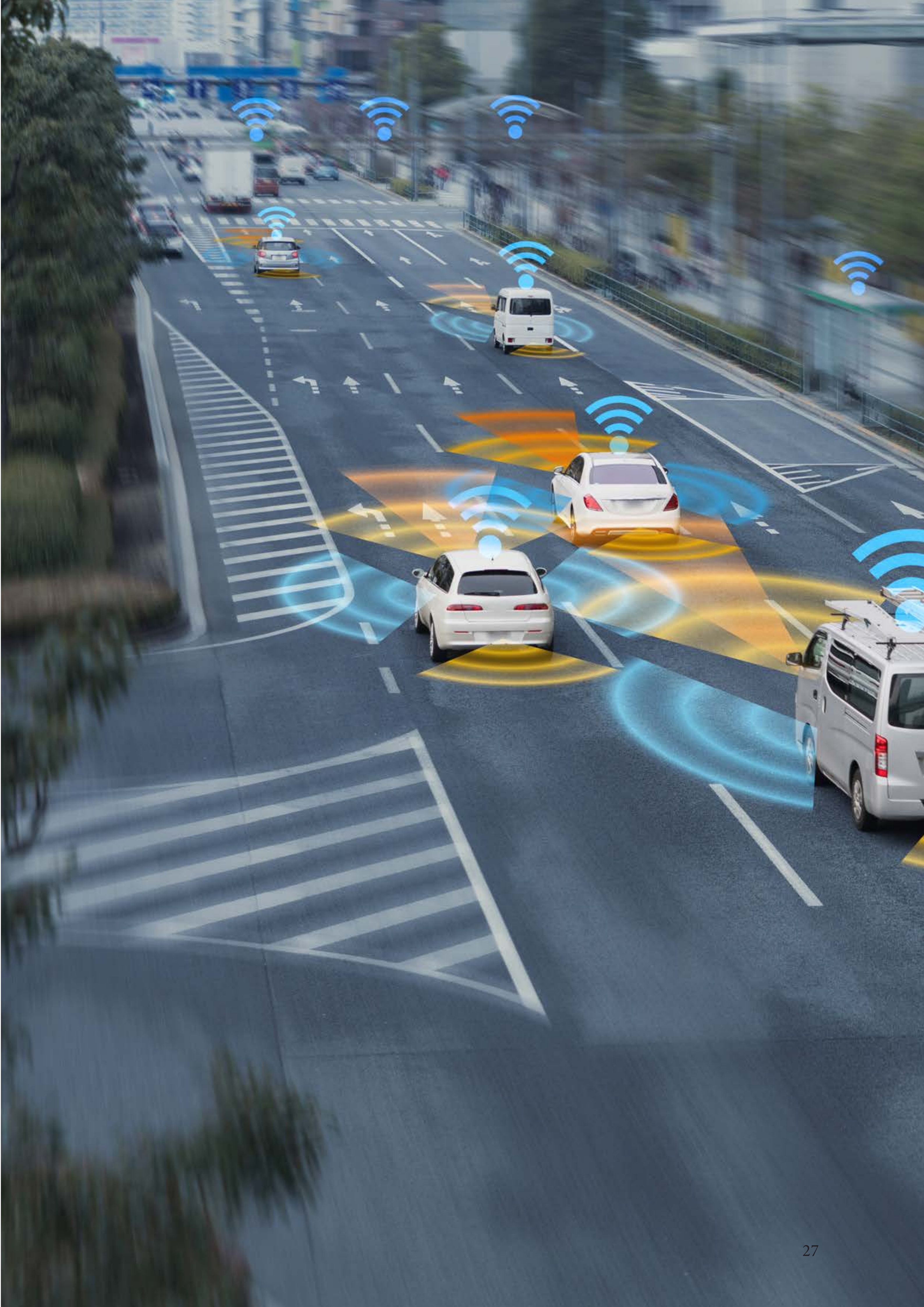

3. Governance and Behavior

The global community, including in particular policymakers and the private sector, is still struggling with how to reduce significantly the global fossil fuel dependence and reach the objectives of the Paris Agreement.

How can we understand this inability of the global community to spur action? In Mistra Carbon Exit, we have learned that many technological solutions and knowledge are available to support a transition to a net-zero GHG future. Still, such technologies are either not scaled up or are not used extensively enough to reduce / abolish the global dependence on fossil fuels.

New policies and business models are urgently needed, and most importantly, such policies must be founded on a deep understanding of how businesses and the public respond to policies and of what drives behavioral changes, both among the public and within businesses. Research conducted during the first phase of Mistra Carbon Exit has studied and identified several challenges to behavioral and legislative changes that need to be addressed when designing policies moving forward.

In this chapter, we present some of our projects and results within this area, including the identification of critical aspects of new business models the role of transformative learning, the roles of cities in the transition, the determinants of policy acceptance, and legislation and policy design that support further actions, such as increased circular flows of materials, coordination among actors, and making carbon price signals more salient.

Green recovery: What drives firms towards climate action?

CECILIA ENBERG

The Green Recovery Package issued by the Government of Sweden as a response to the economic downturn following the COVID-19 pandemic, is designed to cut greenhouse gas emissions while simultaneously boosting economic recovery. However, if not appropriately used, there is a risk that the recovery package will exhaust available state funds for climate transition for a long time to come while not pushing firms away from their business-as-usual mindset.

In the study that we conducted within the Mistra Carbon Exit project, we found that many firms have targets for net-zero greenhouse gas emissions by Year 2045. Moreover, their heads of sustainability agree that efforts aimed at transition make sense from a business perspective. Some firms also suggest that in recent years the rationale for conducting climate work has shifted from a willingness to 'do good' to one that is more concerned with business and profitability. Despite this, they ask for policies that incentivize them to take further action, and that spur those firms that do little or nothing to shape up.

The important question that arises is: Do green recovery packages do that?

Green Recovery Package of low importance?

Our respondents suggested that most of the investments included in the Green Recovery Package were of low importance to their firm's sustainability strategies or priorities. Moreover, they were considered marginal in size, particularly by firms at the beginning of the supply chain (e.g., basic material producers), as these firms need to make large investments, converting their production processes to become electricity powered. These firms asked for investment support and help to reduce the financial risks involved [1]. They also called for public investments to enhance the capacity of the electricity grid.

Difficulties in implementing circular flows

Many of the firms in our study experienced difficulties in implementing circular flows of materials. These difficulties were related to legislation, as many of the used materials are classified as waste, rather than products, and are not allowed to be used in circular flows. Thus, firms asked for changes in the legislation. An investment aimed at increasing the pace of transition to a circular economy was the only one that a majority of our respondents thought would have an impact on the strategies and priorities of the firms, as it both supports steps already taken and could contribute to initiating new activities. This investment is directed at changing legislation and providing guidance, rather than financial support.

In general, a large majority of firms included in our study preferred policies that focus on legislation, e.g., the setting of tougher standards, over policies that focus on financial support.

A possible game-changer?

We conclude that updated legislation is a possible game-changer, which could help create markets for climate-friendly products in ways that make business more difficult for firms that are not on track with reform and provide incentives for those that are onboard. In this context, our respondents suggested that public organizations should use their purchasing power to choose climate-friendly alternatives. Indeed, almost 90 percent of respondents to our survey asked for green public procurement, making it the most-requested policy. Incidentally, green public procurement is not a policy that is included in the government's Green Recovery Package.

Our respondents emphasized the necessity of a supply-chain perspective when implementing policies, including the investments of the Green Recovery Package. Such a perspective would enable a system approach in which the most important pressures, mitigation actions and key actors could be identified.

Moreover, a system approach would enable the implementation of policies along the supply chain that are not in conflict with each other – something that has been suggested to be the case today. It is also essential to understand that the climate targets set by firms in different parts of the supply chain are inter-related and that they can be reached more quickly if policies incentivize joint initiatives.

[1] Credit guarantees for investments in green technologies have been issued by the government but not as part of the recovery packages. Moreover, it is unclear whether they cover the kinds of investments needed by these firms.

Comparing prices with standards for reducing CO_2 emissions towards net-zero emissions

MAGNUS HENNLOCK AND ÅSA LÖFGREN

Carbon pricing is often regarded as the Gold standard of policy instruments for reducing CO_2 emissions, providing incentives for least-cost mitigation, and triggering behavioral changes. With 61 implemented or scheduled carbon-pricing initiatives, of which 31 are emissions trading systems and 30 are carbon taxes, carbon pricing is widely accepted around the globe.

In contrast, emissions standards set direct limits on CO_2 emissions, which are often implemented in specific sectors, such as buildings, transportation, and power production.

However, the Swedish Environmental Code prevents the government from using CO_2 emissions standards in Sweden. This leaves Swedish policymakers with carbon pricing as the only direct policy approach for reducing CO_2 emissions. But does carbon pricing work as expected, and how well does it perform?

The major objective of carbon pricing, regardless of whether it is an emission trading system or a carbon tax, is not to raise revenue but to drive behavioral changes to reduce CO_2 emissions until the emissions target behind a tax, or a cap in the emissions trading system, is reached with efficiency. The price adds a cost for generating an additional tonne of emissions. This cost is then passed on along the value chain of the product.

Using carbon pricing to reach an emissions target with efficient measures builds on companies' interest in reducing their total investment costs for CO_2 reduction and total payments for taxes or permits. If, for instance, companies instead seek the least-cost mitigation per kg CO_2 reduction, the reductions will usually be smaller than the target and the companies' total costs will be larger.

To this end, we conducted a field experiment with 166 managers from the Swedish industry who were randomized into two experimental treatment groups. The 166 managers made in total 1,494 hypothetical investment decisions under either a CO_2 tax or a CO_2 emissions limit, with identical emissions targets.

With a carbon price, managers under-invested resulting in lower CO_2 reductions

The experimental control confirmed that managers in the group that was facing CO_2 taxes underinvested in CO_2 reduction, with the result that the target of the carbon pricing was not achieved for 33 percent of their decisions. One explanation for this was that the managers often sought the least-cost mitigation per kg CO_2 reduction, failing a rational response that would minimize the total investment costs and total tax payments.

With an emissions limit, managers failed to choose cost-effective investment alternatives

Our results show that managers in the group facing emissions standards, under-weighed the cost information, and therefore failed to choose cost-effective investment alternatives in almost 30 percent of their decisions when fulfilling emissions limits.

Managers' understanding of price signals in decision-making needs to improve

To improve fulfilment of the target of the policy, our experimental results indicate that the carbon price signal needs to become more salient in managerial processes regarding investment decisions. More research is needed to understand fully why the managers failed to follow a rational response that would have led to the achievement of the CO_2 target reduction. In Mistra Carbon Exit Phase 2, we will expand our understanding of the cognitive processes in managers' decision-making by testing augmented policy designs that can improve effective managerial responses to price signals in the EU ETS and CO_2 taxation.

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The climate decade: Changing attitudes on three continents

ÅSA LÖFGREN AND THOMAS STERNER

Despite rising global temperatures and increased political awareness of the impacts of climate change, there is still no clear sign of emissions curbing on a global scale. But how have the past 10 years changed international opinions regarding stronger climate policy actions?

The last decade can surely be called the 'Climate Decade'. While increases in global temperatures and levels of carbon dioxide emissions have set new records during the last decade, effective political action has proven elusive. Despite strong scientific evidence of the risks of continued warming and the substantial progress made with renewable energy, there has been only weak overall progress towards a coherent set of global climate policies. The only signature result has been the 2015 Paris Agreement.

Willingness to pay and political polarization

Within the Mistra Carbon Exit program, we have examined whether the emerging warning signs over the last decade indicating earth warming are matched by citizens' demands for stronger policy actions in three key geographic areas: the United States, China, and Europe (represented by Sweden). These three countries reflect very different climate policy contexts, differences that may be reflected in citizens' attitudes towards climate policies and in their willingness to pay (WTP) for climate mitigation.

We have addressed three important issues in the study: (i) how much citizens are willing to pay for reducing CO_2 emissions; (ii) whether citizens' WTP has changed over the past decade; and (iii) whether political polarization has increased or decreased when it comes to opinions regarding climate policies and preferences for decreasing CO_2 emissions.

Demand for stronger policy actions in all countries

Our results show that the warning signs that have appeared increasingly over the last decade indicating that the earth is warming are in fact matched by increased demands for stronger policy actions from citizens in all three countries. Some of the most important results are illustrated in the graph, including details of the WTP per tonne of reduction in CO_2 emissions and how the WTP has changed over the past decade.

However, within countries, there is considerable preference divergence, most importantly in relation to political affiliation. We find a clear ideological left-right division in the demand for stronger climate policy action in both the United States and Sweden. Therefore, while we see convergent tendencies across countries, there is some evidence of increased divergence within countries.

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The Climate Decade?

Changing Attitudes on Three Continents

Were the 2010s the Climate Decade? A multi-continental survey of climate opinion and willingness to pay shows that opinions in China, Sweden, and the United States converged from 2009 to 2019, and that there is overwhelming support for climate action.

United States

Attitudes have become more positive toward climate policies since 2009 in the greatest shift of the three surveyed countries.

Sweden

Attitudes have largely stagnated but have become slightly less positive toward climate policies than in 2009.

China

Attitudes have become more positive toward climate policies, surpassing support in the United States and Sweden.

CLIMATE CHANGE DENIERS

16% — 16% believe that global temperature has not increased, down from 24% in 2009.

7% — 7% believe that global temperature has not increased, up from 6% in 2009.

3% — 3% believe that global temperature has not increased, down from 5% in 2009.

SOLO ACTION

79% — 79% of people in the US think their country should reduce emissions even if other countries do not, up from 68% in 2009.

73% — 73% of people in Sweden think their country should reduce emissions even if other countries do not, down from 81% in 2009.

89% — 89% of people in China think their country should reduce emissions even if other countries do not, up from 77% in 2009.

PRIORITIZE ENVIRONMENT OVER JOBS

60% — In the US, 60% would prioritize the environment even if jobs are lost, up from 40% in 2009.

55% — In Sweden, 55% would prioritize the environment even if jobs are lost, down from 61% in 2009.

82% — In China, 82% would prioritize the environment even if jobs are lost, up from 75% in 2009.

WILLINGNESS TO PAY PER TON CO_2

$31 — In the US, people are willing to pay $31 per ton to reduce greenhouse gas emissions by 30%, up from $18 in 2009.

$129 — In Sweden, people are willing to pay $129 per ton to reduce greenhouse gas emissions by 30%, up from $85 in 2009.

$44 — In China, people are willing to pay $44 per ton to reduce greenhouse gas emissions by 30%, up from $11 in 2009.

RFF.ORG/CLIMATEDECADE

The role of consumers in addressing climate change

KAJSA-STINA BENULIC AND VICTORIA WIBECK

Consumers are an important piece of the puzzle in societal transformations to address climate change, as their choices and lifestyles contribute to greenhouse gas emissions. Therefore, it seems worthwhile to look more closely at the values and perspectives that set the framework for private consumption.

Efforts to reduce consumption-based emissions often focus on the behaviors of individuals and on the characteristics of products. As a result, there is a plethora of instruments with the aim of guiding individual consumers towards a more sustainable path. Examples can be found in many sectors. The electric car premium aims to encourage consumers to opt out of buying petrol-fueled vehicles, smart meters seek to help consumers save energy in their homes, and a new tax has as its aim to encourage consumers to abandon plastic bags. The question is what role this individual-focused approach plays in societal transformations to address climate change.

Earlier research has pointed to the value of perceiving behavioral changes as embedded in the so-called 'personal and political spheres', which include values, worldviews, paradigms, institutions, systems, and structures. Considering consumer behavior as an important piece of this puzzle, albeit one piece among many others, entails shifting the focus from individual consumers' choices to what roles consumption plays in consumers' lives and how it fits into people's everyday activities. This approach opens up new strategies to reduce consumption-based emissions, although it also raises new questions.

Value shifts facilitate practical and political changes

In Mistra Carbon Exit, we have conducted focus group interviews with consumers regarding what a climate-neutral everyday life could look like, and how one can arrive at such a situation. The focus group participants highlighted not only practical behavioral changes but also changes in the political and the personal spheres. For example, this was evident when participants discussed everyday transportation. They argued that the use of electric cars could be increased through changes in the practical and political spheres, such as a shift towards working from home on certain days, enabling the possibility of car sharing or expanding infrastructures for charging electric vehicles.

In addition, they pinpointed that value shifts could facilitate practical and political changes. Examples of such values shifts are if climate aspects would always weigh most heavily when consumers assess transport, or if they reconsider their view of ownership and relationships with people outside their households.

Transformative learning – a way forward

Therefore, we need to explore further how norms and values change. An overview of research into sustainability transformations suggests that so-called 'transformative learning' could be a way forward. Transformative learning focuses on learning processes that render values, perspectives, and worldviews visible, thereby enabling reflection and reappraisal of what was previously taken for granted. Such transformative learning should be seen as an important and necessary complement to political decisions and behavioral changes, as it facilitates the shifts in perspective that are needed to envisage transformations towards sustainable futures.

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The roles of cities in a climate-neutral building process

STINA STENQUIST AND AURORA ØVERENG

Cities should use their mandate in the planning process to guide a development towards climate neutrality and should develop methods to ensure that successful pilot projects become standard for all stakeholders.

To date, many Swedish regions and cities have set more ambitious climate targets than the Swedish national target. For instance, Uppsala's target is to be climate-neutral by Year 2030. Such tendencies to set ambitious targets are also seen throughout Europe and in the US, with initiatives such as Covenant of Mayors in the EU – gathering more than 10,000 municipalities – and the State of California being a long-time forerunner in environmental policies.

Evaluation of transformative solutions

The aim of the Local Arena case study was to evaluate how the transformative solutions identified in the program1 could be implemented in a local context. In this case study, we have assessed the opportunities and barriers regarding the climate transition in the construction process for buildings in Uppsala municipality. Interviews with relevant stakeholders, including local policymakers, developers, designers and material manufacturers, have revealed2 that all the organizations are working with measures to reduce greenhouse gas emissions from the construction process. However, only a few are working towards the objective of attaining net-zero emissions.

Although most of us agree that a successful climate transition requires commitment and cooperation from all actors, it is equally important to identify the city's role in the transition, and to be able to identify pathways towards carbon-neutral processes and practices. Based on the lessons learnt from our case study in Uppsala, we suggest a set of recommendations for cities that want to accelerate their progress towards climate neutrality in the construction process of buildings.

We recommend that cities:

• Use their mandate in the planning processes of all comprehensive and detailed development plans to drive development towards climate neutrality.

• Identify responsibilities, opportunities, and barriers for reducing climate impact as part of the planning process.

• Formulate climate objectives for their municipal real estate companies and the land that they develop.

• Continue to act as a frontrunner by conducting pilot projects with the municipal real estate companies and regarding the land that they develop.

• Develop methods to scale up the pilot projects within their municipality and within the organization.

• Use their collaboration platforms with the local building industry to scale up the successful pilot projects for the whole building industry within the municipality.

• Recognize that municipalities are working on a local level and that companies in the building industry are usually working nationwide. Different sustainability requirements in different municipalities may lead to sub-optimal execution of the transition and make it more difficult for contractors/ property owners to limit the climate impacts of their operations. This calls for a system of national coordination.

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The "Swedish proposal" – Swedish climate leadership under the EU ETS

LARS ZETTERBERG

The European Union's climate package 'Fit for 55' has been presented and we are entering a period of negotiations with all EU Member States. Sweden needs to engage in this process with both a clear vision and determination. Such engagement has proven to be quite successful. In the negotiations for the revision of the EU ETS in 2018, the "Swedish proposal" resulted in the introduction of a mechanism that will cancel emission allowances corresponding to 50-times the annual GHG emissions of Sweden.

When the EU Emissions Trading System was introduced, industry, government and researchers alike were pleased that a price had been set for greenhouse gas emissions that at that time covered about half of EU emissions. Capping emissions guaranteed that the EU would meet its climate target and trading with emission allowances meant that the emission reductions would take place at the lowest possible cost.

Figure 1:EUA prices 2008 - 2021 Source ICAP accessed 22 Nov

Low allowance price stalled the phasing out of fossil fuels

Between 2013 and 2018, the EU ETS was plagued by a consistently low price for allowances (Figure 1). This was due to a large surplus of allowances, resulting mainly from the initially generous allocation, the economic crisis, and the influx of credits under the Clean Development Mechanism. Moreover, support for renewables and energy efficiency policies further reduced emissions, without necessarily adjusting the supply of allowances in a commensurate manner, thereby contributing to a growing surplus. The low price for allowances was clearly not providing incentives for either the phasing out of fossil-based power generation or the adoption of low-carbon technologies by industry.

In response to the low allowance price, some Member States introduced or wanted to introduce additional policies, in order to comply with national climate objectives. However, the introduction of additional emissions reductions under an emissions cap is problematic. If the total volume of emissions allowances is fixed, extra emissions reductions in one country can lead to emissions increasing elsewhere in the EU, undermining the effectiveness and integrity of the national policies. This is sometimes referred to as the "waterbed effect", i.e., sitting down on one side of a waterbed results in the other side rising.[1]

Excess allowances will be cancelled

In Year 2017, the EU ETS was reformed. From Year 2019 allowances corresponding to 24 percent of the allowance surplus have been transferred into a market stability reserve (MSR). From Year 2023 onwards, the MSR will only be allowed to hold as many allowances as were auctioned in the previous year – the excess allowances will be cancelled. Estimates show that about 3 Gt of allowances[2] will be invalidated between the years 2023 and 2030.[3]

This invalidation mechanism is a result of the so-called "Swedish proposal", so-named because it was designed and negotiated by Swedish negotiators.

Sweden can have a huge impact on EU climate action

The Swedish proposal will result in a reduction of EU emissions corresponding to almost 50 times the total of Sweden's annual emissions annually. The reform has driven up the price of allowances from around €5 to over €60, which has accelerated the phasing out of coal in the EU. This shows that, with judicious handling, Sweden can have a significant impact on EU emissions and climate action.

[1] *Burtraw et al (2018). "Companion Policies under Capped Systems and Implications for Efficiency – The North American Experience and Lessons in the EU Context" RFF Report*

[2] *Corresponding to almost 2 year of allowance demand.*

[3] *IVL-report C312, available on www.ivl.se*


CO_2

4. Policy Design

Carbon pricing through the EU ETS is a cornerstone of EU climate policy. Although the EU ETS allowance prices have increased over the last few years, it remains unclear as to what extent the EU ETS will trigger deep emissions cuts in the industries that are in focus in the Mistra Carbon Exit program. Different pathways towards strengthening the EU ETS have been investigated, as have complementary policies and measures.

This chapter discusses the possible future directions for the EU ETS, such as auctioning a larger part of the EU ETS emission allowances that now are allocated for free, a reform of the EU ETS that creates effective carbon pricing incentives combined with Carbon Contracts for Differences, the implementation of an auction reserve price for the EU ETS, and the introduction of flexible performance standards. We also discuss whether carbon border adjustments can accelerate climate action.

Public procurement is often seen as an important tool for the building and construction sector. In this chapter, we discuss the requirements, criteria and incentives to promote carbon reduction by means of public procurement. Finally, the possibility to establish a "transition fund" to finance deep emissions cuts in the basic material industry is proposed and discussed.

Next steps for the EU ETS – the role of free allocation needs and overhaul

LARS ZETTERBERG, MILAN ELKERBOUT, AND CHRISTIAN EGENHOFER

The emerging post carbon industrial landscape need to be supported politically and financially, to cover the "green premium" - the additional cost for low-carbon materials. This could be done by auctioning a larger part of the EU-ETS emission allowances that now are allocated for free and use the revenues to support low carbon materials production. Alternatively, free allowances should be allocated to low carbon materials production in order to provide financial support and create a level playing field for materials production in the EU.

With the climate package "Fit for 55" the EU Commission proposes important reforms for the EU Emissions Trading System – a faster reduction of the cap (4.3 percent per year instead of today's 2.2 percent), inclusion of shipping in the EU ETS, and the introduction of a climate border adjustment mechanism (CBAM) to protect against carbon leakage. In addition, a separate emissions trading system for road transportation and heating of buildings is proposed.

However, more attention is needed on how to support emerging low carbon industries. In Sweden a new, low carbon industrial landscape is emerging. Hybrit, a joint venture consisting of the steel making company SSAB, the mining company LKAB and of the power utility Vattenfall have produced the first batch of zero emissions steel and plan for large scale production in 2025. They have also formed a collaboration agreement with Volvo. In March 2021, a new company, H2 Green Steel, announced they will start production of carbon free steel in 2024. They have formed a partnership with the truck producer Scania, part of the Volkswagen group. These initiatives need to find ways to financially cover the "green premium" - the additional cost for low-carbon materials.

Carbon leakage protection needs to continue in some form, but it is time to take a closer look at how we use free allocation. Mitigating carbon leakage is important for the efficacy of climate policy but safeguards against carbon leakage risk should not deter the transformation of the economy towards climate neutrality. Hence, it is important to find ways to make zero-carbon production more attractive than carbon-intensive production.

Rising carbon prices: a much bigger pot

With the sustained increase in the price of allowances, from 5 euros in 2017 to 60 euros per allowance (September 2021), the value of free allocation has increased significantly. If we look forward at the share of allowances that currently are allocated for free (43 percent of total), approximately 360 billion euro will be issued in the next 10 years (see Figure 1). This constitutes a remarkably large asset – arguably of macroeconomic relevance – which should be used to support the development and deployment of low-carbon technologies. This could be done by auctioning a larger share of the allowances from the free allocation pot and significantly increase the size of the ETS Innovation Fund, so that its size becomes of a similar magnitude to free allocation. In the climate package Fit for 55, the EU Commission proposes to phase out free allocation over a ten-year period, starting 2026, for sectors covered by the proposed Carbon Border Adjustment Mechanism. This is an initiative in the right direction, but if we want firms to start transforming within the next decade, political incentives and financial support need to be in place much sooner, and well before 2035.

Zero-carbon benchmarks

As an alternative to auctioning a larger part of allowances, zero carbon benchmarks can be developed and used to allocate allowances to zero carbon materials production, or indeed for any energy-intensive industrial ETS sector producing climate-neutral products. The idea of a 'zero-carbon benchmark' is to support climate neutral production specifically by allocating free allowances to climate neutral products put onto the market

If traditional steel making and cement making receive free allocation, so should CO_2-free steel and cement, thus creating a level playing field. If we do not move in this direction, we risk a lock-in in old technologies and slow down the transition. Therefore, the boundaries and sector definitions of the benchmarks need to be changed irrespective of how many allowances to give to low and zero-carbon producers. Today, multiple benchmarks exist within a single industrial sector, as there are separate benchmarks for different production processes. Ultimately, we need climate neutral materials, but not necessarily decarbonized versions of every industrial process that exists today. At the very least, a revised benchmark system should do away with different benchmarks for different processes so that low- and zero carbon production is not at a disadvantage.

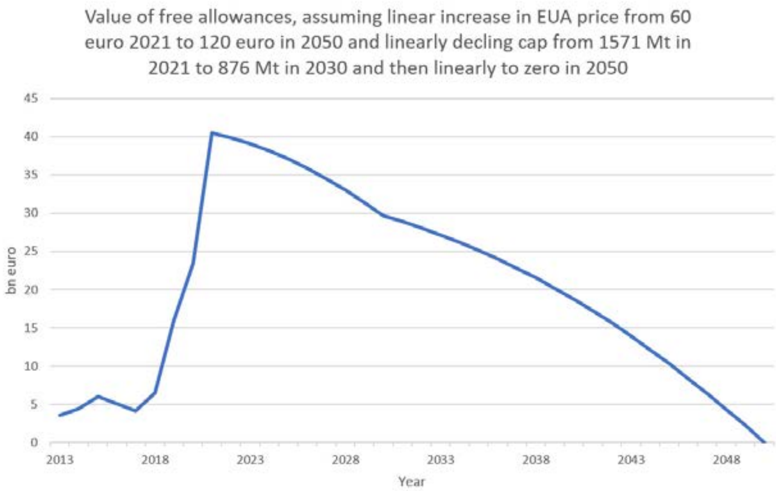

Figure 1. The annual value of free allocation from 2013 to 2020 and an estimate of the value from 2021 to 2050. In billion EUR. Assuming that the cap will decrease linearly from 1571 Mt in 2023 to 876 Mt in 2030 and then to zero in 2050 and that the EUA price will increase linearly from 60 EUR in 2021 to 120 euros in 2050. the total value of these allowances issued from the year 2021 to 2050 will be approximately 690 billion EUR. Approximately 50 percent of this asset, 360 billion euro will be issued from 2021 and 2030.

However, as we move into the future, free allocation in general will become increasingly difficult to defend. If we accept to provide free allocation to zero carbon production, another dilemma waits around the corner. If CO_2-free cement and CO_2-free steel receive free allowances, why shouldn't their substitutes, such as other binders (for instance from clay and fly ash) or wood? We will most likely find ourselves in an increasingly difficult debate on who should be in the free allocation system and who should be left out. The most appropriate action is to phase out free allocation as soon as possible.

The EU legislators need to seize the opportunity of the ETS revision and Fit-for-55 package and make choices that will support industrial investments for the next decades while balancing the burden between citizens and industry.

Tradeable green industrial certificates can strengthen carbon price signals in the industrial sector

DALLAS BURTRAW, ÅSA LÖFGREN, AND CAROLYN FISCHER

Standards set a benchmark for environmental performance, and if made flexible, they can amplify the incentives for innovation and investment. Flexible performance standards, such as benchmarked allocation in the European Union's Emissions Trading System (EU ETS), reward environmental leadership while protecting product markets from unregulated competition.

A performance standard, e.g., a green industrial certificate, establishes a measure of environmental performance, such as emissions per product unit, which may be calibrated to the best practice for an industry. The standard may become increasingly stringent over time. Flexibility enables averaging of the level of performance across the industry. Some firms may surpass the standard and earn value by selling compliance credits to other firms that perform at levels below the standard. Importantly, the value of compliance credits stays within the industry, providing a production subsidy, in contrast to carbon pricing, which typically draws value away from industry into government revenues.

Substantial reductions require substantial investment and innovation

Although modest reductions in emissions from the industrial sector are often achievable in the short term, substantial reductions require investment in known albeit expensive technologies, as well as substantial innovation to reduce costs and identify alternatives. Reducing costs through innovation takes on even greater relevance if one considers the tremendous investment and growth in greenhouse gas emissions expected in the industrial sector in developing countries.

A fundamental characteristic of the industrial sector is long-lived capital. Investments made in this decade using a conventional technology will lock in infrastructure for the rest of the century. Substantial carbon pricing that might be sufficient to drive innovation appears to be politically unsustainable because it places facilities at a competitive disadvantage compared to facilities located in unregulated jurisdictions. Furthermore, a modest carbon price today is insufficient to alter the technological structure of the industrial sector.

Performance standard puts a price on the externality

Flexible performance standards are analogous to the performance benchmarks that already exist in the EU Emissions Trading System (ETS). Other examples of flexible performance standards that allow trading include vehicle fleet efficiency standards and electricity sector renewable portfolio standards. Feed-in tariffs provide similar incentives for renewable energy development, with the costs paid by taxpayers. Together, these policies in Europe and their counterparts in the US have contributed to a major fraction of the reductions in greenhouse emissions achieved to date. Flexible performance standards and benchmarked allocation of emissions allowances in the EU ETS share a common feature—they both reduce the changes in product prices that erode international competitiveness under conventional approaches to emissions pricing. Put simply, the performance standard (and benchmarked allocation in the EU ETS) imposes a price on the externality, which is similar to a carbon price, while retaining the revenue (externality value) within the sector, thereby providing capital for investment.

Flexible performance can be added to the EU ETS

In Sweden, a portion of the industry sector’s emissions is already subject to a carbon tax, primarily covering the manufacturing and food industries and corresponding to less than 10 percent of total industrial emissions.

However, most of the industry sector, including iron and steel production, minerals (cement), oil refineries, and chemical industries, is covered by the EU ETS, albeit at an allowance price that is too low to trigger investments in available transformative technologies or to drive substantial innovation. In this setting, flexible performance can be added to the ETS, with minimal influence on allowance prices in the short term and providing amplified incentives for innovation. Trading of compliance credits between entities with different costs would deliver improved cost effectiveness.

This approach may be challenging for a country such as Sweden, which has only a limited number of national industrial actors, which means that the efficiency gains related to trade are limited. In fact, this points to an important design opportunity to implement the performance standard policy without trade initially, thereafter evolving to a tradeable performance standard scheme that allows the trading of compliance credits relative to a benchmark across multiple sectors or by recruiting additional jurisdictions over time.

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Making the legal and economic case for an auction reserve price in the EU ETS

CAROLYN FISCHER

An auction reserve price for the EU ETS would improve the strength and stability of the carbon price signal. Since it would be legally and economically distinct from a carbon tax, an auction reserve price could be implemented under EU law without unanimity in the Council of Ministers.

At the time that the European Union Emissions Trading System (EU ETS) was launched as the cornerstone of the EU's climate policy, carbon dioxide prices of around €30/tonne were expected. Soon after, prices dropped, a privately held emissions bank ballooned, and low prices persisted for a decade, raising concerns that low levels of investment in technologies and innovation would threaten the achievement of long-term climate goals.

In response, the European Commission turned to various administrative measures, including postponing the introduction of allowances ("backloading") and using a quantity-based criterion for regulating future allowance sales ("the market stability reserve", MSR), ultimately with provisions for invalidation of some excess allowances, as well as tightening of the cap. While prices have now begun to recover, the MSR mechanism is far from transparent, and its effectiveness in managing price expectations is likely to evolve over time. Not everyone is convinced that these measures are sufficient to support adequately the price of carbon dioxide going forward.

Auction reserve price sets a minimum price

At the same time, the EU has tended to rely on overlapping regulatory measures that, unfortunately, reinforce low prices in the ETS and further undermine confidence in market-based mechanisms for reducing greenhouse gas emissions. Some Member States, such as the Netherlands and formerly the UK, have begun to add their own carbon levies to raise prices. In other prominent carbon markets, however, regulators have incorporated an auction reserve price, setting a minimum price in allowance auctions, to avoid the unexpectedly low-price outcomes experienced in the EU ETS.

Opponents of instituting a similar auction reserve price in the EU ETS express two main concerns. First, they fear that a minimum auction price would interfere with the quantity-based nature of the market. Second, they argue that a reserve price would be tantamount to a tax, thereby triggering a burdensome decision rule requiring unanimity among EU Member States that would be difficult to overcome.

No legal barriers

We reviewed the economic and legal arguments for and against an auction reserve price. Our economic analysis found that an auction reserve price is necessary to accommodate overlapping policies and for the allowance market to operate efficiently. It could even reinforce the functioning of the existing MSR. Our legal analysis concludes that, in as much as an auction reserve price is not a "provision primarily of a fiscal nature" and would not "significantly affect a Member State's choice between different energy sources", no legal barriers stand in the way of the incorporation of an auction reserve price into the EU ETS.

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Carbon Border Adjustments: Can they accelerate climate action?

MILAN ELKERBOUT

The potential introduction of carbon border adjustments, or CBAM – with 'M' standing for 'mechanism'– has been the talk of the town in Brussels since their first mention in European Commission President von der Leyen's Political Guidelines. The political momentum is strong, with the main EU institutions all having expressed their support for the idea in general.

The Commission presented its proposal in suammer 2021, after the EU Member States reiterated their support in the European Council of December 2020. The European Parliament then adopted a (non-binding) resolution in favor of the idea.

The proposed CBAM would require importers in certain sectors to acquire 'virtual' Emissions Trading System (ETS) allowances, which mirror the actual ETS price. By doing so, importers face carbon costs similar to these imposed on EU producers. The CBAM will apply to fertilizers and basic materials, such as steel, cement and aluminum, as well as some intermediate goods in these sectors, although not to final goods such as vehicles using these materials. If an exporting country itself applies a carbon price, this will be accounted for in the calculation of the CBAM. Any free allowances granted by the EU to their own producers will also affect the impact on importers.

A safeguard against carbon leakage risk?

Not everyone agrees on the overarching objective of a CBAM[1]. One interpretation is that a CBAM would allow the EU to accelerate climate action. There are two ways in which a CBAM could in theory achieve this. First, carbon border adjustments could act as a safeguard against carbon leakage risk. Mitigating carbon leakage risk is important if European companies need to invest in climate-neutral technologies, as they are then protected against importers who do not face similar carbon costs in their home markets. Second, the existence of a CBAM could prompt other countries to strengthen their own carbon pricing policies, to avoid additional charges at the EU single market border.

There are counterarguments to both of these interpretations. Even with a CBAM, European companies may only invest in breakthrough technologies if there is a market for climate-neutral products. High capital and operational expenditures and non-economic barriers may, nevertheless, hinder large-scale investment, even with higher carbon prices. Moreover, while other economies – particularly the growing group of countries with commitments to 'net-zero' targets – might accelerate their domestic climate actions in response to a CBAM, they might also retaliate or challenge the policy at the World Trade Organization (WTO). In addition, there is risk of 'reshuffling', in that products with the lowest carbon footprint may be selected for trade with the EU, while the higher-carbon products are consumed domestically. As a consequence of this strategy, there is no impact on overall emissions.

A CBAM is complicated to design

Additional design challenges, both technical and political, remain. What should be done with exports? For EU producers with strong exports, this is as important as safeguards against imports. A rebate on ETS costs could apply in theory, although potential export subsidies are difficult to justify at the WTO. Another issue is what happens to free allocation. The Commission in theory sees the CBAM and free allowances as alternatives, rather than complements, while the European Parliament in dropping a reference alluding to this from their final resolution reveals the political sensitivity of this issue. Indeed, the Commission now proposes to combine free allowances and the CBAM until well into the 2030s. Finally, the accrual of revenues from the CBAM – while seemingly attractive – may make it easier for trade partners to challenge the environmental objective of the mechanism.

The scope of an initial CBAM may, therefore, be more limited in terms of sectors and exemptions. For this reason, the impact on accelerating global climate action may turn out to be modest in the short term.

[1] https://www.ceps.eu/ceps-publications/how-eu-trade-policy-can-enhance-climate-action/

A transition fund to foster deep emissions cuts in the basic material industry

FILIP JOHNSSON AND JOHAN ROOTZÉN

A transition fund initiated and managed by private actors to finance deep emissions cuts in the basic material industry could act as a complement to "conventional" carbon pricing and channel an increased willingness to contribute to combating climate change among businesses and the public.

Costs to reduce CO_2 emissions to zero for cement and steel production with today's known technologies are estimated to be at least 100 €/tCO_2 when applying a portfolio of technologies and measures that include Carbon Capture and Storage (CCS) and hydrogen-based steelmaking. This is higher than the cost imposed by current climate policies, such as the European Emissions Trading System (EU ETS), which in the EU is the main policy instrument for controlling emissions from cement and steel production plants and other industries with large point sources of CO_2 emissions.

It is equally important that there will be predictability regarding how the carbon price will evolve over time. Continued unpredictability with respect to the future development of the carbon price will likely mean that firms will not invest or will underinvest in low-carbon technologies.

Increased awareness in business of climate targets

At the same time, there are plenty of signs of a strong and growing awareness in businesses, including the basic materials industry and the construction sector, with respect to their roles in tackling sustainability challenges in general, and in reducing the climate impacts of production processes and products. This is linked to growing expectations from customers, employees, capital markets, governments, and NGOs that companies will be transparent in the ways that they work to improve their environmental performance, including how they plan to meet targets for reducing carbon emissions to meet climate targets.

This is in line with findings that indicate that consumers prefer to purchase products from firms that are engaged in carbon emissions reduction. Furthermore, there seems to be a significant willingness among the public to pay for climate change mitigation, although the extent of this willingness varies greatly between countries and consumer groups and is difficult to measure.

Several industries at the end of the value chain, such as automotive industries, have defined targets of climate neutrality in line with the Paris Agreement. Volvo Cars, for example, has defined a target of net-zero emissions by Year 2040, including Scope 1–3 emissions. This would require that Volvo and other companies with similar targets will be able to purchase climate-neutral basic materials (e.g., steel).

Value chain analysis in Mistra Carbon Exit

From the analyses of value chains for cement and iron and steel production within the Mistra Carbon Exit program, we conclude that current practices and policies for emissions reductions are likely to deliver only incremental reductions in carbon emissions on a timeline that is far too slow to meet the deep emissions cuts required over the next decades so as to be in line with the Paris Agreement. The necessary transformative abatement options, such as CCS and hydrogen-based steelmaking, require large investments, which imply a high financial risk, so they are unlikely to be initiated under the current climate policy regime.

Proposal for a transition fund to accelerate investments

From the above, we conclude that it is important to devise alternative policies, business models and collective initiatives as parts of an overall portfolio of policies and strategies. This would complement "conventional" carbon pricing schemes and channel the increasing willingness of businesses and the public to contribute to combating climate change.

As means to accelerate the transition of the basic materials industry, to engage non-state actors in the process, and to formalize cross-sectorial collaboration, we propose the establishment of a transition fund that would be used to finance high-cost measures in the basic material industry.

We use the Swedish construction industry as a case study for our analysis, although the proposal should have general applicability to other carbon-intensive supply chains involving industries that have the ambition to become frontrunners in mitigating carbon emissions. The transition fund, which would be funded through a fee imposed on basic materials such as steel and cement, would be used to finance investments in the transformative technologies required to meet emissions cuts along the CO_2-intensive supply chains in the building and construction industry, wherein the largest share of emissions is from the production of basic materials.

Unlike other similar proposals (for example, see EU ETS is not the only show in town - Policy packages for industrial decarbonization by K. Neuhoff, J Richstein, O. Chiappanelli), the fund would be initiated and managed by private actors without direct governmental involvement. This proposal is based on supply and value chain analyses, together with the recognition of favorable conditions for a polycentric approach, wherein companies across the value chain show an increased interest in engaging in green business driven by increasing consumer preferences for climate-neutral products and services. A transition fund would facilitate investments in costly CO_2-mitigation technologies, while minimizing the risk for individual companies, as well as for governments and taxpayers.

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Carbon Contracts for Differences can hedge against carbon price uncertainty

OLGA CHIAPPINELLI, KARSTEN NEUHOFF, AND JÖRN RICHSTEIN

A reform of the EU ETS that creates effective carbon pricing incentives combined with Carbon Contracts for Differences (CCfDs) that shield investors against regulatory risks can form the backbone of a policy package for industrial decarbonization.

Basic industrial sectors, such as steel, cement and plastic production, are responsible for a large share of emissions, both in the EU and globally. Reaching climate neutrality by mid-century, as envisaged by the European Green Deal, requires large reductions in emission from these sectors. This will require a robust and comprehensive policy package.

A high and stable carbon price is crucial

It is crucial that the carbon price reaches a sufficiently high level to allow investors to recover the incremental decarbonization costs linked to climate-friendly options. This requires that the carbon cost of conventional material production is reflected in the value chain, to ensure that: 1) the incremental costs of climate-neutral production are charged to the material users; and 2) carbon savings achieved through efficient material use and choice increase profitability. This objective is currently not met by the EU ETS, since producers of materials are granted allowances for free as protection against carbon leakage and, thus, only a small and uncertain share of EU ETS carbon costs is passed on into the supply chain. In addition, uncertainty related to carbon pricing constitutes a major risk for investments in low-carbon projects.

A charge on basic materials passed along the value chain

Studies conducted within the Mistra Carbon Exit program have examined policies that could address these issues. The lack of a carbon cost that is passed through to material prices can be addressed by complementing a continuation of the free allowance systems of the EU ETS with a Climate Contribution, i.e., a charge imposed on basic materials and material-intensive end-products. Such a charge would be passed along the value chain and paid upon eventual consumption of the end-product (regardless of whether the commodity is produced domestically or abroad). The charge would be tied to the weight of the material applying the same benchmark as used for free allowance allocation. The revenues from the charge could be used in part to finance climate action and in part be redistributed to citizens as a per-head reimbursement.

Such an approach would combine full carbon leakage protection with an effective carbon price signal to all actors along the value chain. Building on experiences gained with other consumption charges, implementation would be WTO-compatible and administratively feasible.

CCfDs can hedge against carbon price uncertainty

Carbon Contracts for Differences, CCfDs, issued by governmental financial institutions can help investors in low-carbon projects to hedge against carbon price uncertainty. Based on a contractually agreed strike price for emissions reductions relative to reference technologies, investors are guaranteed a fixed revenue per tonne of non-emitted CO_2. As long as EU ETS prices are below the strike price, the difference is reimbursed by the government. If CO_2 prices exceed the strike price investors must return the difference to avoid windfall profits. By shifting the risk associated with carbon pricing uncertainty from firms to governments, CCfDs lead to investments in clean technologies at lower expected carbon prices than for commonly discussed minimum CO_2 price levels. In addition, CCfDs can substantially reduce the need for public funding to support the transition of basic materials as the state can recover part of the support costs in periods with high carbon prices.

Contracts for Differences for Renewables can provide affordable green electricity

Many low-carbon technologies rely on electrification, which means that overall carbon mitigation costs are driven by electricity costs. CCfDs for Renewables issued in public auctions facilitate low-cost financing for renewable projects via the provision of stable revenue streams, thereby reducing renewable generation costs by about 30 percent. These long-term provisions can also be passed on to electricity users, enhancing the predictability of input costs for clean production processes and thereby simplifying the design of CCfDs.

Creation of low-carbon markets and practices

Other policies are also needed to support the demand side by creating markets for low-carbon products and incentives for improvements in material choice and efficiency in the manufacturing and construction sectors (e.g., by developing procurement practices), as well as to break the inertia towards transformation.

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Public procurement for carbon reduction – the case for sector specific and general policies

ANNA KADEFORS AND STEFAN UPPENBERG

There is growing awareness of the direct impact that public procurement practices and requirements have on the performances of important supplier markets. Consequently, procurement is increasingly seen as an important policy tool to reduce carbon emissions. The construction sector is pinpointed due to the large volumes of public construction in combination with the substantial carbon emissions that arise from the use of fossil fuels for transport and construction equipment, and that are embodied in cement, steel, and asphalt.

Construction procurement is complex, and measures to reduce carbon emissions must fit with the general contracting strategy chosen for a project. In a study of procurement practices used by leading infrastructure clients worldwide, we have identified the following requirements, criteria and incentives to promote carbon reduction:

• Qualification and award criteria, to reward suppliers for carbon competence or, potentially, the carbon footprint of a tendered design for a design-build contract.

• Specific requirements relating to various aspects such as: the use of cement replacement, fuel or type of vehicles; Environmental Product Declarations (EPDs) and other carbon-related documentation; compliance of the facility with environmental assessment schemes; and organizational competence and processes, including standards for carbon management.

• Requirements and bonuses for reducing the carbon footprint of the constructed facility in relation to a baseline.

Our research further shows that all these types of requirements and measures are associated with drawbacks and limitations. On a basic level, there must be enough suppliers that tender for a contract. This limits the applicability of qualification criteria, as well as of any measures that substantially increase the cost of developing tenders. To drive development without reducing competition, clients with a long-term perspective may raise requirements stepwise based on continuous and active communication with the market.

Some clients, however, have policies that prescribe performance requirements and design-build contracts. In such cases, specific requirements may be ruled out on principle. Another option is to reward carbon reductions with bonuses or penalties. The downside to this is that reduction requirements typically entail substantial work to calculate baselines and update them to reflect scope changes. This means that key engineering resources may be tied up during the short period available to investigate the most important design options. In a temporary and unique project, significant options for carbon mitigation may never be investigated due to lack of time. Other limitations relate to client time and resources for evaluating tenders based on award criteria and following up contract performance.

Sector-specific policies based on contextual knowledge

Changes in procurement policies and practices are undoubtedly essential to promote carbon reduction in the demand-driven construction sector. However, designing adequate procurement policies for carbon reduction is a complex process that relies on competences in procurement law, carbon mitigation methods and supplier market maturity, and construction project management and contracts. Our research has shown that policies, practices and tools need to be sector-specific and should address also capability development and learning among clients and other actors in the supply chain. Thus, formulating policies in terms of very general concepts, such as Green Public Procurement and Sustainable Public Procurement, is less helpful, since the

important roles of contextual knowledge and adaptation are downplayed.

Instructions to government-sector construction clients should clearly state that these aspects should be in the forefront when driving carbon reduction through their procurement systems, also if this leads to somewhat higher investment costs.

General policies to enable collaboration and innovation

A focus on the reduction of carbon emissions in procurement policies and practices is not sufficient to realize the full potential for carbon reduction available today, let alone the reductions that will be required in the future. In effect, procurement policies that target carbon emissions without considering the wider organizational and contractual aspects may encounter unforeseen complications during their implementation. It is well known that traditional fixed price contracts frequently induce opportunistic mindsets and hamper knowledge sharing, especially in construction projects with high levels of uncertainty.

Similarly, if carbon performance is associated with sharp incentives or high risks, there is a risk that this could constitute a new ground for conflict rather than acting to spur innovation. Thus, our research shows that procurement strategies that encourage collaborative and integrated project processes will also significantly benefit carbon performance. As mentioned above, we found long-term strategies encompassing several successive projects to be favorable. To drive carbon reduction in smaller and less-complex projects, framework contracts that bundle schemes of projects and enable learning by repetition are particularly powerful. Such integrative and collaborative procurement strategies may not only pave the way for carbon mitigation, but are also essential to achieve innovation, resource efficiency, and quality in construction more generally.

In summary, apart from general financial measures such as carbon taxes, our studies point to a demand for context-specific policies. To be truly potent and effective, such polices will also need to be general in scope, so that carbon abatement goals and measures become part of, and a key driver for, a wider agenda to improve public construction procurement.

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Creating incentives for producing BECCS in Sweden

DANIEL JOHANSSON, FILIP JOHNSSON, KENNETH MÖLLERSTEN, AND LARS ZETTERBERG

Negative CO_2 emissions are prevalent in most global emissions pathways that meet the Paris Agreement temperature targets and are a critical component for reaching net-zero emissions by 2045. Sweden has a significant potential for producing negative emissions in the form of bioenergy and carbon capture and storage (BECCS) – corresponding to approximately 50 percent of Sweden's total CO_2 emissions. Yet, there is a lack of economic incentives to support the commercialization and deployment of negative emissions, in particular for BECCS.

The total potential for BECCS in Sweden is large, being estimated as 20 Mt/year (assuming an 85 percent capture rate), which can be compared with the total Swedish greenhouse gas emissions of around 53 Mt/year of which 43 Mt is CO_2 emissions. A more detailed assessment of CO_2 capture by means of post-combustion capture applied to the 28 largest (>500 ktCO_2/year) industrial emitters hows that 23.7 Mt could be captured (Figure 1), of which around half is of biogenic origin.

Thus, more than 50 percent of Sweden's total CO_2 emissions, from all sectors, could be captured from these 28 industrial units at a cost in the range of 40–110 €/tCO_2, depending on the emission source (Figure 1). This would give a total cost – including transport and storage – in the range of 80–130 €/tCO_2. Partial capture from the most-suitable sites would reduce the cost of capture and, thus, might serve as a low-cost option for introducing CCS. The exact costs for transport and storage will depend on the location and type of transportation infrastructure.

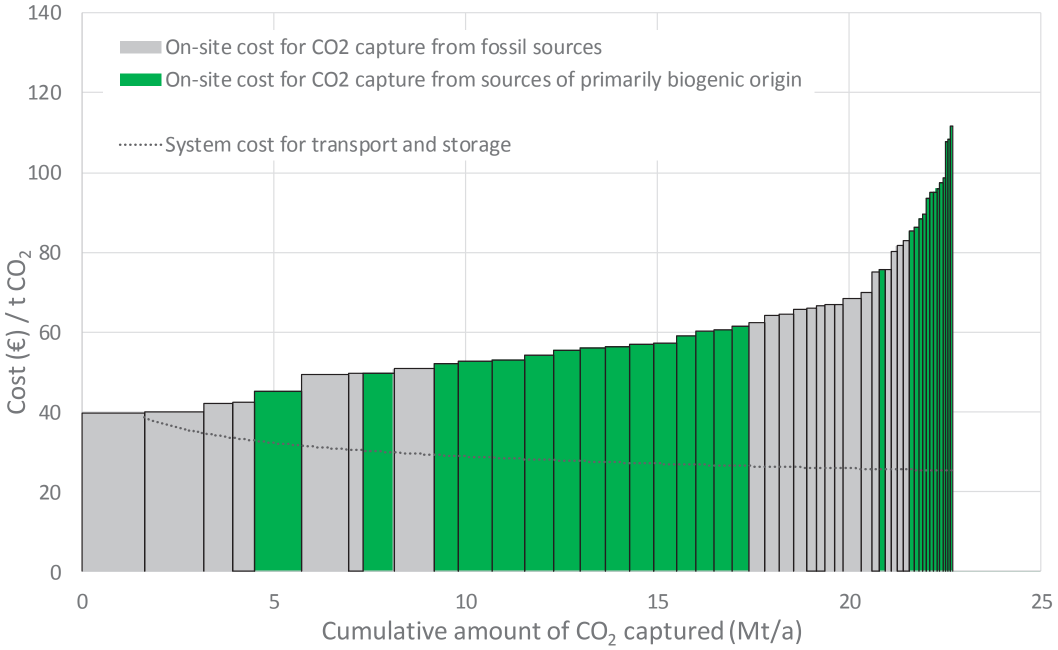

Figure 1. Marginal abatement cost curve for carbon capture and the corresponding system costs for transport and storage from Swedish industrial plants with emissions >500 ktCO2/year. Source: Johnsson et al. (2020).

At present, there are no economic incentives for negative emissions, so these must be created. We have identified five different models for creating incentives and financing for BECCS:

1. The government purchases outcomes from BECCS projects, for instance by organizing reverse auctions and then signing contracts with the lowest bidders. This model was recently proposed by a Government of Sweden public inquiry into negative emissions.

2. The state creates a system for BECCS certificates. These certificates are issued to producers of BECCS after capture and storage has been verified. The state creates a demand for the certificates by imposing a quota obligation on fossil fuel dealers to purchase BECCS certificates that correspond to a share of their fossil-CO_2 emissions.

3. The EU Emissions Trading System (ETS) is modified to allow participants to use BECCS certificates for compliance, thereby creating a demand for such certificates.

4. Voluntary actors, such as Microsoft, Stripe, Shopify and other companies, purchase BECCS credits to compensate for emissions.

5. Other states purchase BECCS credits from Sweden to reach their national commitments following the Paris Agreement.

A challenge is how to decide on the time period necessary for Policy model 1 and its phasing out, while expanding a combination of the other models. Thus, although a policy sequencing approach seems necessary, it is not obvious how it should be arranged, since the capacity to act towards implementing the different policy models presented in this work resides in different organizations (national governments, EU, private firms). Finally, it is important that BECCS policies are part of an overall climate and biomass policy to ensure biomass resource efficiency.

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1 NO POVERTY
15 LIFE ON LAND
10 REDUCED INEQUALITIES
AFFORDABLE AND CLEAN ENERGY
THE GLOBAL GOALS
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
4 QUALITY EDUCATION
13 CLIMATE ACTION
8 DECENT WORK AND ECONOMIC GROWTH
GENDER EQUALITY
14 LIFE BELOW WATER
11 SUSTAINABLE CITIES AND COMMUNITIES
ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
6 CLEAN WATER AND SANITATION
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

5. Sustainable Climate Transition

There is a need for urgent action to combat climate change and its impacts. This will require that applications of zero-carbon materials, transportation, and energy systems continue to grow and become the new normal. This transition, which should unfold in the next 10–20 years, will most likely have the consequence that several sustainability goals will be in conflict, requiring challenging compromises.

For instance, a full-scale transition to zero-carbon steel will require significant growth of carbon-free electrification – for which wind power is likely to constitute a large share – and the establishment of new power transmission lines. This will have an impact on land-use and may pose challenges in terms of social acceptance. A large-scale introduction of electric vehicles will require batteries (and, of course, electricity) that are produced in a sustainable way. Zero-carbon vehicles will have positive effects on air quality. Zero-carbon cement will require an infrastructure for carbon capture and storage.

The climate transition will create new jobs, while some traditional jobs will disappear, with potentially serious social impacts. These impacts will differ depending on the region. Yet, the transition is likely to help Swedish industry to win greater market shares and create new export opportunities.

It is, therefore, important to understand the implications of climate transition for other sustainable development goals. In Mistra Carbon Exit, this work has started in Phase 1 and has included methodology development and the testing of these methods in several case studies

Climate mitigation and sustainability – a game of whack-a-mole?

ANDERS AHLBÄCK, MARTIN ERIKSSON, AND EDVIN NORDELL

Transforming Swedish industry to achieve net-zero emissions of greenhouse gases entails opportunities and risks for other sustainability objectives, as described by the Sustainable Development Goals (SDGs). Moving forward, holistic perspectives, transparency and supply chain coalitions will be key factors in avoiding the creation of new problems when solving the climate challenge, like a game of whack-a-mole.

As more attention is devoted to limiting global warming, finding cohesion between the Paris Agreement and the UN 2030 Agenda for Sustainable Development will be a major challenge. Reaching net-zero emissions of greenhouse gases in Sweden by Year 2045 will require new practices, policy instruments and technologies. In technology terms, the transformation is heavily dependent upon the expanded use of renewables and electrification, as well as the introduction of new raw materials, production processes and carbon capture and storage (CCS).

Exclusively addressing the climate issue will most likely introduce risks and opportunities for other SDGs in Sweden and elsewhere. Therefore, we have assessed the additional impacts from the transformative key technologies of wind, solar and bio power, electric vehicle batteries (EVB), climate-neutral concrete and CCS, all of which need to be considered at an early stage. Moreover, assessments need to be conducted that consider the implications across the entire supply chain.

Table 1. Identified SDG risks and opportunities expressed as being positive (P) or negative (N) or having no impact (-), as well as the knowledge gaps (?) for key technologies in the Mistra Carbon Exit pathways. Note that there are several cases with more than one impact category for the same SDG from each key technology.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Wind	-	-	P/N/N	-	-	N	P	P	P	P/N/N	P/P	P/N/?	P	P/N/?	N/N/?	N	P
Solar	-	-	?	-	-	N/N	P	P	P	-	P	P/N	P	-	?	-	-
Biomass	-	N	N	-	-	N	P/N	P	P	-	?	P	P	N	N/P	-	-
CCS	-	-	-	-	-	-	P/?	P/N	P/?	-	P	N	P	N/N	N	-	P
Concrete	-	-	-	-	-	P/N	P	P	P/P/?	-	P	P/N	P	N/N	N/?	-	-
EVB	-	-	P/N	-	-	N	P/?	P/N	P/ P	?/?	P	?/?	P	P/?	N	N	?

Large-scale expansion of new technologies comes with risks

The SDG impact assessments carried out within the Mistra Carbon Exit program (see Table 1) show that large-scale expansion of key technologies may lead to environmental concerns for aquatic and land-based ecosystems (SDG 6 "Clean Water and Sanitation", SDG 14 "Life Below Water", and SDG 15 "Life on Land") in terms of reduced biodiversity and the degradation and contamination of ecosystems. Moreover, extractions of raw materials for use in the production of wind turbines, solar cells and EVB also entail risks to human health (SDG 3 "Good Health and Well-being").

Increased pressure on reuse and recycling

Further risks to human health are apparent downstream of the supply chains. These include air pollution from the combustion of biomass and noise pollution from wind power. In addition, there are few established systems to handle large volumes of disposed wind turbines, lithium-ion batteries and photovoltaic cells, which might exert a negative impact on SDG 12 "Responsible Consumption and Production". Thus, as usage continues to grow, there will be increased pressure on the capabilities to reuse and/or recycle raw materials and components.

Climate mitigation brings opportunities

Undoubtedly, the transformation will confer opportunities and benefits on Swedish Society and stakeholders around the world. Most notable will be: the creation of new jobs and economic growth (SDG 8 "Decent Work and Economic Growth"); innovation opportunities for industry at both component and system levels (SDG 9 "Industry, Infrastructure and Innovation"); and greater accessibility to clean and renewable energy (SDG 7 "Affordable and Clean Energy").

Managing trade-offs towards a sustainable climate mitigation

To stimulate opportunities and minimize the risks associated with reaching net-zero emissions of greenhouse gases in Sweden, actors across the supply chains will need to find new ways to collaborate, both nationally and globally. There is a need to monitor the sustainability performance of supply chains, both continuously and transparently, to identify trade-offs among the SDGs. Taking responsibility across supply chains and beyond national borders while adopting a holistic perspective will be crucial to handling trade-offs and minimizing negative impacts, towards the goal of sustainable climate mitigation. These perspectives are pivotal to avoid playing whack-a-mole with sustainability.

Concrete sustainability goals are required for a green restart

FILIP JOHNSSON, IDA KARLSSON, JOHAN ROOTZÉN, ANDERS AHLBÄCK, AND MATHIAS GUSTAVSSON

It is important that assessments of Sustainable Development Goals in firms are carried out in a way that discourages so-called "greenwashing". Thus, any SDG assessment that relates to climate targets in line with the Paris Agreement should identify abatement possibilities and their associated processes and activities that can be expected to be particularly challenging.

This aim of this work is to contribute to the establishment of a robust framework for the assessment of Sustainable Development Goals (SDGs) in businesses, using the construction industry as an example and with the primary focus on combating climate change (SDG 13). We have carried out a critical analysis of a selection of relatively widely used SDG impact assessment tools, combined with a case study involving the construction industry, to explore how a meaningful SDG assessment can be framed with linkages between SDG 13 and other related SDGs.

Our analysis points towards the importance of framing SDG assessments in a way that discourages "greenwashing". Any SDG assessment that relates to climate targets in line with the Paris Agreement should identify abatement possibilities and their associated processes and activities that can be expected to be particularly challenging. In our construction work case (a road), we identify four such hard-to-abate activities:

1.Introducing biomass for the provision of renewable transportation fuels for use in construction equipment and heavy transport.

2.Electrification of transport and industrial processes.

3.Substitution of fuels as part of the process of transitioning from fossil fuel use.

4.Applying carbon capture and storage technologies to the production of basic materials, such as cement and steel.

There is a risk that businesses use SDG analysis in a selective way, for instance focusing exclusively on SDGs in situations where they are already performing well or can apply low-cost measures or set a narrow scope that only pertains to their own part of the supply chain (Scope 1 emissions).

For an SDG assessment to provide the basis for informed decisions regarding real change towards more sustainable and equitable corporate practices it should:

(i)¨Identify and include concrete measures to align with the terms of the Paris Agreement;

(ii) Include relevant value chains; and

(iii) Consider both the short-term and long-term effects of strategic choices.

Companies that follow this pathway can use the Agenda 2030 framework to increase sustainability and to reduce their business risks in the long term. Companies that today avoid those areas that are most difficult to remedy may in the future find it very difficult to transform when public opinion no longer accepts continued emissions of greenhouse gases and other unsustainable activities.

No longer room to focus on the easier goals

In June 2020, the Government of Sweden submitted a new bill to increase the pace of Sweden's Agenda 2030 work. The Minister of Climate stated that the coronavirus pandemic has exposed many of society's vulnerabilities and that implementation is now more crucial than ever. There is no longer any room to focus exclusively on the easier goals. Instead, companies must dare to take on the biggest challenges. The transition to a low-climate-impact economy/ recovery from the pandemic will, in part, depend on economic stimulus packages. The Government of Sweden should, therefore, develop as a matter of urgency criteria for making such economic support conditional, so that it makes a concrete contribution to the Agenda 2030 framework. A successful set of criteria, based on the SDG framework, could contribute to Sweden taking the lead in efforts towards increased sustainability, at the same time as our business community gains a competitive advantage by being at the forefront of the transition.

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Climate economics support for the Paris Agreement

CHRISTIAN AZAR, THOMAS STERNER, AND DANIEL JOHANSSON

Refined climate-economic modeling shows that an economically optimal climate policy is in line with the Paris Agreement's 2°C goal. This research as part of the Mistra Carbon Exit program, published in Nature Climate Change, may increase support for climate targets in line with the Paris Agreement and increase the level of acceptance of carbon prices.

For at least a decade, a clear division has existed between the United Nations Framework Convention on Climate Change (UNFCCC) negotiations, which aim for stabilization of the global mean surface temperature at 2°C or less above the pre-industrial level, and the main message from Cost-Benefit Analyses (CBAs) of climate change, in which economic estimates of the damages of climate change are weighed against the cost of reducing emissions.

Based on the latter approach, the recipient in 2018 of the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, William Nordhaus, has argued that the world community should instead aim for a global temperature increase of 3.5°C in Year 2100 (Nordhaus, 2019).

More accurate calibration and updated estimates

With our new research, we believe that this discrepancy between mainstream CBAs and the UNFCCC can be laid to rest. We show that the climate targets of the Paris Agreement may very well be optimal even in Dynamic Integrated Climate Economy modeling (DICE), that is the Integrated Assessment Models (IAMs) developed and used by Nordhaus, when appropriately updated.

Changes made to DICE include a more-accurate calibration of the carbon cycle and energy balance model, and updated climate damage estimates. To determine economically "optimal" climate policy paths, we use evidence from a range of expert views on the ethics of intergenerational welfare.

Using the updates that we deploy from the climate and economic sciences jointly, we find that around three-quarters and one-third of the expert views on the ethics of intergenerational welfare translate into economically optimal climate policy paths that are consistent with the 2°C and 1.5°C targets, respectively.

Model output supports CO_2 prices

In the broader international discussions on climate policy, this research may help to increase support for climate targets in line with those adopted in the Paris Agreement, as well as to increase the level of acceptance of carbon prices (the 'Social Cost of Carbon'), in line with meeting the adopted climate targets. For example, the model output provides support for CO_2 prices on a par with the current CO_2 tax in Sweden, which is roughly three-times higher than the prevailing allowance price in the EU ETS.

Furthermore, the Biden Administration in the USA is on the verge of updating the numbers for the Social Cost of Carbon, and it is possible that our research will have an influence on those discussions. Only time will tell.

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Winners and losers in societal transformations to mitigate climate change

SEJIN LEE, BJÖRN-OLA LINNÉR, AND VICTORIA WIBECK

Transformative changes that pave the way for achieving a low-carbon future and sustainable society could entail different consequences for peoples' lives and livelihoods. To be effective, decarbonization policies need to accommodate just transformations.

To reach the goals of the Paris Agreement and the 2030 Agenda, we need comprehensive and enduring changes in the ways that we live our lives and run society. Such societal transformations involve governance towards systemic cultural, social, economic, and political changes that induce an end to fossil fuel dependency and unsustainable resource use. The transformation concept signals not only a change from one technology to another, but also the creation of a new form of society.

All societal transformations create winners and losers. This poses two challenges for aspirations towards transformative sustainability. First, the UN Sustainable Development Goals, including the climate objectives, depart from the slogan to "leave no one behind". Thus, a successful transformative agenda needs to include considerations of its potential unintended negative social consequences. Second, to avoid counter reactions or obstructions, efforts towards sustainability transformations need to be perceived as legitimate and desirable. The yellow vest movement (Mouvement des gilets jaunes) in France is a recent reminder of this.

Socio-economic advantages for all

For our Mistra Carbon Exit project on just transformations, we have reviewed 133 scholarly papers. This body of literature reveals that for a just transformation, four pillars of social justice should be considered: 1) Distributional justice – allocating equitably the socio-economic advantages and costs of structural changes towards a low-carbon society to all social groups; 2) Recognitional justice – decision-making has to depart from an understanding of the prevalent cultural and historical knowledge and governance of different places, including race, class and gender aspects; 3) Procedural justice – the voices and interests of different stakeholders need to be incorporated into the decision-making processes; 4) Restorative justice – rectifying damages to social groups that are caused during the transformations.

Job training, education and differentiation

When scrutinizing the Swedish efforts to achieve just transformations, in line with the Just Transition Mechanism of the European Green Deal, our MCE studies showed that they largely emphasize distributional dimensions. The draft transition plans for the Norrbotten and Gotland regions, with their respective steel and cement industries, highlight the need for job training, new higher education programs with relevance to the development of fossil-free industries, and the differentiation of the business sectors in the targeted regions.

Just decarbonization must include many dimensions

In our review of earlier studies of just transformations, we identified distributional priorities similar to those encountered in previous efforts to mitigate the socio-economic repercussions of transformations in regions that were heavily dependent upon carbon-intensive industries, such as the Ruhr region in Germany, where hard-coal mines were closed after stakeholder consultations. However, since just transformations cover a wide palette of justice aspects, we conclude that future efforts toward just decarbonization transformations need not only to handle the distributional aspects, but must also clearly include the recognitional, procedural and restorative dimensions.

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Linnér analyses how the political processes and actors affect conditions for social changes towards decarbonization and sustainable development in different parts of the world. An important part of his research is to develop new methods and platforms for analysis.

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Marcus' work focuses on reducing the carbon footprint of the construction sector by promoting low-carbon materials and supporting manufacturers to reduce their emissions.

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Research implementation

The external partners engaged in Mistra Carbon Exit represent a range of firms with production facilities and markets in Sweden and abroad, including vehicles (personal and freight), materials production, construction (components, buildings and infrastructure), and energy supply and distribution. Included are also real estate owners, the financial sector, NGO:s and national and local authorities, with strong engagements in, and responsibility for, future climate abatement measures and policy.

The interaction between our scholars and representatives from these non-academic partners is an important part of the research in Mistra Carbon Exit since we aim at successful implementation of the research results. The interaction is two-way, and help the researchers to prioritize, adjust and focus the research, as well as the opportunity to inform our end-users about our results directly. As part of the research, we have applied and further developed a participatory methodology for co-producing results with our end-users within and outside the group of external partners.

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About Mistra Carbon Exit

The Mistra Carbon Exit program addresses and identifies the technical, economic, and political challenges that Sweden will encounter when it attempts to reach the net zero greenhouse gas emissions target by 2045.

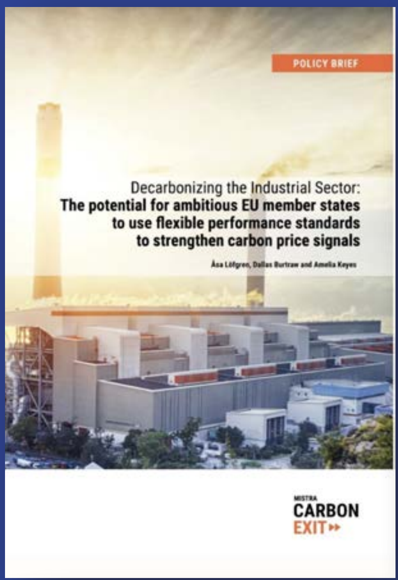
This target will require transformative pathways in virtually all industrial processes and their associated products and services. Mistra Carbon Exit takes a novel approach in addressing this challenge by focusing on opportunities and barriers for mitigating carbon emissions along industry supply chains – from the input of raw materials, through primary and secondary activities, to final products and services demanded by the end user.

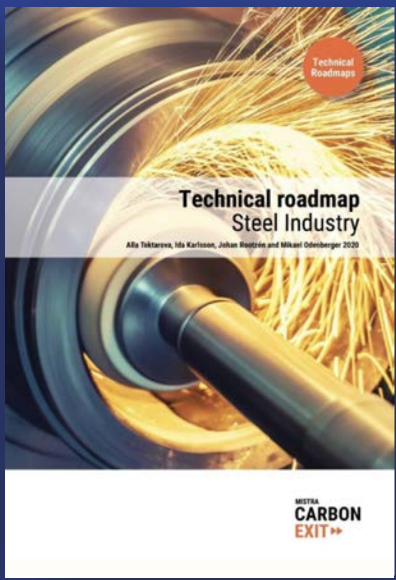
The program gathers key Swedish industries, covering the supply chains of buildings, transportation infrastructure and transportation, which allow the capture of at least 75 percent of Sweden's CO_2 emissions. Mistra Carbon Exit was approved for funding by Mistra in December 2016 and started in April 2017. In December 2021 Mistra approved a second phase of the program.

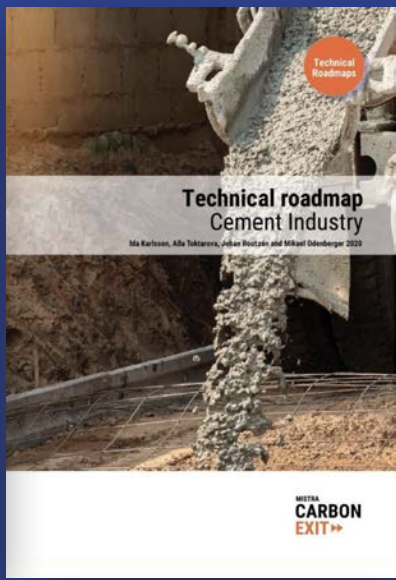
In Phase 1 we identified technical pathways, including a first assessment of opportunities and barriers for their implementation. We also identified and analyzed a set of policy instruments that can trigger these transformative changes, and we started to understand the importance of attitudes and behavior for a successful transition of the supply chains investigated.

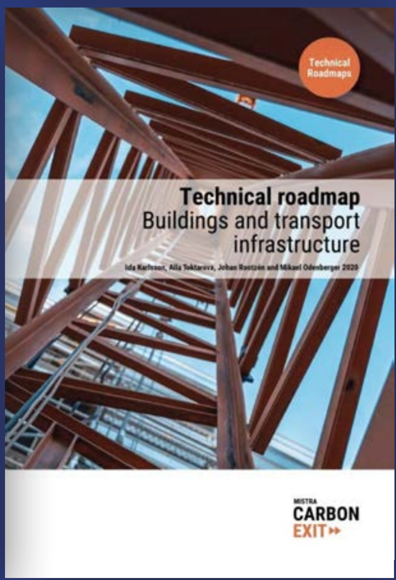
In Phase 2 we will focus on key areas related to technologies, governance, behaviors, and policies. By identifying pathways and policies, we aim to show how Sweden and Swedish companies can become frontrunners in transforming society and industries, providing low-carbon products and services while at the same time addressing market risks.

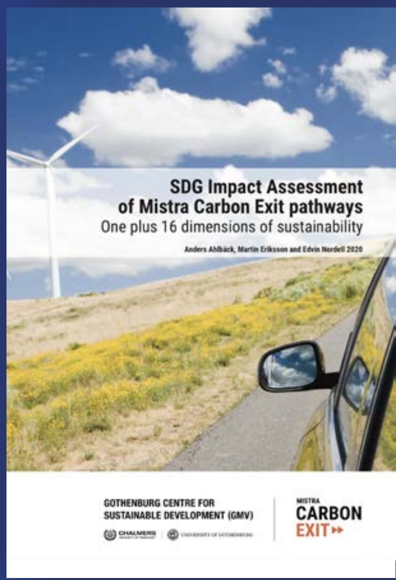
The Mistra Carbon Exit consortium includes a broad representation of researchers and actors: four universities:, including four universities Chalmers University of Technology, University of Gothenburg, Linköping University, and the Royal Institute of Technology (KTH)], four research institutes IVL Swedish Environmental Research Institute (program host), Resources for the Future (RFF), The German Institute for Economic Research (DIW), and the Centre for European Policy Studies (CEPS)], and some 20 companies, authorities and non-governmental organizations.











You will find all our publications at **mistracarbonexit.com/publications**

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