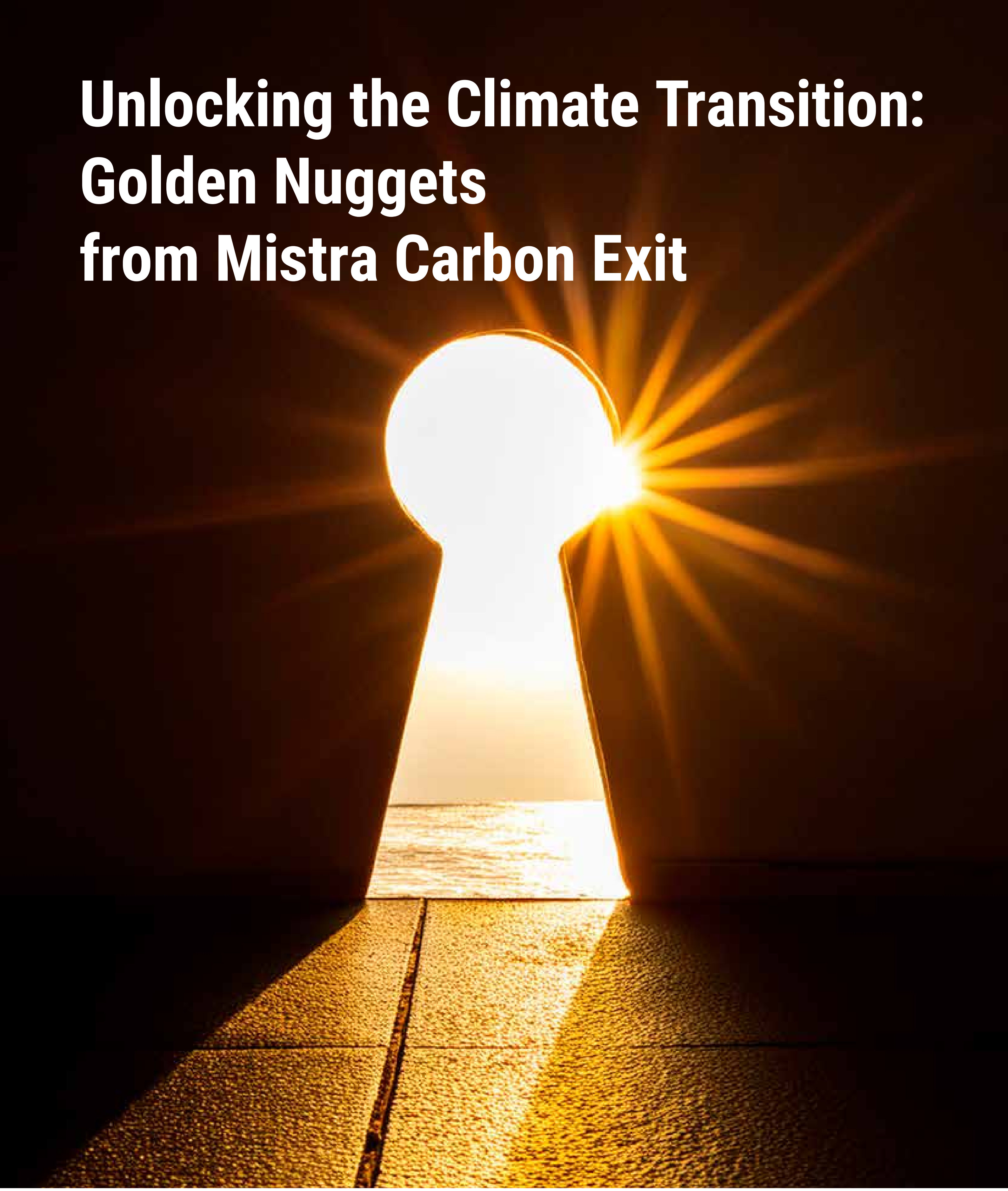
Unlocking the Climate Transition: Golden Nuggets from Mistra Carbon Exit



MISTRA CARBON EXIT

Editors: Lars Zetterberg, Filip Johnsson and Maria Ljung.
Layout: Maria Ljung, IVL Swedish Environmental Research Institute.
Photo: Adobe Stock page 1, 13, 15, 19, 23, 29, 34, 35, 37, 39, 41, 43, 44, 47, 49, 51, 52, 53, 55, 56, 59, 72. Christin Filipsson page 7, 27. Chalmers page 7, Skellefteå Municipality page 8, Swedish Environmental Agency page 8. Pixabay page 11, 63, 68. Visit Skellefteå page 17. RealPeopleGroup page 21. Andrea Hallencreutz/IVL page 26. Anna Edlund page 45. Dati Bendo/European Union page 61. Erik Cronberg, IVA, page 66.

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Mistra Carbon Exit, in operation 2017-2025, was a research programme funded by Mistra with the aim to identify and analyse the technical, economic and political opportunities and challenges for Sweden to reach the target of net zero greenhouse gas emissions by 2045

MISTRA

Mistra , the Swedish Foundation for Strategic Environmental Research

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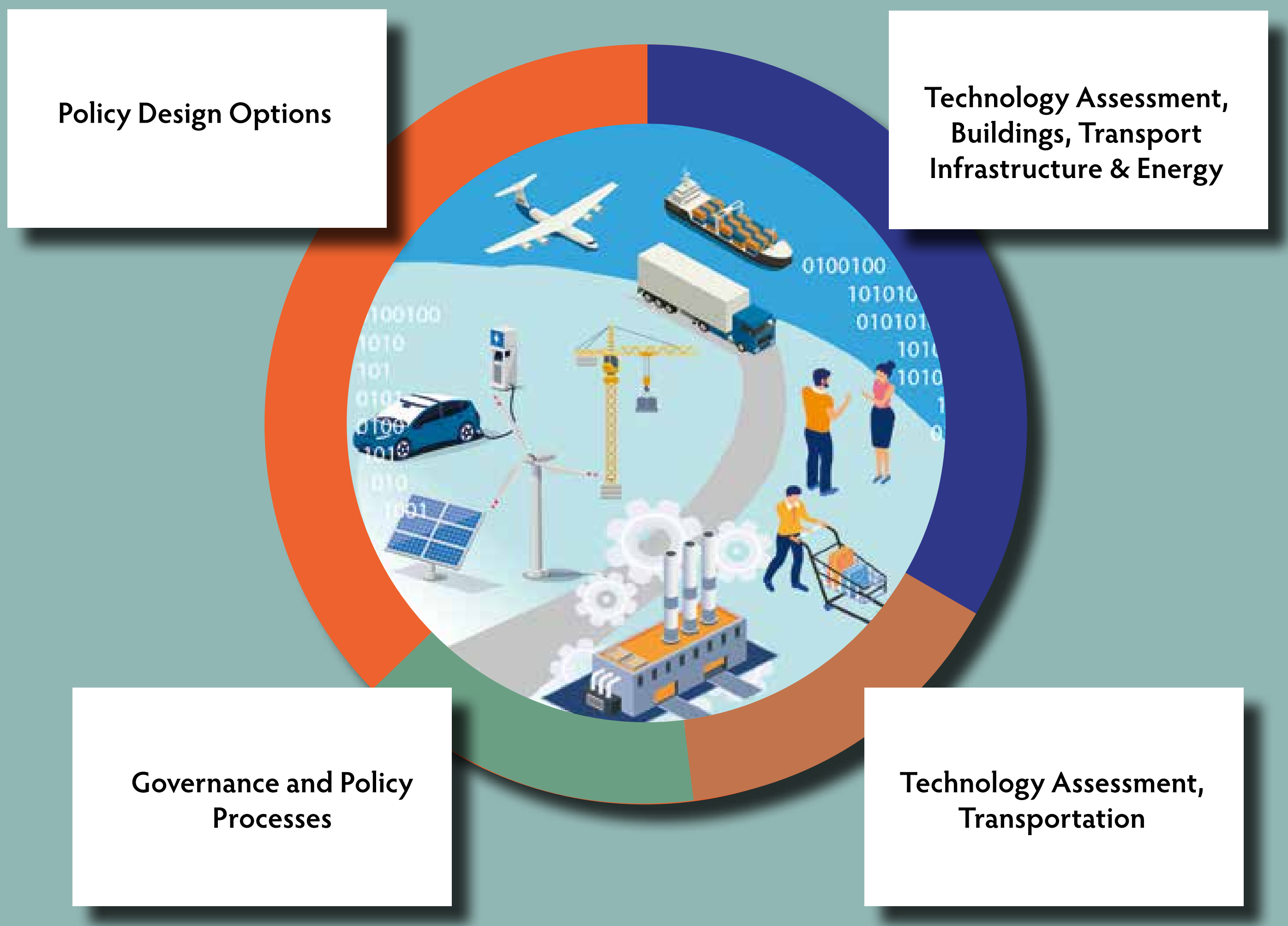
Dear Reader,

This report describes the highlights of the Mistra Carbon Exit programme (2017–2025). The full legacy of the programme is best reflected in the collective knowledge of its contributors, as well as by the impacts that the research findings from the programme have had on our end-users. Nevertheless, in this report, we want to share some examples of what we have accomplished over these years.

A central theme of the programme has been to look at the climate transition from a supply chain perspective. This has allowed us to identify those areas in the value chain where there are significant potentials for unlocking improvements, understanding barriers to the transition, and devising strategies to overcome these obstacles. The scope is broad, covering the supply chains of *buildings, transportation and transport infrastructure*, including the production of *base materials and energy carriers*. The programme has been multi-disciplinary in approach, including technical assessments, policy analyses, and studies on governance and social attitudes towards the transition. We have worked in close collaboration with our end-users to understand their priorities and provide means for communicating our results directly to them. Some of our partners, from industry and authorities, have participated in case studies and provided valuable data and feed-back.

When the programme started in 2017, we understood that over the next 8 years, if the world were to comply with the objectives of the Paris Agreement, to keep the global mean temperature rise to well below 2°C and preferably at 1.5°C, we would need to see evidence of the climate transition very quickly. As our research progressed, we expected to see political policy development, investments in mitigation measures and a decline in emissions. This meant that here was a unique opportunity for our researchers to have an impact on the decision-making by producing results that were relevant and timely to support policy-makers and the industry.

Looking back on these 8 years, we can conclude that there has been progress but also disappointments in how the world around us has dealt with climate change mitigation. The EU Green Deal and the *Fit for 55* climate package, negotiated when Europe was starting up after the pandemic, were surprisingly ambitious. The EU emissions trading system has been reformed twice, and allowance prices have increased from around 5 EUR in 2017 to over 100 EUR in early 2023, providing strong incentives for industry to produce green materials. The costs for renewables have fallen and, together with the increased prices for emissions allowances, have contributed to the phasing out of coal from the EU, as well as the initiation of numerous research and development projects on different emissions mitigation measures. In Sweden, two companies are investing in green steel production and car manufacturers are shifting to electrified vehicles and construction equipment. On the down-side, one of the largest battery factories in Europe, Northvolt in Skellefteå, has declared bankruptcy. The global temperature increase exceeded 1.5°C in Year 2024. In Sweden, the removal of the reduction mandate, which was originally designed to increase the share of renewable fuels in diesel and petrol, as well as the lowering of the taxes on these fuels have led to increased emissions in the transport sector. In the US, President Trump has decided to leave the Paris Agreement (for the second time) and is rolling back environmental legislation. Nevertheless, the green transition continues, in Sweden, Europe, China and in the US. Simply because there is no future in fossil technology. There is no question as to the direction that industry needs to take now, although there are different opinions regarding the pace of change, who should pay for the transition, and how the financial risks should be shared between actors.



In this report we present 27 "golden nuggets" from our research in four chapters.

Has the Mistra Carbon Exit programme made a difference? We think so. Here are some examples:

- We have shown that although the costs to manufacture green steel and cement are high for the producers, the cost increase for the end-consumers, i.e., the buyers of buildings and cars, is marginal. Climate transition is not an economic challenge, it is a distributional challenge.

- Case studies of buildings and transport infrastructure have shown that it is possible to reduce greenhouse gas emissions by almost 50% by applying already available measures and practices.

- The development of Carbon Contracts for Differences, a policy instrument that de-risks investments in green technologies, was in part funded by Mistra Carbon Exit and is now being implemented in several EU countries.

- Researchers from Mistra Carbon Exit have supported the Government of Sweden in analysing and designing a support system for Bioenergy Carbon Capture and Storage (BECCS).

- Results from Mistra Carbon Exit have been used in several public investigations (*Vägen till en klimatpositiv framtid*, SOU 2020:4, *Sveriges globala klimatavtryck*, SOU 2022:15, and *Värdet av Vinden*, SOU 2023:18).

- Our results have contributed to developing Sweden's climate action plans.

- Three members of our management group have been appointed to the Swedish Climate Policy Council, which is an independent, inter-disciplinary expert body that is tasked with evaluating how well the government's overall policy is aligned with the climate goal of zero net greenhouse gas emissions by Year 2045.

- The programme has produced three PhD's and two more are undergoing training.

These are just a few examples. In this publication, we present 27 "golden nuggets" from our research to date, presented in the following chapters:

Chapter 2 Technology Assessment, Buildings, Transport Infrastructure & Energy. We discuss how to scale up experiences from net-zero buildings and construction by implementing new practices and supporting urban climate governance. We show how machine learning can be used to fill data gaps in the building and construction industry. We discuss the role of electrification and flexibility in industry and how Sweden can develop an electricity system with a large share of renewables. We also present impacts of the climate transition on other sustainable goals.

Chapter 3 Technology Assessment, Transportation focuses on transportation and what impacts the increased use of electric vehicles (EVs) and biofuel may have. We look at how Sweden can cut down on the need for critical battery minerals and how mental models can lead to smarter charging of EVs. We look at how parking can be used as a tool to promote the climate transition.

Chapter 4 Governance and Policy Process describes citizen attitudes and preferences for climate leadership, the role of policy makers and why the green transition needs to be just.

Chapter 5 Policy Design Options analyses policy options for industry, energy, buildings and infrastructure. In this context, carbon pricing through the EU ETS is a corner stone of EU climate policy, although it needs to be complemented by other policies, for instance Carbon Contacts for Differences and standards. We discuss why we haven't come further in using public procurement to drive the climate transition. We discuss how to create a sound market for carbon removals. We present EU priorities in the light of Russia's war in Ukraine and the US government under President Trump. Finally, we discuss the role of carbon clubs and how to deal with carbon leakage and competitiveness.

For us leading the programme, it has been eight very rewarding years. The COVID-19 pandemic created challenges with conducting collaborations between research groups and with supervising visiting scholars and PhD students. However, this turned out to be manageable thanks to the dedicated researchers and research leaders.

We want to thank Mistra for supporting us financially and morally and being available for all types of discussions. We want to thank our Board for its guidance and support, and for always being constructive, positive, and sharp. We want to thank our industrial partners, NGO's and participating authorities for offering us cases to work with, giving us feed-back, sometimes co-producing research, and offering us the means to communicate directly with decision-makers. We want to thank the members of the management group for engaging and designating this programme as high priority in your already busy calendars. Our thanks also go to to all the administrative staff at the 30 participating organizations for providing services diligently and in a timely manner. Finally, we want to thank our fantastic researchers, 50 in total, including our PhD students, for the devotion, energy and ingenuity that you have invested in this programme.

Lars Zetterberg and Filip Johnsson

Reflections From the Mistra Carbon Exit Board

Kristina Sundin Jonsson, Municipal Director, Skellefteå Municipality

"*Municipal strategic spatial planning faces major challenges in the transition to a fossil-free society. We need scientifically based knowledge in order to make well-informed decisions. Mistra Carbon Exit has given us access to a strong network and unique expertise. The programme has acted as a catalyst in our climate work.*

Stefan Nyström, Head of Climate Unit, Swedish Environmental Agency

"*In the Swedish Environmental Protection Agency's work on emissions statistics and analyses of proposals for new regulations in Sweden and the EU, Mistra Carbon Exit has given us access to new scientific findings covering the entire supply chains in key emissions sectors such as transport, construction and cement, and iron and steel. The new, partly ground-breaking knowledge provided by the Mistra programme has increased the quality of our analyses, but also opened up a new type of discussion and understanding in the public debate of the relatively small cost increases on the end product that fossil-free production of basic materials can result in. Very valuable!*

Scaling up Implementation for Net-Zero-Carbon Construction

IDA KARLSSON, JOHAN ROOTZÉN, AARON QIYU LIU, FILIP JOHNSSON

Despite insights from pilot projects, carbon reduction measures in the building and construction sector remain limited. Mistra Carbon Exit (MCE) has supported decision-making in the sector by mapping emissions reduction strategies across the value chain, helping companies, municipalities, and local initiatives to establish ambitious requirements for new construction. Ongoing efforts are aimed at expanding and adapting these requirements to additional project types and organisations at varying maturity levels.

Significant progress with climate calculations and mitigation has led to the development of clearer procurement guidelines, processes, and controls. However, strict carbon limits are not yet standard in the Swedish building sector, and there is still no comprehensive integration of these limits into existing tools, templates, and procurement documentation.

A broader shared understanding is needed, and the building and construction sector appears ready to apply existing knowledge through progressive procurement measures to meet climate goals.

MCE researchers have, in collaboration with supply chain stakeholders, mapped and analysed the emissions reduction potentials in the building and infrastructure sectors by synthesising industry roadmaps, corporate plans, case studies, and reviews of the relevant literature. The analysis identifies barriers, enablers, and achievable emissions reductions across the value chain – from individual materials to entire projects – toward near-zero emissions by Year 2045.

The measures are categorised by project stage, with significant emissions reductions achievable through resource efficiency, circularity, and electrification of industrial processes and transport. An illustration of measures and reductions related to the construction of buildings with halved carbon footprint to Year 2030 is shown in Figure 1. To support different project contexts and organisations with varying carbon management experience, three levels of carbon limits have been developed, with the overall aim of contributing to meeting national climate goals. Organisations can either apply uniform requirements across all projects or create a portfolio of projects that collectively meet their carbon goals.

By considering timelines, technical maturity, and scalability, the research provides actionable roadmaps to decarbonise embodied emissions in buildings and infrastructure. To support climate action, procurement strategies should prioritise the early involvement of contractors and suppliers and balanced risk-sharing.

While the research has already led to tangible results through collaborations with companies, local initiatives and municipalities, more rapid progress is needed to meet climate targets. Towards this goal, we work with value chain actors to: (i) tailor and share knowledge in accessible formats; (ii) develop project-specific carbon requirements and reduction measure portfolios; and (iii) integrate these elements into widely used industry tools for broad adoption.

A key advance is the introduction of carbon requirements for building renovation projects, reflecting their significant emissions, as shown in *"Embodied Emissions in Building Renovations: An Overlooked Policy Challenge"*, (page 20). As policies and the sector increasingly prioritise resource efficiency and focus on the existing building and infrastructure stock, renovation will attain greater importance. Recent efforts also extend the carbon requirements for new construction to include ground preparation and reinforcement.

We have discovered that carbon reduction requirements must be tailored to the specific project type.

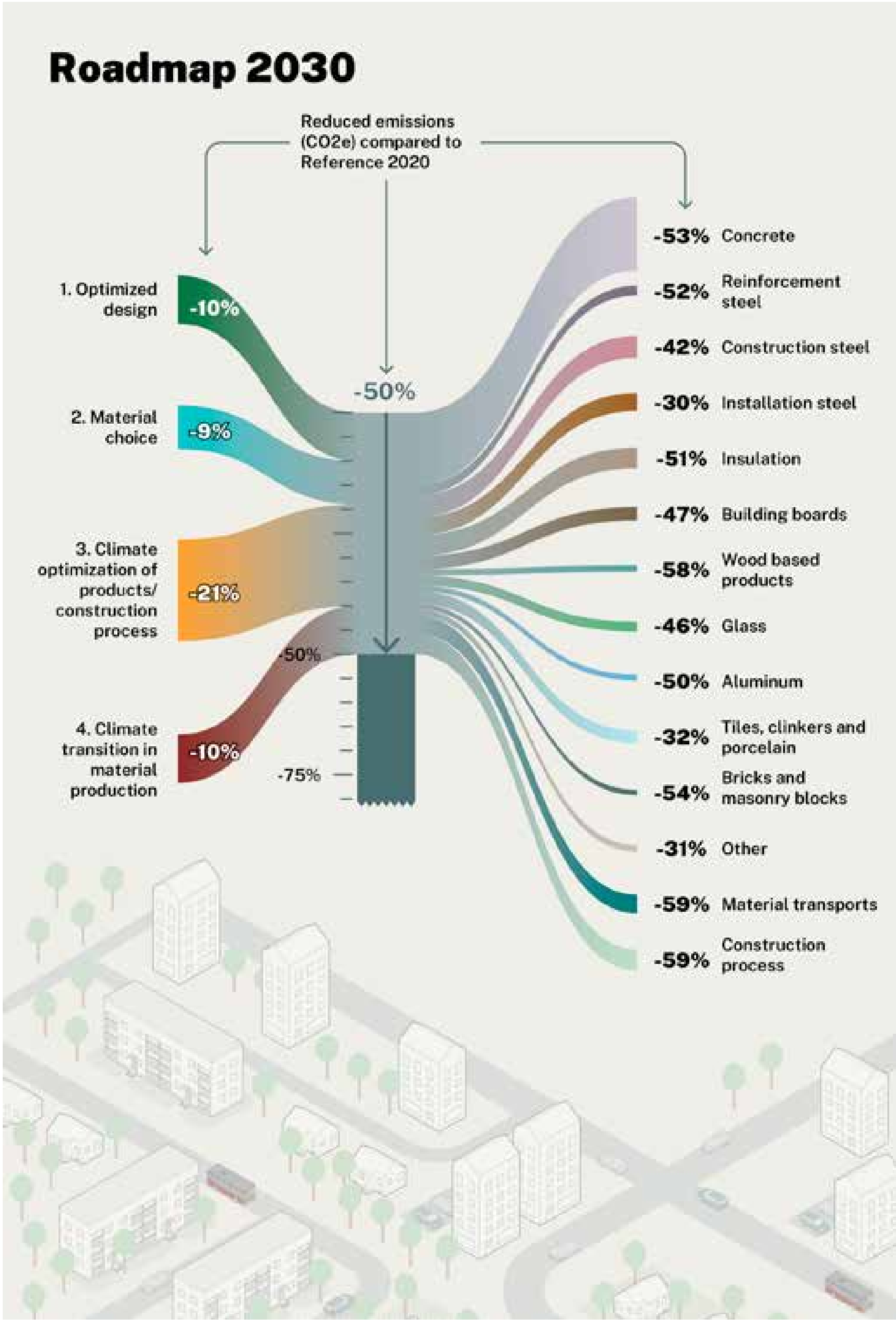


Figure 1. *Illustration of carbon footprint reductions for new building construction to Year 2030, as compared to the Year 2020 reference level, in line with the national target of 50% reduction. The left-hand side of the graph shows the percentage reduction for each component, while the thicknesses of the emission flows indicate the contributions to the overall reduction. The right-hand side of the graph displays the reductions from various types of measures. Illustration developed by @Pasejo based on MCE research results..*

For new buildings or structural framework renovations, reference values enable requirements in kg CO_2-eq/m^2 gross floor area. For projects that entail infrastructure, groundwork or building renovations – where the scope varies – the requirement is set as a percentage reduction relative to a project-specific baseline. When the baselines are too complex to define, an alternative is to apply maximum carbon limits for specific materials and fuels. In support of this, we have developed progressive carbon performance values for common materials and processes, as detailed in "*Implementing Mistra Carbon Exit Carbon Transition Scenarios in Construction Industry Practice*" (page 12). In addition, we have worked to clarify how these requirements should be monitored and followed up, so as to ensure fair competition and be certain that the delivered results meet the set targets.

With this support for practical implementation, MCE researchers have laid a solid foundation for accelerating the climate transition in the construction sector. However, data gaps – especially for the non-residential sector and related to detailed material and product flows – limit effective monitoring. Filling in these gaps is crucial to enabling transparent, nationwide tracking of carbon reductions and towards ensuring that the sector stays on course, with the ability to trigger additional measures or policy responses as needed.

Key Takeaways for Policy-makers:

- Set ambitious carbon requirements – Utilise the differentiated carbon limits for various project types, integrate them into procurement documentation, tools, and templates, and follow up on this to drive demand for low-carbon solutions.
- Enhance collaboration and early involvement – Prioritise early contractor and supplier engagement and balanced risk-sharing in procurement, in order to accelerate carbon reductions across the value chain.
- Improve the data and monitoring for accountability – Address data gaps, particularly in non-residential sectors and material flows, to enable systematic tracking of the progress of carbon reduction measures and to inform future policy actions.

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Implementing Mistra Carbon Exit Carbon Transition Scenarios in Construction Industry Praxis

STEFAN UPPENBERG, IDA KARLSSON, JOHAN ROOTZÉN

In recent years, many ambitious projects have demonstrated how to reduce the embedded carbon emissions in the construction industry. However, to accelerate the carbon transition across the sector as a whole, carbon requirements need to be implemented more broadly and systematically. In the SKUNK sub-project, we have investigated how the construction industry carbon transition scenarios developed within Mistra Carbon Exit can be used as a guide for practitioners. Our aim is to explore how these long-term visions can be translated into concrete actions, tools, and procurement strategies that support a low-carbon transformation as part of everyday decision-making.

Case studies with Swedish municipalities[1] included in the project have highlighted the relevance of MCE's carbon transition scenarios as a basis for formulating procurement requirements in construction contracts. Among measures targeting the design, materials, and processes, the material requirements are particularly recognized as being straightforward to standardise. This applies both to the technical descriptions supported by the reference document AMA Anläggning[2] (Svensk Byggtjänst) and to municipalities' own designs and technical manuals.

1 Case studies were conducted for the municipalities of Eskilstuna, Skellefteå, and Uppsala.
2 AMA Anläggning is one of the key reference tools used across the Swedish construction industry for procurement purposes.

Carbon footprint	2015 (ref.)	2025	2030	2035	2040	2045
Asphalt kg CO_2-eq/ton	43	21	17	11	8	5
Concrete kg CO_2-eq/m³	388	263	52*	43	21	3
Construction steel kg CO_2-eq/ton	2200	2020	1610	1030	800	70
Rebar kg CO_2-eq/ton	780	530	300	220	100	40
Aggregates kg CO_2-eq/ton	4,3	3,0	1,9	0,9	0,5	0,2

* with CCS in cement production

During the SKUNK project, the Swedish Transport Administration (STA) introduced accessible carbon requirements for asphalt and concrete in a new format, integrated into Svensk Byggtjänst's description tool. These carbon requirements effectively demonstrate how knowledge of carbon performance improvements can be embedded in industry standard tools to drive the broad-scale carbon transition.

We propose that the clients of municipalities include carbon performance requirements for materials in the technical description section of their tender documents, using the following simplified approach:

1. **Update technical manuals:** Revise the municipality's own technical or design manual, or similar, and incorporate or refer to carbon requirements in STA's addition to AMA Anläggning 23. Optionally, align the requirement levels with MCE's carbon transition scenario for a higher level of ambition.

2. **Integrate into tender documents:** Ensure that designers include these requirements in the technical description sections of their tender documents for construction contracts.

3. **Compliance verification:** Require contractors to submit specific environmental product declarations (EPDs) for the delivered product, to verify compliance with the set requirements.

This approach ensures that carbon performance becomes a standard component of municipal construction projects. It can also be used for other materials, such as reinforcement, granite stone, and similar, using requirement levels that are taken directly from the MCE carbon transition scenarios.

The participants in the case studies found the described approach to be both logical and practical, with good potential to streamline processes. They emphasised the importance of leveraging existing frameworks and prioritising simplicity. In the absence of such guidance, procurement often becomes resource-intensive, requiring significant effort to define performance levels and formulate requirements for each project.

Advancing Whole-Life Carbon Policy – Targeting Embodied Emissions in the Building Sector

IDA KARLSSON, PATRICIA URBAN

Sweden is a frontrunner in addressing Whole-Life Carbon (WLC) emissions from buildings. However, policy gaps remain at both the national and European Union (EU) levels. Key actions for decarbonising the built environment include: setting ambitious limits for new construction; introducing climate declarations for renovations; valuing more effectively the existing building stock; and fostering demand for low-carbon materials. These measures could be implemented or strengthened through existing policies.

There are many measures to reduce both the relative and absolute WLC emissions in the built environment, addressing embodied emissions from materials and construction processes, as well as operational emissions from building energy use. The EU's existing and emerging policies target different aspects of the building value chain. While carbon pricing, energy, and end-of-life policies provide a trajectory towards emissions reduction, others such as the Energy Performance of Buildings Directive (EPBD) and the Construction Products Regulation (CPR) directly address building life-cycle aspects. While progress has been made, remaining gaps may hinder attainment of the EU's climate goals.

Sweden is one of few EU Member States that already requires climate declarations for new buildings. However, planned limit values have been replaced with future implementation of the recast EPBD. Adopted in Year 2024, the recast EPBD is a flagship policy framework for buildings, mandating gradual life-cycle global warming potential (GWP) calculations, nationally set limit values for new buildings, minimum energy performance requirements for both new and existing buildings, and national renovation plans for up-grading the existing building stock. While this provides a strong foundation for addressing WLC emissions, we believe that certain elements of the policy package could be strengthened to incorporate more-effectively life-cycle impacts across the built environment.

First, nationally differentiated pathways for limit values under the EPBD are needed to achieve the EU climate objectives. Based on similar principles as the Effort Sharing Regulation, individual Member State capacities could serve as the framework for setting progressive limit values for different life-cycle stages in the roadmaps for new buildings under the EPBD. The current low ambition of existing or planned limit values in EU Member States (except for Denmark) emphasise the need to close the gaps between potential emissions reductions and policy requirements to meet climate targets.

Second, there is a significant emissions-saving potential associated with better utilising the existing building stock. The EU could provide significant leverage by including relevant provisions in the EPBD roadmaps and renovation plans, including data on vacant or underused buildings as a basis of needs assessments for new construction. It may also include requirements toward prioritising existing buildings with a clear hierarchy, including filling or repurposing vacant or underused buildings.

The measures taken at an EU level need to be accompanied by simplified planning and building regulations at a national level. Sweden and Denmark are already reviewing its regulations to facilitate rebuilding and re-purposing, with Denmark also considering limits on demolition.

Delegated acts linked to the EU Taxonomy Regulation could support these measures by introducing ambitious

WLC limits, prioritising renovation over new construction, and promoting adaptive re-use to preserve embodied carbon in the built environment.

Third, if new buildings are necessary, increasing their life-span, flexibility, and material circularity could reduce WLC impacts. Eco-design requirements for construction materials is a key component but is currently missing from the CPR. Introducing extended producer responsibility for construction and demolition waste through the Waste Framework Directive or CPR could further enhance material circularity.

Finally, EU policies could support market creation for low-carbon and circular construction materials and processes by introducing higher ambition levels in both the EU Taxonomy and Green Public Procurement provisions.

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Learning and Amplifying Urban Climate Governance through Cutting-Edge Projects

JONAS SONDAL, ÅSA HULT

Cutting-edge projects can play an important role in realising the climate transition. However, while practical, single-loop learning often occurs, such learning is rarely transferred across municipal departments. To improve learning and generate change beyond those directly involved, greater focus should be placed on recipients of knowledge, rather than relying exclusively on projects as modes of knowledge dissemination.

To address sustainability challenges, municipalities often use cutting-edge projects to generate learning and amplify new solutions for urban governance. Cutting-edge projects are urban experiments that have ambitious climate mitigation objectives, and that are testing new technologies or work practice. However, the depth of learning (i.e. single or double loop-learning) and what types of amplifications are generated (e.g. upscaling into new policy, replication into new projects, or deep scaling into new norms) remain unclear.

Thus, this study explores how cutting-edge construction projects in a Swedish municipality are used to generate learning and amplify climate mitigation measures both within and across municipal departments. In Spring 2023, interviews were conducted with civil servants from all building-related departments in the studied municipality. The interviews were analysed using theories pertaining to urban climate governance, governance learning, social learning, organizational learning, urban experimentation, amplification theory, and institutional capacity.

The study presents two key findings:

There is a discrepancy between the reported learning outcomes and the strategic ideas of cutting-edge projects. Interviewees primarily highlighted practical, single-loop learnings that are easily replicated in new contexts. These learnings include how to install an electric rock crusher or how to formulate climate requirements in procurements. In other words, reported learning focus on how things should be done to reduce climate emissions efficiently in construction projects. However, these learnings were rarely transferred across departments due to differences in project types, budgets, etc. Strategic civil servants, on the other hand, argue that the true value of cutting-edge projects lies in shifting attitudes regarding what is possible in climate transition processes, beyond those directly involved in the project. In other words, the strategic idea was that cutting-edge projects would foster double-loop learning and deep scaling, thereby influencing values and norms around what should be done and what role the municipality has to drive climate transition forward through urban governance. However, the study did not confirm that such learning actually occurs as a result of cutting edge-projects.

To enhance cross-departmental learning, greater focus must be placed on recipients of learning, rather than relying exclusively on cutting-edge projects as tools for knowledge dissemination. This includes providing clear leadership on climate transition and hiring individuals who want to act as bridging agents for climate mitigation.

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Silver Bullet or Not, Electrification of the Basic Materials Industry is Going to Be Part of the Carbon-neutral Future

ALLA TOKTAROVA, LISA GÖRANSSON, FILIP JOHNSSON

- The electrification of the basic materials industry, which includes the manufacturing of steel, cement, ammonia, and plastics, has the potential to change the cost structures of industrial production. As a consequence, the most-cost-effective geographical locations for new production sites may also change.

- The cost of basic materials production can be reduced through the use of production processes that follow electricity price variations. Such production processes require investments in over-capacity of certain production units and storage facilities, such as hydrogen storage.

- The results of comprehensive modelling of the electrification of industries in the MCE program reveal: (i) the possible relocation of job opportunities; (ii) the importance of gaining social acceptance for new industrial sites; (iii) the significance of co-ordinated efforts to promote circular flows across value chains for basic materials; and (iv) the need for successful implementation of the EU's Grid Action Plan with respect to increasing the capacity of electricity transmission systems.

The basic materials industry is embedded in many strategic value chains and accounts for 15% of the EU's

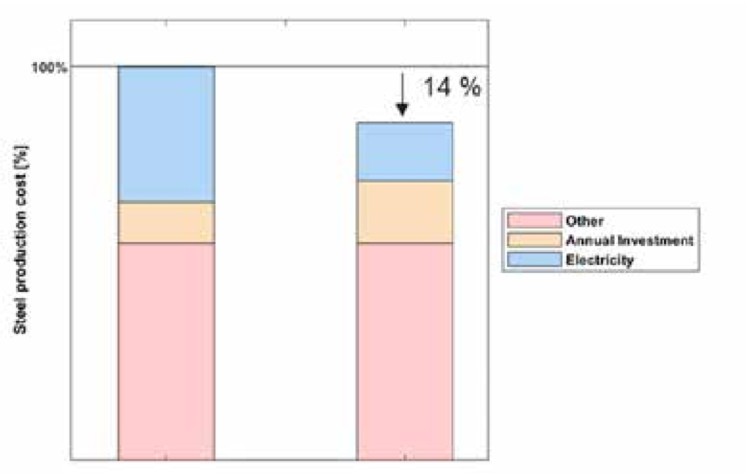

Figure 1. *Breakdown of the modelled cost of steel production into other costs (mainly for iron ore), the annualised investment cost, and the electricity cost for the Business as usual scenario, i.e., without investments in over-capacity and storage units (left column) and for the scenario with time flexibility, i.e., with investments in over-capacity and storage units (right column).*

carbon dioxide emissions. The exploration of feasible, low-carbon options for the basic materials industry is of the utmost importance, to avoid further lock in into emissions-intensive infrastructures. The declines in cost and low-carbon environmental impacts of wind and solar power, as well as the possibility to harness low-cost electricity for flexible consumers have made direct and indirect (through hydrogen) electrification a key pathway towards decarbonisation of the basic materials industry.

Applying a comprehensive energy systems model, we show that electrification of the energy-intensive basic materials industry in the EU increases the electricity demand by 44% (by 1,200 TWh) for the assumptions made. For the cases modelled, the future EU electricity demands with the present-day locations of the industrial plants will primarily be met by solar, wind, and nuclear power.

For the electrified industry, low costs for hydrogen and electricity can be achieved by avoiding high electricity price hours through operational flexibility of the industrial capacity, in conjunction with the storage of hydrogen and commodities.

Given the urgency of abatement of industrial emissions, the optimal location for industrial production may shift from being close to the demand and/or raw material supply centres to places where zero-emissions electricity is readily available at low cost, or where there are favourable conditions for carbon capture and storage (CCS).

The studies published by Toktarova et al. (2024) and Johnsson et al. (2024) highlight the following societal and policy implications:

The electrification of industrial processes can lead to significant changes with respect to the types of jobs and skills required by the industry. Thus, the work-force will need to be re-trained or will require new education, which could create new employment opportunities but might also lead to disruption of current employment patterns.

The electrification of industries depends on social acceptance of the technology and the transition process. It is important to engage with stakeholders, i.e., community members, workers, and industry representatives, to ensure that their concerns and perspectives are considered.

The transition of the basic materials industry towards electrification will require concurrent efforts towards increasing materials efficiency, promoting circular flows across value chains for basic materials, phasing out existing emissions-intensive capital, and phasing in new production capacity. Successful implementation of the Net-Zero Industry Act (NZIA) – a central pillar of the European Green Deal Industrial Plan – will be important. NZIA aims to accelerate the green transition and deployment of green technologies by simplifying approval processes, improving market access for strategic technologies, enhancing work-force skills, and co-ordinating the activities of Member States.

Development of the current electricity system will be increasingly challenged to accommodate the increasing electricity demand from the electrification of industry. The EU's Grid Action Plan can be used strategically to support and accelerate industrial electrification, while also improving the electricity grid. In implementing this plan, the European Commission should collaborate closely with industry stakeholders to ensure it meets their electrification needs, particularly with regards to long-term grid planning.

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Embodied Emissions in Building Renovations: An Overlooked Policy Challenge

AARON QIYU LIU, IDA KARLSSON, FILIP JOHNSSON, JOHAN ROOTZÉN

The quantification of embodied emissions from the built environment requires large volumes of data, and such data are often incomplete or unavailable. Machine learning has emerged as an effective method for addressing data gaps through the generation of reliable and context-specific estimates. We leverage this tool to create a more-accurate model for estimating the embodied carbon emissions from construction activities in Sweden.

Material demands related to the maintenance and renovation of the built environment are expected to increase due to factors such as the increased impacts of climate change on roads and the need for energy-efficiency renovations in buildings. This underscores the importance of developing methods that estimate

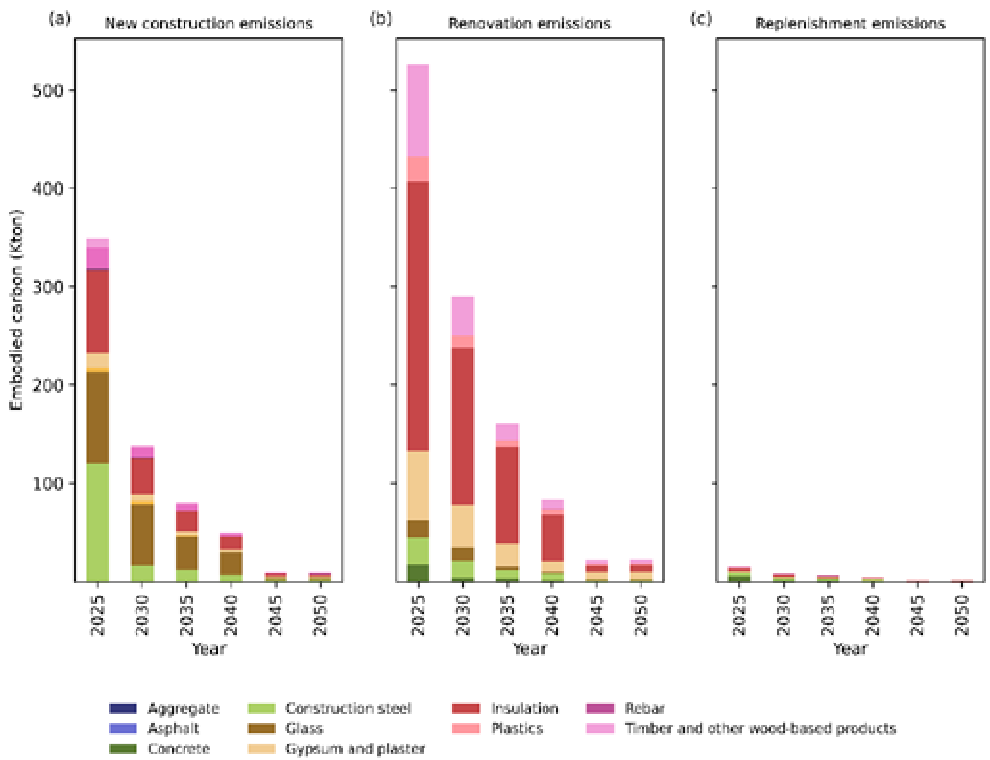

Figure 1. *Embodied emissions over time from new construction, renovation, and replenishment activities.*

accurately the material flows from renovations; to date, such factors have been under-studied. We address this gap by first filling in the missing data in road and building inventory datasets using machine learning models. This enables us to develop a novel, bottom-up building stock model (Liu et al., 2024;2025).

The main policy-relevant take-away of this work is that there is a need for policy initiatives on how to reduce embodied emissions from building renovations. The results also indicate that more attention needs to be paid to embodied emissions from insulation materials as they dominate the embodied emissions from renovations. On a methodological level, the take-away is that machine learning models can be applied to predict building attributes to a high level of accuracy that can inform policy decisions.

Significance of renovation

Renovation and maintenance activities may range from replacing building elements so as to maintain visual quality to ensuring the structural or operational performance of a building or road. As shown in Figure 1, the total embodied emissions from renovation activities are expected to be higher than the emissions from new construction. The main reason for this is that the level of new construction of buildings is low relative to the existing buildings. Furthermore, the demolition rate (under the mass balance assumption, all demolished buildings are replenished) of residential buildings is very low, as shown in Figure 1(c).

These results highlight the need for policy initiatives on how to reduce embodied emissions from renovations. This is especially pertinent since the EU has introduced the revised Energy Performance of Buildings Directive, which aims to renovate 16% of the worst-performing buildings by Year 2030, and 26% by Year 2033. Unlike the standards for new construction, renovation emissions can be more difficult to regulate. In the future, this work will be developed to include operational emissions from energy use and to evaluate the trade-off between embodied emissions and energy savings.

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Flexibility Is the Future of Electrification

LISA GÖRANSSON, ALLA TOKTAROVA AND FILIP JOHNSSON

- **Flexibility is a key element of the future energy system in which the transport and industrial sectors are electrified.**
- **We show that flexibility contributes to cost efficiency and is required also in cases with nuclear power – in contrast to the current debate suggesting that nuclear power yields low and stable electricity prices.**

Direct and indirect electrification of transport and industry are the main measures to mitigate carbon emissions in these sectors. Of course, this requires that electricity generation is carbon-free. In Sweden, electricity generation is already almost carbon-free with hydro, nuclear and wind power supplying the lion's share of the electricity supply. Yet, to electrify the Swedish energy-intensive industry at the rate required to meet emissions reduction targets, there is a need to almost double the level of electricity generation up to Year 2045. Until at least Year 2035, the increase will mainly have to come from weather-dependent electricity generation (wind and solar power), since it is unlikely that new nuclear power can be in place before the second half of the 2030s.

Using modelling, we show that it is entirely possible to meet the increased electricity demand with a large share of weather-dependent generation. We investigated several scenarios with and without nuclear power (carried out in co-operation with the Mistra Electrification Program). In all the studied scenarios, we find that the electricity system can meet the demand in a cost-effective manner, by combining different flexibility measures.

Thus, all scenarios – including scenarios that prescribe new nuclear power – exhibit significant volatility of electricity generation. Consequently, investments in flexibility are no-regret options for Society.

We conclude that politicians must stop putting wind power against nuclear power and instead remove the various barriers to expanding new electricity production, regardless of the type of generation, and facilitate investments in flexibility.

Fortunately, there are many possibilities for flexibility in the electricity system, on both the demand and supply sides. These include: smart charging of electric vehicles; smart control of heat pumps in district heating systems, possibly in combination with heat storage; control of individual heat pumps; flexibility in industry demand derived from over-investments in electrolysers combined with hydrogen storage; and flexible combined heat and power plants.

The real challenge is to make investments in new electricity generation go hand in hand with increased demand for power. Avoiding a Catch 22 situation (in which there is a mismatch between the timing of investments in generation and high demand) is the real challenge for politicians and markets – not whether there should be wind power or nuclear power.

The possibilities linked to flexibility measures in connection with industries have been studied in Mistra Carbon Exit, as described in the article titled Silver bullet or not, electrification of the industry is going to be part of the carbon-neutral future, and this work now continues in Mistra Electrification.

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How Sweden Can Reduce Its Global Carbon Footprint

JOHANNES MORFELDT, JÖRGEN LARSSON, DANIEL J.A. JOHANSSON, JOHAN ROOTZÉN, DAVID ANDERSSON, CECILIA HULT, IDA KARLSSON, JONAS ÅKERMAN, FREDRIK HEDENUS, FRANCES SPREI, JONAS NÄSSÉN

Consumption-based climate targets are currently under consideration in the Swedish Parliament. However, an important question is: How can Swedes effectively reduce their emissions linked to the goods and services that they consume? Researchers from Mistra Carbon Exit and Mistra Sustainable Consumption explore pathways to reduce Swedish consumption-based greenhouse gas emissions. The analysis highlights the need for policies that incentivise both technological advancements and behavioural changes.

National targets for emissions reductions are typically based on emissions that occur within a country's borders. However, this approach overlooks emissions generated abroad to produce the goods and services consumed domestically, which are substantial in the case of Sweden. In April 2022, a Swedish cross-party committee proposed setting consumption-based emissions targets1. Two alternative targets, reflecting different levels of ambition, were presented.

Researchers from Mistra Carbon Exit and Mistra Sustainable Consumption have examined the theoretical basis for the proposed targets and how Sweden can meet these targets. By examining key sectors, such as

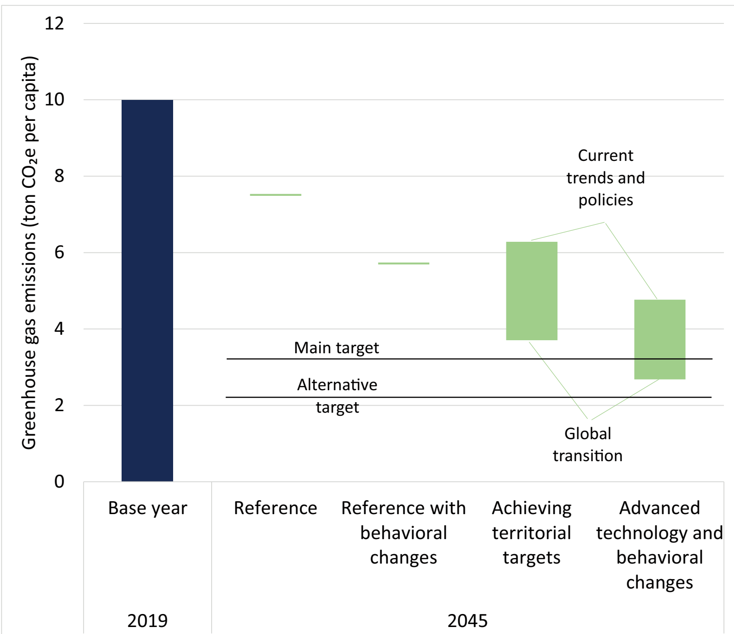

***Figure 1.** Greenhouse gas emissions in Year 2045 for the analysed scenarios, as compared with the proposed target levels and the base year (2019).*

buildings, transportation, and food, we identify those areas in which policy and industry could generate substantial reductions in emissions. Findings from an early version of the study have also directly contributed to Swedish policy discussions2, playing a key role in the committee's decision to propose consumption-based climate targets.

Benefits of complementing perspectives

Complementing the territorial approach to emissions reductions with a consumption perspective motivates additional actions to shift consumption patterns and reduce the demands for carbon-intensive products and services. Policies that are aimed exclusively at producers can result in carbon leakage and domestic job losses, since emissions reduction ambitions vary across countries. Nevertheless, it is crucial that such actions are implemented through incentives for low-carbon technologies and for producers to reduce emissions across supply chains.

Both technological and behavioural actions are needed

The analysis shows that neither technological advancements nor behavioural changes alone will be sufficient to meet Sweden's proposed consumption-based target – both will be needed. Moreover, Sweden's consumption-based emissions levels in Year 2045 will be influenced by global climate policies because the emissions from imported goods depend on international mitigation efforts (illustrated by the range of each bar in the figure), which, however, could be mitigated by an extended carbon border adjustment mechanism. Our analysis suggests that Sweden's consumption-based emissions in the most advanced scenario will decrease from 9.8 tonnes of carbon dioxide equivalents (tCO_2-eq) per capita in Year 2019 to between 2.7 and 4.8 tCO_2-eq per capita by Year 2045, depending on global climate policies and the responses of other countries.

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Sustainability Performance Indicators for the Swedish Climate Transition

ANDERS AHLBÄCK, MARTIN ERIKSSON

Moving towards climate neutrality will entail both positive and negative impacts for the environmental, social and economic dimensions of sustainability. Here, we show that the positive impacts of the Swedish climate transition are realised domestically, whereas the negative impacts emerge as international spill-overs linked to the extraction of critical minerals.

Achieving net-zero greenhouse gas emissions in Sweden by Year 2045 requires a large-scale deployment of climate-neutral technologies, including biomass, carbon capture and storage, climate-neutral cement, electric vehicles, green hydrogen, solar photovoltaics (PV) and wind power. This transition carries implications for sustainability, here expressed in terms of positive and negative impacts on the Sustainable Development Goals (SDGs). Our SDG impact assessment of the technologies shows that most of the positive impacts arise domestically in Sweden, bringing opportunities for job creation, exports and economic growth. In contrast, the negative impacts predominantly occurs in other countries, in the forms of spill-overs that are driven by increased demands for critical minerals, many of which are extracted in the Global South. If not mitigated, these impacts may have deleterious consequences for human health, local environmental degradation and, in the context of the procurement of specific minerals, increased corruption and modern slavery.

Based on 95 identified SDG impacts, we propose a set of 32 indicators that can be used to follow urgent sustainability aspects of the Swedish climate transition. The indicators are monitoring impacts that appear domestically or as international spill-overs across relevant themes, such as human health and environmental risks, raw materials, energy, green growth, industry and innovation, and local democracy and social acceptance.

Figure 1 presents 21 indicators for which there are available data, together with the Swedish territorial greenhouse gas emissions. Since Year 2010, the territorial greenhouse gas emissions have declined, while, at the same time, most of the indicators for domestic negative impacts have trended downwards.

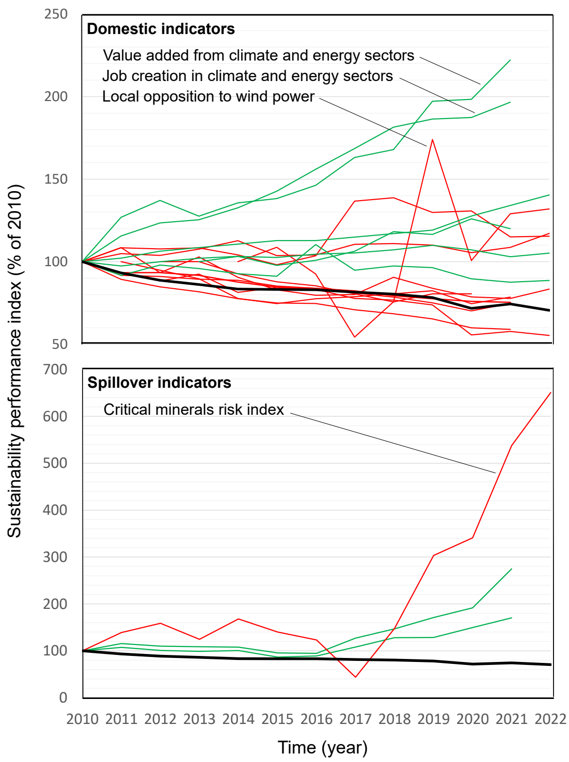

Figure 1. *Domestic and spillover indicators categorised as negative (red) or positive (green) impacts, and Swedish territorial greenhouse gas emissions (black) from 2010 to 2022..*

This indicates that the risks associated with the Swedish climate transition are, so far, diminishing. Simultaneously, most indicators that follow positive impacts have increased, indicating that the added value from decarbonisation seems to be realised both in Sweden and internationally. The exceptions to this are the increasing local opposition to wind power installations and the increasing material intensity in Sweden. In addition, there is a substantial increase in the spill-over risks associated with embedded imports of critical minerals.

To achieve a sustainable climate transition, sustainability aspects associated with the large-scale expansion of climate-neutral technologies need to be recognized. The current lack of urgency in highlighting and monitoring urgent sustainability impacts can be addressed through the set of sustainability performance indicators suggested here.

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Climate Impacts of Transition Pathways for Swedish Road Transport

GÖRAN BERNDES, JULIA HANSSON, DANIEL JOHANSSON, JOHANNES MORFELDT

- **The global temperature impacts of road transport depend on life-cycle fossil carbon dioxide emissions and how carbon storage in ecosystems and bio-based products is affected when biomass is used to produce transportation fuels.**
- **Several inter-connected systems determine the outcomes, which include the manufacturing of vehicles, forest management and harvesting, and the production of liquid fuels and electricity.**
- **Global temperature impacts can be modelled for different vehicle and fuel uses and for different time horizons, helping policy-makers to consider both short-term and longer-term climate goals.**

To reach the Swedish climate targets, road transport emissions must be significantly reduced. For this purpose, increased electrification of the vehicle fleet and the use of biofuels have been identified as important strategies. From a life-cycle perspective, these strategies involve several different systems that have different impacts on the global mean surface temperature. The ways in which Sweden contributes to the global temperature change reflect how different technologies and systems, related to the transition of road transport, are developed.

The levels of carbon dioxide (CO_2) emissions and climate impacts (i.e., global mean surface temperature impacts) from car traffic depend on the development of several inter-connected systems that are considered in our assessment, including the manufacturing of vehicles and batteries, production of liquid fuels (gasoline, diesel, and biofuels) and electricity, as well as how biofuels produced from forest-based raw materials affect biospheric carbon storage. Battery electric vehicles and the use of biofuels in internal combustion engine vehicles, can make significant contributions to reducing Swedish fossil CO_2 emissions. The extents to which they can contribute to reducing the total net CO_2 emissions and influence the global temperature depend largely on the upstream emissions in the production of electric vehicles, including the batteries, and the electricity used for charging, as well as the impacts that production and use of biofuels will have on carbon storage. Historically, there has been a general trend towards lower CO_2 emissions from the manufacture of electric vehicles, as well as from the production and use of electricity. This trend is expected to continue if the world strives to reduce emissions in line with the Paris Agreement, meaning that the climate impact of electric vehicles will decrease over time.

The global temperature impacts depend on the origins of CO_2 emissions and how the use of biomass for biofuel production affects the biogenic carbon stock

The impacts on the global mean surface temperature of using fossil fuels and biofuels from the Swedish forest for road transport differ. The temperature change is close to proportional to the cumulative CO_2 emissions from fossil fuel use, leading to an effect that lasts hundreds of years. However, this is not generally the case for biogenic, tailpipe CO_2 emissions from the combustion of biofuels. The global temperature impacts of biofuel use (in addition to its upstream life-cycle emissions) instead depend on how the production and use of biomass to produce biofuels affect the levels of carbon storage in forests and bio-based products (the biogenic carbon stock). The biogenic carbon stock is affected by how fast the biomass would have decomposed naturally if it was left in the forest instead of being used to produce biofuels (but also on the alternative use). As a consequence, the expanded use of biofuels may initially increase the global mean surface temperature, but this effect may decline in the long term.

The modelling provides useful information for policy-makers by showing how the impacts on global temperature depend on both fossil CO_2 emissions and the usage of land to provide biomass for biofuels. For transport-related policies to be effective in terms of climate impact, they need to consider greenhouse gas emissions and the climate impacts from the short-term and long-term life-cycle perspectives.

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Limiting Demand for Critical Materials in Sweden's Transition to Electric Cars

JOHANNES MORFELDT, DANIEL J.A. JOHANSSON, SIMON DAVIDSSON KURLAND

- Electrification of passenger cars will dramatically increase the demands for critical raw materials, such as nickel, lithium, cobalt, manganese, and graphite.
- Demand can be significantly reduced – by up to 75% – through measures such as improved energy efficiency, car down-sizing, shorter driving ranges, car sharing, and reduced travel demand.
- These measures combined are more impactful than material recycling in a mid-century time horizon for reducing raw material dependency.

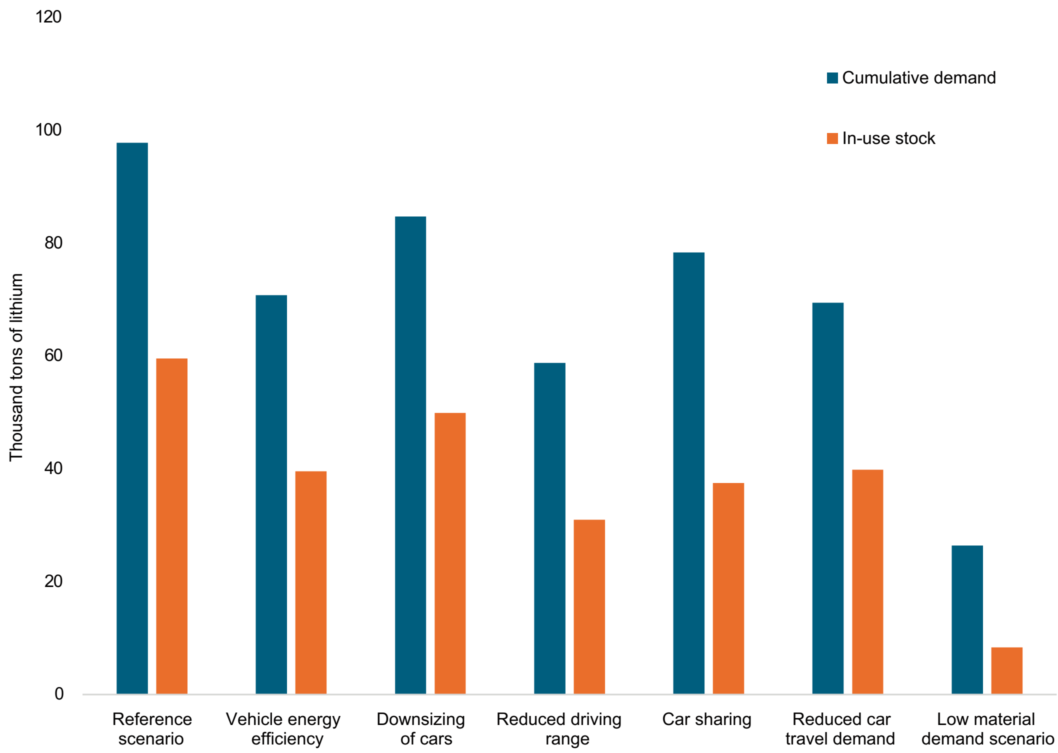

Figure 1. *Impacts of various efficiency measures on the cumulative demand for lithium through Year 2050, and on the amount of lithium embedded in the vehicle stock in Year 2050, depending on the measures analysed.*

The electrification of Sweden's passenger car fleet is a corner-stone of the climate transition, although it comes with increased demands for critical raw materials, such as nickel, lithium, cobalt, manganese, and graphite. Researchers used the Vehicle Turnover model Assessing Future Mobility services (V-TAFM) to estimate material needs in different scenarios. The reference scenario shows a rising material demand until Year 2050, while the low material demand scenario – with combined behavioural and technological shifts – reduces the cumulative demand by 50%–75% and in-use stocks by up to 87% by Year 2050.

The most-effective measures include reducing vehicle range (enabled by an improved charging infrastructure), promoting car sharing, down-sizing vehicles, and increasing energy efficiency (see Figure 1 for the example of lithium). These reductions surpass those that can be achieved by recycling alone, and are essential for restraining Sweden's material demand to within its global per capita share of resources. The theoretical maximum impact of recycling can be seen as the difference between the cumulative demand and the in use-stock (Figure 1).

To unlock these potentials, targeted public interventions will likely be necessary. These could include stricter vehicle efficiency standards that exceed current fleet-average CO_2 emissions limits, expanded support for charging infrastructure, incentives for smaller vehicles, and policies that promote car sharing, public transport, and active mobility.

Finally, reducing dependency on critical materials would not only bring environmental benefits, but would also enhance Sweden's resilience to geopolitical risks and supply chain disruptions.

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Mental Models Guide Electric Vehicle Charging Patterns

FRANCES SPREI AND WILLETT KEMPTON (NOT IN MCE BUT CO-AUTHOR OF THE STUDY)

Recharging of electric vehicles (EVs) differs from refuelling of conventional vehicles. Through in-depth interviews with new and experienced EV drivers, we show that applying the same behaviour and reasoning as used with liquid-fuel vehicles leads to lower acceptance of EVs and greater EV range anxiety. Thus, policies and information measures should facilitate a shift to EV-appropriate mental models.

The charging of batteries differs both in time and the underlying physics from refuelling liquid-fuel vehicles. In this study, we investigated the challenges related to user perceptions, mental models, and refilling strategies arising from liquid fuels, and considered how these can be barriers to the efficient and convenient use of EVs. Based on interviews with 35 households (25 novice and 10 experienced EV users), we identified three mental models that drive EV charging:

A. Monitor gauge (or liquid fuel): Monitor the fuel (or battery) gauge and refill/recharge when low.

B. Planning: Plan ahead for locations and times when charging will be needed. This is especially used for long-distance trips.

We find that EV users who transition from a monitor gauge to an event-triggered model reduce range-related anxiety and increase the level of appreciation of the EV. The event-triggered mental models also have other cognitive advantages, such as being convenient and simple, not needing much attention as the actions are executed almost automatically. This also lowers the perception of the time that charging takes, since the user is occupied with other events while the vehicle is charging. The advantage from a grid perspective is that this leads to long plug-in times, which increase the opportunities for automated systems to adjust the actual charging times to those that are most-beneficial for the grid.

Stakeholder recommendations based on our findings are:

- EV manufacturers, dealers, and third parties can educate drivers as to how EVs work and the appropriate mental models for charging.
- Charging infrastructure planning and development needs to place greater emphasis on access to charging where vehicles are parked during longer periods of time, i.e., close to homes and work-places. This is especially important for EV drivers who do not have dedicated parking spaces.
- Interventions can be designed to ensure that charging and plugging-in are done at times when the impacts on the grid are minimal.
- EV-appropriate mental models could facilitate appropriate sizing of the battery, thereby reducing the need for additional scarce minerals.

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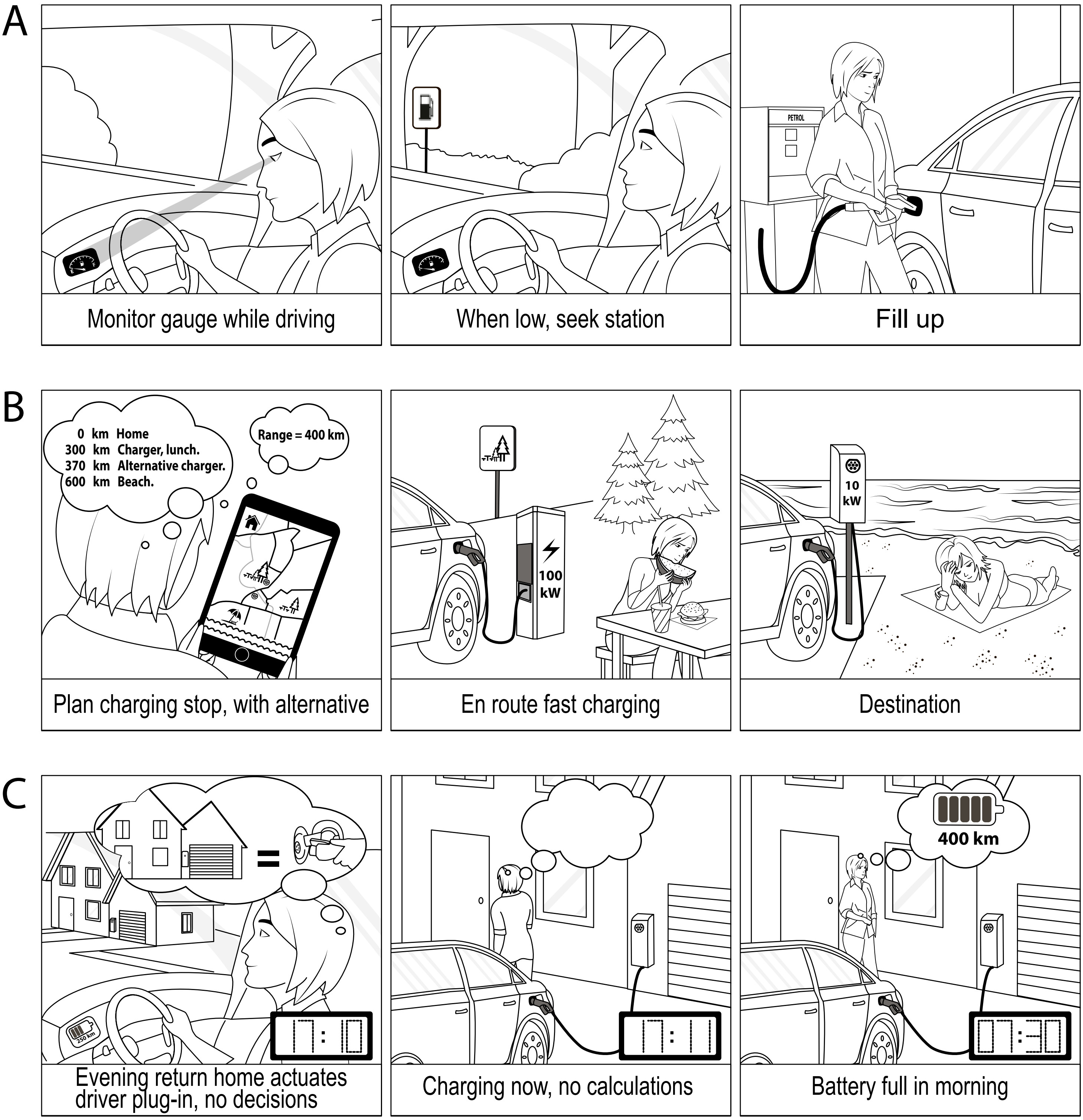
A
Monitor gauge while driving
When low, seek station
PETROL
Fill up
B
0 km Home
300 km Charger, lunch.
370 km Alternative charger.
600 km Beach.
Range = 400 km
Plan charging stop, with alternative
100 kW
En route fast charging
10 kW
Destination
C
=
250 km
17:10
Evening return home actuates driver plug-in, no decisions
17:11
Charging now, no calculations
400 km
07:30
Battery full in morning

Parking Policy and Pricing as Tools for the Road Transport Climate Transition

JOANNA DICKINSON, HENRIK KLOO, FREDRIK HOLM, ANDERS ROTH.

Parking as a climate policy instrument

Pricing and access to parking effectively influence the levels of urban car traffic and greenhouse gas (GHG) emissions [2]. In Västra Götalandsregionen (VGR), municipalities can adopt "climate promises," including the use of parking policies to reduce road traffic emissions.

Survey among civil servants

A survey [1] of civil servants in 32 of VGR's 49 municipalities regarding their parking policies and climate commitments reveals that small municipalities face few parking issues that are due to car dependence and available space, and rarely use fees as a regulatory measure. Instead, time limits and pricing are used to improve accessibility and reduce long-term on-street parking. Larger municipalities (10,000+ inhabitants) all have parking strategies, primarily to manage urban space rather than reduce car traffic or emissions levels.

Politicians' views on parking

To follow up the survey, interviews with politicians in three municipalities with more than 10,000 inhabitants were conducted. They reveal fragmented perspectives on parking and climate impact. Parking pricing is widely regarded as a tool to manage space use and for urban planning, rather than as a climate policy instrument. Some politicians view cars as essential to urban life, while others emphasise the role of parking in promoting sustainable modes.

Aim to promote sustainable modes

Smaller municipalities highlight the importance of car dependence for commuting from peripheral villages and rural areas where there are limited or no public transport options. Parking fees and time limits in central areas aim to improve short-term parking flows and encourage walking, cycling, and transit use. However, enforcement and evaluation of these policies remain weak.

Notably, there are challenges when municipalities want to expand sustainable travel options due to bureaucratic obstacles encountered during collaborations with regional and national transport authorities. It is described as time-consuming and difficult to establish new public transport connections. New pedestrian and cycle paths, where the Swedish Transport Administration (STA) is the responsible road manager, cost double if built by the municipality. This is why one municipality has tried to be creative in building cycle lanes on stretches of road that are not under the control of the STA.

Public attitudes to parking regulations

No broad public surveys on this topic have been conducted. Opposition appears when paid parking is introduced in areas where it was previously free, such as near healthcare facilities, and when parking lots are removed.

Conclusions

Parking is seen as a tool to balance urban space use rather than to reduce climate impacts. Larger cities actively strive to reduce car traffic volumes, while smaller municipalities balance the necessity to use cars with efforts to limit the amount of central urban space available to cars, and they promote sustainable modes in their urban areas. There are bureaucratic obstacles to increasing commuting with sustainable modes from rural and semi-rural areas.

Key take-aways:

- Pricing and access to car parking are effective tools at the municipality level to influence car traffic levels and, thereby, reduce GHG emissions.
- Various measures, including parking fees and time limits are employed in municipalities, although views on parking as a climate tool are divergent.
- Municipalities address car parking to manage the use of urban space rather than to mitigate climate impacts.

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Who is in charge? – Policy-makers' Views of their Roles and Responsibilities in Governing the Green Transition for Industry

CECILIA ENBERG

Who is in charge of the green transition for industry? And how do policy-makers in the Swedish Parliament view their roles and responsibilities in this transition? It is often stated that the Paris Agreement brought about a new polycentric climate governance landscape. For this landscape to be effective, concerted action is needed among its multiple, semi-autonomous, decision-making units (Ostrom et al., 1961). However, research that my colleagues and I have conducted shows that concerted action is largely lacking in the governance of Swedish industry's green transition (Benulic et al., 2023).

Policy-makers consider that they have far-reaching responsibilities for crafting and implementing policies that are designed to govern industry's green transition. They also state that they are knowledgeable about and mindful of the needs and requirements of industry, and that they take these into consideration when crafting and implementing policies. Our research shows that industrial actors ask policy-makers to implement "stable and imperative regulations to clearly set the rules" (Benulic et al., 2023:1). However, the policies that are implemented are primarily self-regulatory and incentive-based (e.g. financial support rather than imperative rules and regulations). Moreover, policy-makers consider their roles as facilitative, in that they provide infrastructure, access to financing and support to industrial actors that are competent to decide regarding their own green transition. Along the same lines, policy-makers, in some respects, tend to hand over their mandate to craft policies for political governance not only to the industry actors themselves, but also to different national authorities.

With respect to policy-makers' descriptions of the roles and responsibilities of the European Union (EU), these mirror the industry's descriptions, as both actors assign to the EU the responsibility for setting imperative regulations. However, while both actors assign this role to the EU, the industrial actors also ascribe a regulatory role to national policy-makers. The policy-makers instead describe a shift of the regulatory role from the national level to the supranational level. This can be interpreted as policy-makers having accepted the new polycentric governance landscape, acknowledging roles and responsibilities, including those related to the crafting and implementing of policies with respect to industry's green transition to multiple (additional) actors, as compared to what the industrial actors do. However, it also contributes to a lack of concerted action and, thus, to a lack of effectiveness at the systems level.

An important conclusion from this research is that in a polycentric system of governance, it is not sufficient that the actors take each other into account for concerted action to occur. Instead, the ways in which they assign roles and responsibilities throughout the system must be aligned, as must the expectations that they ascribe to each other's contributions to the governance of the green transition. For this to happen, forums for deliberations among the multiple actors that constitute the polycentric system need to be established. This is important for the various actors – the semi-autonomous, decision-making units – to be able to accept or refute the roles and responsibilities ascribed to them by others in real time and to build a consensus for governance.

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Citizen Preferences for Climate Leadership

FREDRIK CARLSSON, MITESH KATARIA, ELINA LAMPI, ÅSA LÖFGREN, THOMAS STERNER

Key Take-aways

- **Conditional leadership – whereby a country reduces emissions while assuming that other countries will follow – plays a crucial role in mitigating the free-rider problem in climate policy.**
- **A high percentage of EU citizens express support for their own country to lead by example, but trust in other countries' reciprocal actions, and costs greatly influence the extent of this support.**
- **Moral or ethical motives (un-conditional leadership) also exist, whereby some citizens favour climate leadership regardless of other nations' responses.**
- **Communicating the fairness and collective benefits of climate action can bolster willingness to lead, highlighting the importance of EU co-ordination frameworks (e.g., the Fit for 55 package).**

Within this research project, we investigate how the citizens of EU Member States perceive their country's potential role in reducing greenhouse gas emissions beyond existing commitments, such as those defined under the Effort Sharing Regulation. Drawing on both theoretical and empirical insights from earlier literature, we distinguish between conditional and un-conditional climate leadership. Conditional leaders support stronger mitigation targets only if other nations are expected to do the same, whereas un-conditional leaders are willing to bear additional costs even in the absence of guaranteed reciprocity.

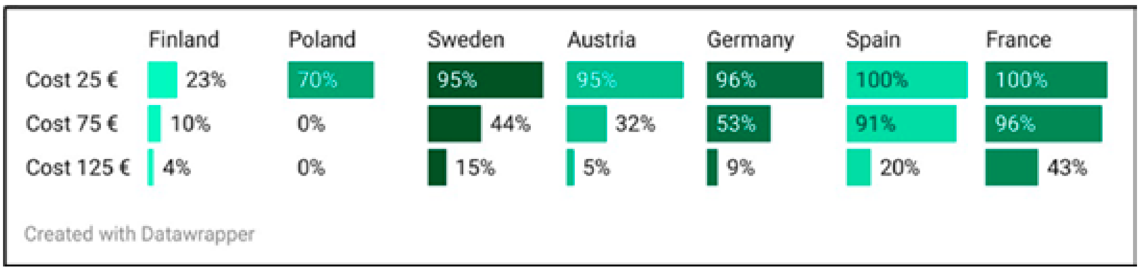

Figure: *Predicted share of "yes" votes in support of leading by example, by country and cost level. Cost levels represent the annual additional costs to households until Year 2030 that result from a policy that reduces emissions by 10 percentage points above the country's existing EU commitment.*

Survey data from seven EU Member States reveal that public support for taking the lead is highly sensitive to the perceived cost of doing so. Crucially, preferences for climate leadership are shaped by expectations of reciprocity, with many individuals seeking assurance that other nations will not respond by increasing emissions or abandoning their own efforts. Beliefs about others' actions, as well as their moral convictions, play a central role in shaping support for more-ambitious domestic climate actions.

The results point to the importance of EU-wide co-ordination to strengthen reciprocal commitments among Member States. Highlighting tangible co-benefits, such as technological innovation and improved air quality, can help to justify greater climate ambition to the public. Embedding conditional co-operation into formal EU processes, where national commitments are made transparent and credible, could reduce free-riding, foster public trust, and enable deeper collective emissions reductions.

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The Double-Edged Sword: When Car Sharing Undermines Sustainable Mobility in the Value Chain

MAGNUS HENNLOCK, ANNACARIN KARLSSON

While shared mobility is often celebrated for its potential to reduce private car ownership, our experimental results show that with expansion of car-sharing services in Gothenburg and Stockholm most adopters would not be car owners but people who previously relied on public transport, walking or cycling. This result raises critical questions about the potential of actual environmental and value chain measures to expand car-sharing in large cities.

A shift from private car ownership to shared mobility solutions would transform the urban mobility value chain, re-shaping roles, revenue models, and infrastructure requirements. In the traditional model of private ownership, car manufacturers sell vehicles to individual consumers, who are responsible for financing, insurance, maintenance, and parking. Fuel and energy providers serve a dispersed market, and urban space is dominated by private parking. While convenient, this model leads to low vehicle utilisation rates, high production volumes relative to actual use, substantial ownership costs, and inefficient use of urban land. In contrast, shared mobility solutions consolidate vehicle ownership under fleet operators who manage the financing, insurance, maintenance, and operations. Municipalities play a more active role by regulating fleet sizes and service quality, while shared charging and parking hubs replace the need for private parking spaces. Revenue shifts from one-time vehicle sales to recurring usage fees and subscription models, improving vehicle utilisation and potentially reducing levels of congestion and emissions.

A common assumption made for this outcome is that car-sharing primarily substitutes for private car use. However, our choice experiment, a survey-based study in which participants make choices while facing systematically varied information about car-sharing offers, suggests otherwise. We examined the increased availability of car-sharing in Gothenburg and Stockholm in a choice experiment that involved 1,918 participants living in these cities. We found that the majority of those who opted for car-sharing were not people with regular access to a car but rather individuals who currently rely on more-sustainable modes of transport, such as walking, cycling or public transit. Among the participants without regular access to a car, 70% chose one of the car-sharing options, whereas only 30% preferred their current travel habits. Conversely, among those with regular car access, 80% opted to continue with their existing travel behaviour using the car that they had regular access to.

In summary, the success of car-sharing depends not only on its technological feasibility or user-friendliness, but also on the types of trips that it replaces, who adopts it, and how it reshapes the broader transport system.

Implications for the Value Chain and Emissions

The results of our experiment have important implications for the automotive value chain and for broader environmental issues. Car-sharing is often positioned as a way to reduce the number of cars produced and operated, thereby lowering emissions from both manufacturing and daily use. This holds true when car-sharing replaces private car ownership.

However, when shared mobility also replaces non-car modes, the net effect is quite different. Car-sharing in this context also adds new vehicles to the system to meet the demand from users who did not previously require access to a car. These cars not only sustain but may even increase the demands along the automotive value chain – from raw materials and manufacturing to logistics, servicing, and end-of-life management.

From the emissions perspective, this presents multiple challenges. We find that expanding car-sharing in high-car ownership areas usually reduces emissions, while expanding car-sharing in areas that have a large share of public transport usually increases net emissions. An increase in the number of vehicle kilometres travelled then leads to higher operational emissions, especially if fleets are not fully electrified or powered by renewable energy. In addition, the embedded emissions associated with vehicle production –particularly for electric vehicles, which require energy-intensive battery manufacturing – can increase the environmental foot-print if the total vehicle stock remains the same or expands in the area.

Policy Implications

To ensure that car-sharing contributes positively to urban sustainability and emissions reduction goals, strategic policy interventions are necessary. Based on the findings of our study, we make the following recommendations:

- **Prioritise electrification of car-sharing fleets,** and ensure that they are powered by renewable energy sources. This is crucial for mitigating the negative emissions impact of modal back-slide.

- **Target high-car ownership areas for deployment of car-sharing services.** This increases the likelihood that shared vehicles will substitute for privately owned cars rather than for active or collective modes.

- **Avoid over-provisioning car-sharing stations** in areas where they may compete with already sustainable transport options. The focus from the beginning should instead be on improved public transport in these areas.

- **Incentivise reductions in private car ownership,** through programs that offer financial or service-based benefits for giving up a car, or that bundle car-sharing into broader mobility-as-a-service (MaaS) packages.

- **Integrate shared mobility into public transport planning,** ensuring that car-sharing complements rather than competes with buses, trams, trains, and active modes.

- **Monitor behavioural patterns over time,** as early interest in car-sharing may not translate into long-term shifts. Continuous evaluation is essential to identify when and where car-sharing contributes to increased car dependency in modal back-slide versus genuine modal shift.

Only with such targeted measures can cities unlock the true potential of car-sharing – as a tool to reduce car dependency, rather than as an additional convenience that inadvertently reinforces it.

For car-sharing to fulfil its promise, it must be strategically implemented to replace rather than supplement private car use, and it must be part of an integrated, multi-modal transport system. Policies must be designed that not only promote shared mobility but guide its effects towards creating public value in terms of reducing emissions, easing congestion, and creating more-liveable urban environments.

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Just Transitions are Critical in Societal Change towards a Fossil-free Future

VICTORIA WIBECK, BJÖRN-OLA LINNÉR, ARDIANA JAKU, SEJIN LEE

For societies to decarbonise and achieve climate resilience, cross-sectoral, transformative changes are needed. In such processes, there is a risk that some groups will see themselves as winners and others as losers in the green transition. To mitigate these risks, it is imperative to pay attention to fairness and justice dimensions.

'Just transitions' is a core principle in the UN 2030 Agenda and the Sustainable Development Goals, as stated in their aspiration of 'leaving no one behind'. Originating from the trade union movement in the USA in the 1970s-1980s, the just transition concept has now found its way into the Paris Agreement, Just Transition Declarations from the UN climate negotiations COP24 and COP26, as well as the European Green Deal.

In the research literature on climate change and other sustainability challenges, attention is increasingly focussed on the justice dimensions related to transformative societal changes. To map this expanding research field, we conducted a systematic review of 494 scientific papers published between 1998 and 2023. The aim was to assess the empirical evidence in different parts of the world and in different sectors regarding the ways in which: transformations can be made in a just manner; different schools of thought conclude that the benefits and costs of transitions and transformations can be fairly distributed; affected groups can become involved in decision-making procedures and transformative processes.

We see a rapid increase in the number of papers dealing with just transitions and just transformations during the last few years of this review. More than seven out of ten papers were published in the period of 2021–2023. The older papers in our sample have largely focused on distributive justice aspects: how to distribute the benefits and harms of the green transition, both geographically and between groups. This could, for instance, address ways to compensate communities in fossil fuel-intensive regions where low-carbon transitions have led to job losses, for example through economic compensation, up-skilling programmes, and the creation of new green jobs. While such distributional aspects are still seen as crucial, the recent literature broadens the scope. Increasingly, it discusses the need to recognize existing bodies of knowledge, cultures, and histories, and to engage a broad variety of stakeholders in dialogues and decision-making processes, for example regarding 'recognitional justice' and 'procedural justice'. In addition, some papers go beyond a human-centred view of justice, emphasising that ecological concerns should also be seen as legitimate interests in justice discussions.

Justice concerns are relevant for different types of transformative changes towards fossil-free societies. For example, changes in cultural norms can be spurred by procedural tools that support societal dialogue where different perspectives can be heard and recognized. For technological changes, it is important to take distributional justice aspects into account, paying attention to how the benefits and risks of technological development are distributed between and within communities. In relation to political changes, procedural justice dimensions are again often discussed.

The research literature also demonstrates a growing awareness that transitions should be seen as multi-dimensional processes – or as transformative processes – in which several, inter-linked, changes are ongoing and for which multiple justice dimensions could be relevant.

The recent climate backlash in times of populist politics is a sign of the surging interest in the fairness aspects of decarbonisation. A rigorous international scientific assessment is warranted that takes stock of the wealth of evidence and examples of how justice can guide legitimate and effective decarbonisation transformations.

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Green Industrial Policy for Decarbonising Basic Materials Industries

ÅSA LÖFGREN, FILIP JOHNSSON, JOHAN ROOTZÉN, LARS ZETTERBERG

Key take-aways:

- Green industrial policy is crucial to overcoming market and co-ordination failures that hinder industrial decarbonisation.
- Effective green industrial policy combines sector-specific support with long-term credibility and institutional safeguards.
- Public support should promote learning and private co-financing, while managing the risks linked to regulatory capture and inefficiency.

The transition to net-zero carbon emissions in basic materials industries, such as those producing steel, cement, and chemicals, requires policies beyond carbon pricing. Primarily, this is because these industries are capital-intensive, traditionally slow to innovate, and exposed to multiple market failures, including knowledge spillovers, credit biases, and co-ordination problems across their value chains and infrastructures.

Green industrial policy is defined as an active, sector-specific policy to support clean technology development and deployment. Our research, which has been carried out as part of the Mistra Carbon Exit program (van den Bijgaart et al., 2024; Söderholm et al., 2025), emphasises the need for a well-balanced policy mix that includes:

- **Technology-push instruments** (e.g., R&D support, demonstration projects);
- **Demand-pull mechanisms** (e.g., green procurement, carbon border adjustments); and
- **Systemic support** (e.g., skills, infrastructure, long-term commitments).

Central to a successful green industrial policy is directionality, sending clear long-term signals that shape industrial expectations and re-direct private investment. Pilot and demonstration projects are essential learning tools, especially for technologies that are immature and associated with high risk. However, public support must be designed to complement, rather than crowd out, private capital, and should include mechanisms for knowledge sharing, evaluation, and exit strategies.

Our work also highlights institutional challenges. A green industrial policy must be shielded from rent-seeking behaviours and designed with discipline, accountability, and embedded sectoral expertise. Policy-makers must accept some failure as part of the learning process. while preventing persistent inefficiencies or prestige-driven support for under-performing projects.

Policy implications

While carbon pricing is essential for internalizing the cost of emissions and incentivizing low-carbon choices across the economy, green industrial policy addresses additional market failures that carbon pricing alone cannot resolve. Both instruments are necessary to support a successful and timely green transition. A well-governed green industrial policy should foster innovation, mobilise investments, and build coalitions for change, while managing the risks that come with targeted state interventions. Policy-makers must strike a balance between persistence and recognizing that some failure is inevitable in the innovation process, while ensuring that limited public funds are used wisely and appropriately.

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Twenty Years of Emissions Trading: Evolution, Impacts, and Lessons Learnt from the EU ETS

THOMAS STERNER, DALLAS BURTRAW, JOS DELBEKE, FILIP JOHNSSON, ÅSA LÖFGREN, LARS ZETTERBERG

Key Take-aways:

- **The EU Emissions Trading System (EU ETS), which is the world's largest carbon market, has evolved continuously since Year 2005, overcoming major challenges such as an over-supply of allowances.**
- **Policy design elements of the EU ETS (e.g., free allocation vs. auctioning, the Market Stability Reserve, price floors) exert crucial influences on the carbon price signals and emissions outcomes.**
- **Empirical evaluations show the EU ETS has reduced emissions while mitigating competitiveness impacts and spurring low-carbon innovation, although concerns remain regarding price volatility and political buy-ins.**
- **Future reforms must address distributional effects, global coordination (e.g., CBAM), and new technologies, so that the EU ETS can scale its ambition in line with mid-century climate targets.**

Origins and Early Challenges

Launched in 2005, the EU ETS initially covered CO_2 emissions from energy production and heavy industry. The early phases saw an over-allocation of free allowances, leading to allowance surpluses and low prices, which undercut incentives for deeper emissions cuts. Economic downturns and the influx of international offsets exacerbated this trend, prompting reforms.

Key Design Elements

A defining feature has been the evolution from largely free allocations towards greater use of auctions, complemented by flexible provisions such as the Market Stability Reserve (MSR). Other ETS programs world-wide (e.g., California, RGGI) vary in scope (electricity only vs. economy-wide) and use mechanisms such as price floors to avoid the low-price trap. These experiences highlight how coverage, allocation methods, and cost containment tools affect environmental effectiveness and market stability.

Evaluating the EU ETS

Academic research, using advanced econometric and simulation approaches, consistently finds that the EU ETS reduces emissions without crippling economic performance. Studies also reveal that allowance prices – even when they are relatively low – foster incremental technological change. Free allocations and other safeguards limit leakage risks and competitiveness concerns, although on-going monitoring is essential.

Alternatives and Complements

Carbon pricing rarely acts in isolation. Complementary measures (e.g., renewable energy subsidies, energy efficiency mandates) can bolster emissions reductions but risk overlapping "waterbed effects" if not carefully aligned. In some sectors (e.g., transport), targeted regulation or taxation may be more politically palatable. Co-ordination within the EU (and internationally) helps ensure coherence across multiple policy instruments.

Future Outlook

Recent reforms, such as the Fit for 55 initiative, CBAM, extended coverage for shipping, and a separate ETS for buildings and transport, signal on-going policy innovation. Nonetheless, the EU ETS faces political head-winds from nationalist pressures, technology cost uncertainties, and equity concerns. Addressing these challenges will require sustained institutional commitment, stable yet adaptive rule-making, and close alignment with emerging global carbon markets.

What are Carbon Contracts for Difference? Why Were They Developed and How Are They Currently Implemented?

KARSTEN NEUHOFF

Investments in climate-neutral primary material production processes are hindered by uncertainties related to: (i) future carbon prices; (ii) the allocation of free emissions allowances for green and conventional production processes; and (iii) the price difference between clean and conventional fuels. Governments tender Carbon Contracts for Difference (CCfDs) that hedge these risks for companies, thereby enabling investments in climate-neutral production processes at competitive mitigation costs.

Shifting from conventional to climate-neutral materials production could address about 30% of global CO_2 emissions. For companies, this will involve substantial up-front investments, and they will incur higher operational costs than for conventional, fossil fuel-based materials if the carbon costs are not internalised. Investments will only be undertaken if there is a clear and sufficiently reliable business case (Chiappinelli et al. 2021). Two basic options exist. First, conventional producers face the full externality costs of carbon and increase the price of the materials that they produce accordingly. This increases the market price at which climate-neutral producers can sell their product and, thus, affects their revenue. Second, climate-neutral producers are rewarded for their emissions reductions, by a green premium that is funded by private consumers or governments, paying for green materials or for the emissions saved during their production.

For the period of 15 to 20 years, which is relevant for investments in basic materials production, it is difficult to predict these future regulatory and societal developments. Currently, it is clear that EU ETS prices, in combination with the high shares of free allowance allocations to conventional producers, do not provide sufficient incentives for decarbonising basic materials production. This situation has motivated the development of a hedging instrument to address these regulatory risks.

The first tranche of CCfDs were tendered in Year 2024 in Germany (Federal Ministry for Economic Affairs and Climate Action, 2024). The Netherlands had already in Year 2020 introduced a related SDE++ instrument (Dutch Ministry of Economic Affairs and Climate Policy, 2023).

In a public tender, basic material producers can submit bids that specify as the strike price the revenue that they require per tonne of CO_2 reduction. Emissions savings per tonne of material are calculated in comparison to the EU ETS emissions benchmark for a conventional production process. Successful bidders are then guaranteed revenues for a 15-year operational period for each tonne of CO_2 saved. CCfD payments are adjusted for the effective carbon costs for conventional producers under the EU ETS. Since it is a hedging instrument, if the EU ETS prices exceed the strike price specified in the contract, the firms have to reimburse the government (Richstein and Neuhoff 2022). Building on experience gained from long-term energy contracts in the private sector, provisions for a variety of future developments have been implemented, so as to avoid excessive risks or costs for firms or governments and to clarify, for example, the exit conditions (Richstein et al., 2024).

The broad participation in the first tenders suggests that CCfDs are an effective instrument to support

investments in and operation of climate-neutral primary materials production, if three conditions are met. First, it will now be important to pursue tenders at reliable intervals and at scale to facilitate a smooth transition process. Second, a structural reform of EU ETS is necessary to ensure a reliable funding stream dedicated to CCfD tenders, e.g., by complementing EU ETS with a bridging instrument with a climate contribution. Third, a parallel, simplified version should be considered, to meet the needs of smaller, more-standardised projects and of small- and medium-sized firms.

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Tradable Performance Standards in the Transportation Sector

SONIA YEH, DALLAS BURTRAW, THOMAS STERNER, DAVID GREENE

Key Take-aways:

- **Tradable performance standards (TPS) offer a flexible, market-based approach to reduce emissions in the transportation sector.**
- **By allowing the trading of "credits" between entities that exceed or fail to meet performance benchmarks, TPS can reduce compliance costs and incentivise innovation.**
- **Effective TPS design requires clear performance metrics, robust monitoring, and supportive complementary policies (e.g., fuel taxes or infrastructure investments).**
- **TPS can be more politically feasible than a direct carbon tax because they lead to a smaller increase in consumer (product) prices and provide a production incentive that helps to mitigate against the leakage of economic activity to companies outside the area covered by the policy.**
- **TPS do not provide government revenue that might be used for investments or compensation.**
- **TPS do not prevent a potential rebound effect, which can be addressed by introducing an overall cap to avoid increases in emissions.**

This article examines the potential of TPS to control and reduce emissions in the transportation sector. Performance standards have a long history in the US transportation sector, beginning at the national level with the Corporate Average Fuel Economy (CAFE) standards, and in California with the Zero Emission Vehicle (ZEV) program adopted by the California Air Resources Board (CARB) in 1990. Outside of the US, feebate (price-based incentive programs) and China's new national carbon market are the prominent examples. Unlike technology mandates, which prescribe specific technology (e.g., a three-way catalytic converter), performance standards set a goal (e.g., maximum emissions per unit of performance (e.g. gCO2/km), or vehicle efficiency of at least x km per liter), enabling the regulated entity to choose any technology mix that achieves that outcome.

Few of these programs, however, allow companies to trade credits for compliance. Current examples include the national regulations for greenhouse gas (GHG) emissions from passenger cars and trucks, zero-emission vehicle programs in 10 U.S. states, the U.S. Renewable Fuel Standard, and California's Low Carbon Fuel Standards.

Unlike a carbon tax, TPS provides flexibility by allowing actors that exceed the standards gain credits, while those that lag behind can purchase credits to remain compliant (as seen in the figure to the left, taken from Yeh (2021)). From a policy perspective, TPS can be an attractive option in jurisdictions where a direct carbon tax faces political resistance. However, policy-makers should address concerns about market manipulation, competitive fairness, and the distribution of costs across different stakeholders, in order to ensure equitable and effective outcomes.

Key advantages of TPS are their potential to spur technological advancements and to lower the overall cost of meeting emissions targets. However, a key research insight is the importance of careful policy design: standards must be regularly updated, and robust monitoring and enforcement mechanisms are critical to maintain market integrity. The study also found that complementary policies (for example, targeted investments in low-carbon infrastructure or consumer incentives) can amplify the effectiveness of a TPS.

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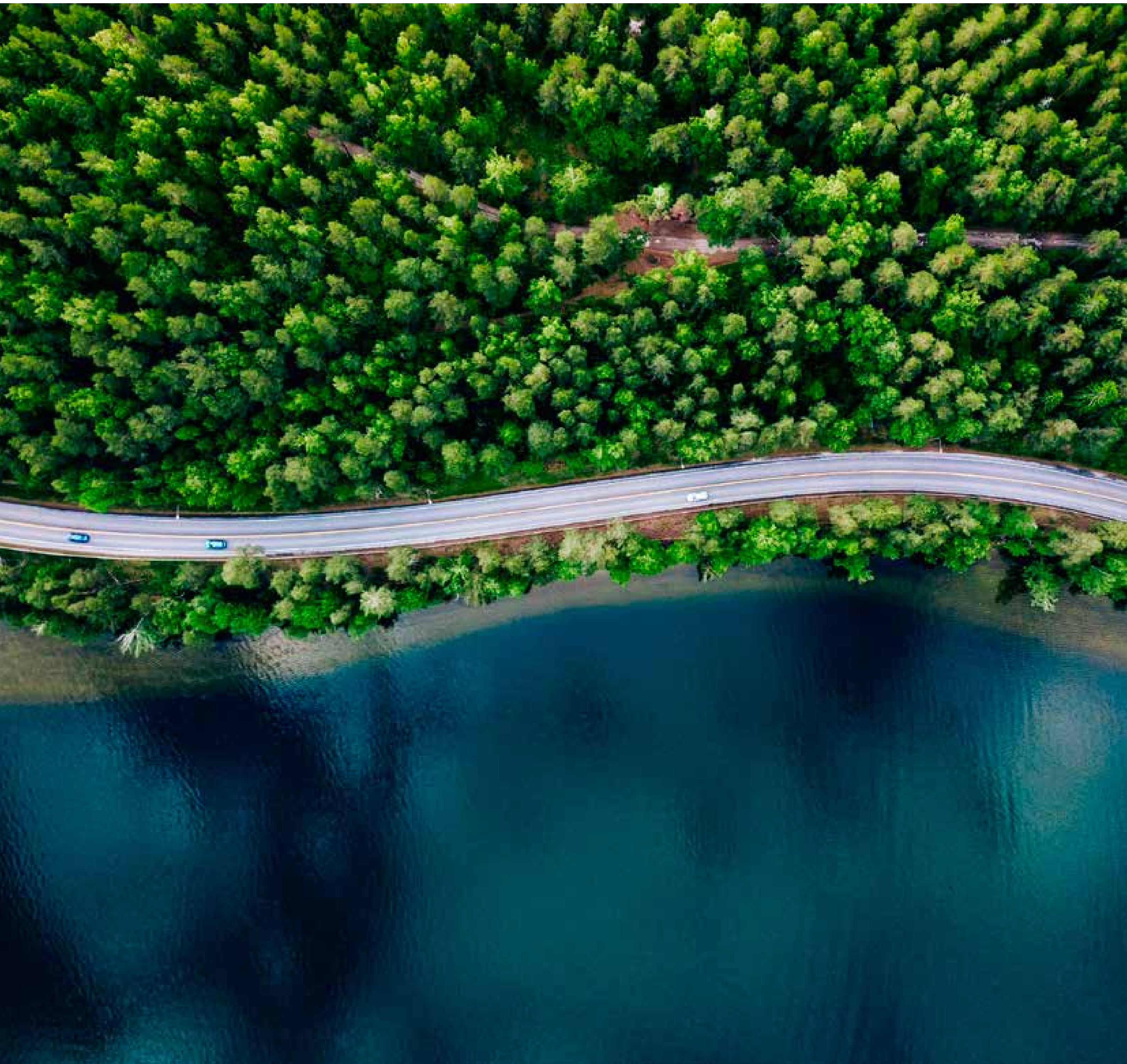

Catching Carbon – Towards a sound Market for Negative Emissions

LARS ZETTERBERG, KENNETH MÖLLERSTEN

Key take-aways:

- **All global greenhouse gas emissions scenarios that reach the targets set by the Paris Agreement rely on substantial emissions reductions and significant volumes of carbon removals. These measures are needed to balance the remaining emissions that are economically and technically hard to mitigate, and to remove historically emitted carbon dioxide from the atmosphere.**
- **The possibility to compensate emissions with carbon removals has led to concerns that carbon removals will be used instead of reducing emissions (known as "mitigation deterrence"). In the case of Bio-CCS, there is also a risk for over-use of the limited bio-resource. Therefore, separate targets for emissions reductions and carbon removals need to be adopted.**

Carbon removals include afforestation, reforestation and other nature-based solutions, as well as permanent removals through Bio-Energy Carbon Capture and Storage (BECCS), Direct Air Carbon Capture and Storage (DACCS) and other novel carbon removal methods. Despite the need for significant volumes of carbon removals, there are currently few policies and programmes that provide incentives and funding for carbon removals. We present five models for creating incentives and funding for permanent carbon removals through BECCS and DACCS:

State funding. This can be achieved through long-term agreements with the producers of BECCS and DACCS, whereby the State guarantees to buy a certain level of carbon removal over a certain time period. With this model, favourable conditions can be created for establishing the first carbon capture facilities. A major risk is that the cost for the State can be high.

Quota obligation. The State (or the EU) imposes a quota obligation, requiring companies to purchase BECCS/DACCS credits that are equivalent to a certain percentage of their emissions. The advantages of a quota obligation model, as compared with model 1, are that it widens the financing basis and reduces costs for the State.

Allow credits in the EU ETS. This could create a significant demand for BECCS/DACCS and reduce the costs for participants in the EU ETS. To avoid any over-use of carbon removals, a control mechanism will be needed that manages how many credits enter the EU ETS.

Other States as buyers. Under Article 6 of the Paris Agreement, countries can co-operate on a voluntary basis to reach their respective national commitments for emissions reductions. The goal of this co-operation is to increase the overall ambition level, i.e., to create greater net emissions reductions than would be the case without such co-operation

Private entities for voluntary compensation. Companies and individuals can, on a voluntary basis, compensate for their climate impacts by buying credits that represent carbon removals. There is a risk for double-claiming if both the company/individual and the country that produce the removals claim these removals as part of reaching their individual targets.

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Reverse Auctions to Procure Negative Emissions at Industrial Scale

DALLAS BURTRAW, CHARLES HOLT, ÅSA LÖFGREN, WILLIAM SHOBE

Key take-aways:

- **This paper explores the use of reverse auctions to procure carbon dioxide removal (CDR) credits at an industrial scale.**
- **It compares the performances of sealed bid and clock auction designs in the context of a fixed government procurement budget and common value uncertainty. A clock auction is an auction format where the price is gradually increased or decreased, and participants indicate whether they are still willing to buy or sell at each price level, often used to reveal bidder valuations more dynamically than sealed bids.**
- **Preliminary results from laboratory experiments suggest that clock auctions reduce the average cost for the buyer, while minimising bidder losses.**

The paper discusses the importance of carbon dioxide removal (CDR) technologies for achieving net-zero emissions, particularly for hard-to-abate sectors. It highlights the challenges associated with procuring CDR credits due to the capital-intensive nature of the technologies and the need for large investments in capacity. The authors propose using reverse auctions (specifically, sealed bid and clock auctions) to procure CDR credits in an efficient manner.

Laboratory experiments were conducted to test the auction designs. The results indicate that clock auctions tend to restrict bidder profits, reducing the average cost for the buyer. However, both auction formats showed infrequent occurrences of the 'winner's curse', whereby winning bidders may face losses that—if realized—could lead to default. The study also emphasises the importance of government incentives and risk-sharing mechanisms to support early investments in CDR technologies.

Policy implications:

- Governments should consider using reverse auctions to procure CDR credits, as they can help achieve cost-effective carbon sequestration.
- Policy-makers need to design auction mechanisms that balance cost efficiency with the risk of bidder default.
- Supporting early investments in CDR technologies through subsidies and risk-sharing could accelerate the development of the CDR industry and contribute to achieving climate goals.

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Why Haven't We (And How Can We) Come Further in Using Procurement to Drive Carbon Reductions in the Infrastructure Construction Sector?

ANNA KADEFORS

Procurement is increasingly seen as an important policy tool to achieve political and societal goals, such as carbon reduction. The infrastructure construction sector is pinpointed due to the high volume of public construction, in combination with the substantial embodied carbon emissions from cement, steel, asphalt and fossil fuels. While reduction goals have up to now been reached by picking low-hanging fruits, future ambitions call for more-advanced approaches.

Fortunately, in recent years, it has been possible to test various procurement models. So, what have we learnt from this?

1. Look beyond performance requirements

Initially, reduction requirements in relation to a baseline were expected to drive emissions down at lowest cost. However, construction projects are unique, and time and resources are short in the bidding and design processes. As a consequence, follow-up studies showed that projects missed out on important opportunities for carbon reductions, and that these types of performance requirements were not sufficient to drive supply-side innovation. Moreover, reduction requirements introduced high transaction costs – calculating baselines and updating them as projects evolve is both time-consuming and expensive. Given this back-drop, there is a trend towards setting specific requirements to ensure that projects include best-practice solutions regarding, for example, materials, energy use, and carbon management. Proceeding from this basic level, ways to enable and incentivise further performance can be designed.

2. Use procurement strategies to unlock further reduction opportunities

To reach more-ambitious goals, requirements that specifically target carbon reductions need to be integrated into general procurement strategies. These involve the delivery model (which party is responsible for the design), payment principles (fixed price, cost-reimbursable, combinations), award criteria (lowest bid or most-advantageous tender), and collaboration ambitions (when to involve contractors, how to collaborate). The procurement strategy is designed to fit the goals and risks in the project, as well as in relation to client resources and the market situation. Collaborative contracts with early involvement of the contractor often provide additional opportunities for design optimisation, and frame-work contracts that bundle schemes of projects enable learning and economies of scale. Collaborative contracts also share risks, which may be valuable when reduction ambitions are raised and risks become hard to price up-front by contractors.

3. Focus on learning and governance

While procurement is often seen as an incentive problem, it is equally about learning and capability development. For example, aligning ambitions for carbon reductions with a procurement strategy calls for close collaboration between client project managers, procurement professionals, environmental and technical specialists, and operations staff. Such cooperation is not a given, especially since these actors belong to different departments with distinct cultures, priorities and knowledge bases. Moreover, for new practices to be widely disseminated, the broad population of smaller clients must be reached. This is not easy when knowledge generation is fragmented and many sector initiatives are temporary in nature.

Implementing new requirements and strategies also relies on the availability of relevant competencies and resources on the market. To motivate supply-side investments, innovation processes need to encompass multiple projects and involve many clients. Long-term capability development, therefore, implies that the sector and supporting public agencies establish structures for systematic learning and development at the institutional level. Such flexible governance is especially important as there are few eternal truths in the field of procurement. New materials, products, competencies, regulations, certification systems and digital tools change opportunities to formulate and follow up requirements, sometimes quite rapidly.

4. Acknowledge and embrace complexity

The construction sector is highly complex and should be approached accordingly. A key lesson from improvement initiatives in various countries over time is that achieving change and innovation in this project-based industry requires high system understanding, sustained resource commitment and a certain level of humility.

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Lingegård, S., Alkan Olsson, J., Kadefors, A., & Uppenberg, S. (2021). Sustainable Public Procurement in Large Infrastructure Projects—Policy Implementation for Carbon Emission Reductions. Sustainability, 13(20), https://doi.org/10.3390/su132011182.

Publications from a recent study are under development.

EU Climate Policy in the New World Order

LARS ZETTERBERG, CHRISTIAN EGENHOFER, MILAN ELKERBOUT

The world is undergoing dramatic change, notably following the Russian invasion of Ukraine and the change in government in the US. The trans-Atlantic relationship has moved from one of co-operation on security issues, technological development, trade and climate policy to a more-adversarial position. Support from and co-operation with the US can no longer be taken for granted. President Trump has imposed new tariffs on US allies. The US is threatening to annex Greenland, Canada and Panama on the grounds that "the US needs them". Similarly, the European security situation has changed fundamentally. Climate policy has been dismantled. The US has exited the Paris Agreement. President Trump is trying to stop climate investments and instead favours oil extraction under the motto "Drill, baby, drill", and he has commissioned studies that will show that climate change is good for the economy. Europe's weaknesses in terms of security and competitiveness were highlighted in the Draghi Report that came out in September 2024. The Draghi report has, together with the Letta Report formed the backbone of the new European Commission policy, under Ursula von der Leyen, dubbed Von der Leyen II. For example, the first major strategy document by the new European Commission, called the Competitive Compass, has designated 'closing the innovation gap' alongside a 'roadmap for the phase-out of fossil fuel' and 'increased independence and security', as the three over-riding priorities. Some groups see Europe's need for industrial development and the new security situation as excuses to delay parts of the Green Deal. However, decarbonisation will make Europe less-dependent upon imports of energy and bring down energy prices and costs. Decarbonisation will also support Green Tech development and improve Europe's competitiveness in the long term. However, the new security situation requires a new approach to balance and ultimately, to align industrial competitiveness with decarbonisation and security concerns, notably ensuring economic resilience when faced with volatile international political and economic landscapes. The Clean Industrial Deal, as a (logical) follow-up to the European Green Deal is setting out a strategy to achieve this new balance. Given the emerging new geopolitical situation, the following areas are likely to be of high priority for the EU in the coming years:

Energy security: Decarbonisation as the structural solution to reduce energy prices and reduce dependency on outside sources. Phasing out of fossil fuels and expansion of low-carbon electricity will make Europe less-dependent upon energy imports, increase Europe's resilience to external shocks, and reduce the revenues paid to Russia.

Green technology development: In addition to renewable energy systems, this will include green materials (steel, chemicals, cement, aluminium, etc.), as well as technologies such as carbon capture and storage, electric vehicles and biorefineries.

Critical metals and minerals: The EU needs to secure the sourcing of critical minerals and metals and increase domestic production, refining and reuse.

Defence: A strengthening of the EU defence system and increasing resilience will not only require a more-unified security and defence policy, but also the improvement of transport infrastructure (road, rail, harbours). Using green materials for these projects can create lead markets for green steel and green cement.

A trade war with the US will result in the EU seeking to expand trade with other countries. This, along with the implementation of a revised Carbon Border Adjustment Mechanism (CBAM), may provide an avenue for deepening the collaboration on climate action, for instance through climate clubs.

From Carbon Pricing to Climate Clubs?

MILAN ELKERBOUT, ETHAN ZIEGLER

In a 2022 CEPS report, we analysed different approaches to carbon pricing, addressing carbon leakage, and options for increased global cooperation on industrial decarbonisation, especially against the backdrop of the EU announcing its carbon border adjustment mechanism. While geopolitical circumstances have changed significantly since then, industrial decarbonisation policies and the need to deal with different policy ambitions and designs persist.

- **Carbon pricing is an effective tool to reduce emissions, provided the policy design does not shield producers from the impact of the carbon price signal.**
- **Carbon leakage risk and competitiveness considerations will continue to dominate policy design.**
- **Partnerships that go beyond carbon pricing should be pursued to accelerate industrial decarbonisation.**

Carbon pricing, in the form of a carbon tax or an emission trading system (ETS), has been applied across the world to internalise the externality of greenhouse gas emissions . A carbon tax allows the government to set a price which will lead to emissions reductions, with prices gradually increasing over time until a region entirely halts its CO_2 emissions. An ETS allows the market to attach a price on carbon based on supply and demand, defining emissions as tradable property rights. Proper policy design of any carbon pricing system is imperative to decrease emissions efficiently long-term. These explicit policies must be made keeping in mind the factors that contribute to an implicit carbon price as well. These factors include other instruments that affect the marginal cost of emitting carbon, such as climate, energy, or environmental regulations that polluting firms must abide by.

Maximizing the efficiency of carbon pricing is difficult, in part because of the barriers to implementing such policies. A country must have administrative and infrastructural capacity, including a credible monitoring, reporting, and verification system, a competitive market, and technical expertise. Since the price will disincentivize the output of GHGs, alternatives for production of energy and carbon-intensive goods will need to be available. These alternatives, however, are not adoptable at a large scale in many energy-intensive industries, so additional policies supporting this transition are crucial. If these additional regulations are not promoted, many industries may witness the effects of carbon leakage, whereby firms displace their production and emissions to regions with weaker climate policies. The political and economic circumstances of a country must also come into consideration. Many developing economies wishing to expand will seek out fossil fuels to support industrialization. Distributionally, the effects of carbon prices may further impose costs on low-income households, while institutionally, carbon prices may be altered based on political leadership. Since the publication of this report in 2022, many governments have been replaced with governments that are less supportive of climate policy, especially where households are directly implicated. At the same time, carbon pricing is also being adopted – or existing systems expanded by an increasing number of countries, reflecting the "policy spillover" impact of the EU's CBAM.

Carbon pricing has proven to be effective both in reducing emissions and generating revenue. Increasing geopolitical tension will affect coordinated global efforts to use economic levers to reduce carbon emissions. While a global carbon price would alleviate many concerns about carbon leakage, the prospects are more remote than ever for now. In a world with fragmented climate policies, countries implementing their carbon pricing separate from each other will want to include safeguards against leakage. The increasing popularity of carbon border adjustment mechanisms (CBAMs) play an increasing role, as CBAMs can strengthen carbon price signals domestically and incentivize industrial decarbonisation policies abroad. Global coordination should focus on linking all policies relating to a thriving environment, not just carbon pricing. A climate club, where member states agree to deploy low-carbon technology, standardize carbon abatement strategies, and align carbon prices, would be an efficient means to materializing this cooperation. These clubs would shift climate policies away from their protective nature, as they would prioritize diplomacy and allow countries to support one another in their efforts to improve their environmental performance.

The EU's CBAM can be an impetus for more international coordination on industrial decarbonisation. This can take the form of clubs, although it is unlikely to take the form of explicitly harmonized carbon pricing between countries. Rather, the EU should be willing to engage in partnerships that go beyond pricing, focused on investment, technology and measurement.

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Clausing, K., Elkerbout, M., Nehrkorn, K., Wolfram, C. (2024). How Carbon Border Adjustments Might Drive Global Climate Policy Momentum. https://www.rff.org/publications/reports/how-carbon-border-adjustments-might-drive-global-climate-policy-momentum/.

Dealing with Carbon Leakage and Competitiveness: Different Options Exist but Require Political Choices

MILAN ELKERBOUT, CHRISTIAN EGENHOFER

Key Take-aways:

Uneven climate policies impose different costs on industries across economies. The resulting risk of carbon leakage has inhibited and still is inhibiting more-ambitious climate policies for industries. The EU CBAM has tried to address this issue. Yet, as the design has evolved, new challenges have emerged. There are new ideas as to how to use the ETS as a tool to accelerate industrial decarbonisation. To do so will require political will.

When dealing with the decarbonisation of energy-intensive, trade-exposed goods, policymakers have to contend with concerns about carbon leakage and competitiveness. In the early stages of decarbonising industry, there is little tension: most producers will be carbon-intensive and if they face high carbon costs, they will lose competitiveness against foreign producers that do not face such costs. Free allocation was a good policy response in the early days of the EU ETS. However, as producers start to decarbonise, the question as to whose competitiveness actually has to be protected becomes more important.

The analysis conducted by CEPS on how the free allocation system provides incentives (or disincentives) for the deployment of low-carbon technologies tried to offer a response to this question. With the EU CBAM, an alternative to free allocation is available. While the CBAM is an effective mechanism to mitigate the risk of carbon leakage, it will do little to protect carbon-inefficient producers in Europe from competition. Neither does it (for now) address export competitiveness.

When the CBAM proposal was introduced, it was also immediately clear that there would be some implementation challenges related to the re-shuffling of goods and the impacts on developing countries. Indeed, these challenges persist even as the EU CBAM is going through its trial phase. At the same time, industrial policies, which have become much more popular around the world, especially in the US (even the Trump administration is keeping in place many of the provisions of the Inflation Reduction Act for now), also have the potential to distort significantly trade and investment flows.

To address these shortcomings, stakeholders have proposed to keep free allocations and to delay the CBAM. However, a simple calculation shows that as of around Year 2030, under current rules, there will be insufficient free allocations to cover the carbon costs that EU industry incurs. Furthermore, maintaining free allocation in its current form undermines the investment case in the EU for low-carbon materials, such as steel, cement, and chemicals.

Since, in the long run, preserving the competitiveness of industry requires the transition to low-carbon technologies, there is a need for incentives for innovative – and for now more expensive – approaches to accelerate the decarbonisation of industry. It has, therefore, been proposed to use the ETS free allocations to actively support low- and zero-carbon production processes by introducing a new 'zero-carbon' benchmark, which would reward zero-carbon producers with additional free EU ETS allowances (EUAs), so as to (partly) cover their investment costs. The idea of granting free allocations to low-carbon investments has gained traction again in the context of the EU's Clean Industrial Deal. Free allocation might be used as an additional revenue stream – and subsidy – for industries that are bidding successfully to the Industrial Decarbonisation Bank (IDB).

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Elkerbout, Milan, 'Can free allocation be used as innovation aid to transform industry?', CEPS Policy Brief 22-01, Januray 2022.

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Ida Karlsson, the programme's second PhD

Ida Karlsson successfully defended her PhD in June 2024. After a long, well-needed summer break, she has continued working towards implementation, utilisation and outreach. This has included collaborative projects with actors across the construction sector on accelerating use of procurement requirements and carbon reduction measures in both building and infrastructure construction. It has implied taking knowledge from research as well as practical experiences and adapt these insights into easily accessible formats and practical guidelines. To ensure the potential for broad application Ida and other actors have also worked to get the developed knowledge integrated into tools and reference works widely used in the every day work of actors in the sector.

"I have also continued to work on the link between costs and climate optimization in building projects, which has provided interesting insights", says Ida.

Otherwise Ida has spent a large share of her time travelling and presenting the research findings in a range of different contexts. The great interest in the research indicates that the timing is right and that the sector is ready to accelerate.

"This provides me with continued ambition and hope in these somewhat gloomy times", says Ida.

In this report you can find Ida's contributions on pages 9, 12 and 14.

Ella Rebalski defended her PhD in October

Ella joined Mistra Carbon Exit as a PhD student in 2018, and defended her PhD in the fall of 2024. She studied how connected and automated vehicles (CAVs) will affect carbon dioxide emissions in Sweden. As a transportation researcher, Ella was drawn to the project out of excitement for CAVs, coupled with an awareness that they will soon transform the way we travel and move in society. She is currently working on a study examining the political readiness for CAVs in the Gothenburg Region. Ella finds that the mixture of perspectives from the different academic, industry and government parties involved in Mistra Carbon Exit has helped to make her research more applicable to the real-world context, and to understand how everyday habits aggregate into societal transitions that affect carbon dioxide emissions at a larger scale. Originally from Vancouver, Canada, Ella recently moved to Umeå after many years in Gothenburg, and started a job as a Researcher in the Sustainable Transport and Systems group at RISE.

Aaron Qiu Liu, researching estimates of embodied emissions in the Swedish built environment

Aaron joined phase 2 of the Mistra Carbon Exit as a PhD student in October 2021. Aaron grew up in China and he completed a master's degree in Industrial Ecology at The University of Sydney in Australia before moving to Sweden.

His research focuses on improving estimates of embodied emissions in the Swedish built environment using a combination of Machine learning and Material flow analysis. This research aims to improve bottom-up modeling of the material stock and flow of the Swedish built environment and use the material flows as a basis to estimate embodied emissions. The main result of this work highlights that renovation and maintenance activities are responsible for a larger share of embodied emissions than new constructions for both roads and buildings. This result indicates there is a need to consider embodied emissions of insulation materials in order to decarbonize the Swedish building stock.

Aaron defends his licentiate degree in June of 2025, and he will carry on the research by investigating how sufficiency measures could reduce embodied emissions, for example converting vacant offices into residential buildings.

In this report, you can find Aaron's contributions on pages 9 and 20.

Alla Toktarova, the programme's first doctor

Alla completed her PhD in May 2023 and transitioned into a postdoctoral research position as part of the Mistra Carbon Exit programme. As a postdoctoral researcher, Alla continues her pursuit of a strong interest in the research of the energy-intensive industry transition towards decarbonisation.

The results of her previous work showed that the achievement of close-to-zero emissions in the energy-intensive industries up to Year 2045 is not feasible without the implementation of alternative technologies, i.e., hydrogen, carbon capture and storage and biomass.

In her current work, she analyses reinvestment cycles based on the plant ages of the existing plant stock and economic competitiveness to determine the speed of transition from conventional production processes to alternative ones.

The economic competitiveness of alternative production processes in energy-intensive industry varies across countries, depending on electricity and natural gas prices. Being part of the program facilitated her pursuit of the set research goals by providing a collaborative environment where interdisciplinary discussions and knowledge sharing thrived. Alla is now entering a new role within the industrial decarbonisation team at the Joint Research Centre. There, she will support the European Commission policymaking to achieve decarbonisation while maintaining a robust and competitive industry. Her research focus will be on energy and industry, specifically analysing the potential and cost-effectiveness of implementing alternative production technologies in industry.

Alla has contributed to this report on pages 18 and 22.

Cecilia Hult, on interaction in the transport sector

Cecilia joined Mistra Carbon Exit as an industrial PhD student as he programme entered the second phase in May 2021. Cecilia works at IVL Swedish Environmental Research Institute and will carry out her PhD at the division of Physical Resource Theory at Chalmers University of Technology. Her research within Mistra Carbon Exit focuses on the interaction between technology and behaviour in the transport sector. "I've been working on how people will choose to travel when faced with new technologies such as autonomous and electric cars and buses and e-bikes", says Cecilia. "It's really important, but also difficult, to consider consumer preferences as well as theoretical potential when evaluating the benefits of new technologies. I'm also happy that I could contribute to a paper in Nature Communications Earth & Environment looking at emission pathways for consumption-based climate-targets in Sweden. Collaborating with authors from other work packages in Mistra Carbon Exit as well as Mistra Sustainable Consumption was real fun and a good experience for a PhD studentnization.

In this report, you can find Cecilia's contribution on page 24.

High Level Conference: Climate Urgency and the Nordic Response

Our main event in 2024 was the High Level Conference: Climate Urgency and the Nordic Response, on June 12, arranged by the Royal Swedish Academy of Engineering Sciences (IVA), in collaboration with Mistra Carbon Exit and Mistra Electrification.

The conference was recorded and can be seen here.

Dallas Burtraw, RFF.

Lars Zetterberg , IVL and Birgitta Resvik.

Romina Pourmokhtari, Minister for Climate and the Environment

Media Exposure in 2024

Mistra Carbon Exit and its scholars have been visible in media in 2024, with over 100 unique hits. Here are some examples:

- ”Emissions from building and construction can be halved with current technologies and practices”. Open Access Government, October. Filip Johnsson, Ida Karlsson.
- ”Ny rapport: Grön omställning av stålindustrin kräver tydligare styrning”. IT-hållbarhet, Grönt Samhällsbyggande, Metal Supply Premium, Industripress et. al. September. Johan Rootzén, Lars Zetterberg.
- ”DEBATT: Aktiv politik krävs för grön omställning, såväl nationellt som lokalt”. Opinion piece, Dagens Industri, October, and several local and region papers in December. Lars Zetterberg, Filip Johnsson, Johan Rootzén, Anna Krook-Riekkola, Patrik Söderholm, Kersti Karltorp.
- ”Professor: ”Regeringen har en religiös tro på kärnkraft”. Opinion piece Aftonbladet, Omni Ekonomi, December. Filip Johnsson.
- ”Halvering av koldioxidutsläpp möjligt redan i dag”. Samhällsbyggaren, November. Ida Karlsson.
- ”Siffrorna visar – Långt till klimatmålen.” Byggindustrin, December. Susanna Toller, Ida Karlsson.
- ”Klimatoptimering i byggsektorn - möjligheterna att minska koldioxidutsläppen”, Samhällsbyggaren, December. Ida Karlsson.
- ”Samhällsomställningen i Skellefteå – forskning och utmaningar”. Mistra. Lars Zetterberg. September.
- ”Alla vill ha el, men ingen vill ha kärnkraft”. DI.se plus, December. Filip Johnsson.
- ”Kärnkraftens tredubbla utmaning: tid, plats och pengar”. Realtid, December. Filip Johnsson.
- ”Forskare efterlyser politisk vilja kring vindkraft”. Forskning och Framsteg, December. Filip Johnsson.
- ”Island gör utsläppt koldioxid till sten - och glaciärerna får gravstenar”. Sydsvenskan, Helsingborgs Dagblad et.al. December. Filip Johnsson.

Publications

In 2024 and 2025, the programme produced 40 publications (peer-reviewed papers, policy briefs, working papers, and other reports), most of which are specific to Mistra Carbon Exit, and some are co-funded by Carbon Exit and other programmes. A list of publications is available in chapter 9.

Other Outreach Activities

Ida Karlsson, Stefan Uppenberg, Jeanette Sveder Lundin, Susanna Toller, Niklas Nillroth, Mats Wendel and Marcus Svensson at the seminar the 18th of November 2024.

Mistra Carbon Exit has organised or participated in a number of physical seminars and workshops throughout 2024 and the spring 2025. A few examples:

Seminars and conferences:

- On the 3rd of March, at the CEPS Ideas Labs in Brussels, Patricia Urban, CEPS, discussed **The role of sufficiency in shaping the future of the EU**.
- On 31 March 2025, Mistra Carbon Exit and SDSN's Global Climate Hub hosted the seminar **Decarbonization, climate policy & research outlook**.
- On 9 April 2025 Mistra, in collaboration with Sweden's permanent representation in Brussels organised the seminar **Sustainability and Democracy – The Role of Research for Navigating in an Era of Climate Change and Geopolitical Instability.** Lars Zetterberg represented Mistra carbon Exit.
- On the 3rd of June, **Ida Karlsson** defended her PhD thesis. Göteborg 3 June.
- On the 25th of June Mistra Carbon Exit hosted the seminar **New conditions for the green transition after 2030** (Nya förutsättningar för den gröna omställningen efter 2030) in Almedalen. Lars Zetterberg and Filip Johnsson represented the program.
- On October 4, **Ella Rebalski** defended her thesis. Göteborg.
- On the 24th of October, 2025, Joint Massiv+ and Mistra Carbon Exit hosted the workshop **Emission accounting** and climate leadership. Göteborg
- On the 18th of November, the program hosted the seminar **Levelling up the Climate Transition in the Built Environment**. The seminar summarised eight years of research on how to reduce GHG emissions in the building and infrastructure construc-tion supply chain. The seminar also discussed lessons learned and what are the next steps. Presentations and the results from the seminar's Menti surveys here.

Our webinars:
Our webbinars (digital seminars) have continued in 2024 and have been a simple and effective way to share results within the consortium, both from our researchers and from our partners in industry and authorities. The following seven webbinars have been organised:

- **Towards EU climate neutrality: progress, policy gaps, and opportunities** – Lars J Nilsson (Lund University) 07 March 2024.
- **Bygg- och anläggningssektorns uppgraderade färdplan** – Emma Bonnevier (Byggföretagen) 02 May 2024.
- **Achieving net-zero carbon emissions in construction supply chains - Analysis of pathways towards decarbonization of buildings and transport infrastructure** – Ida Karlsson (Chalmers University of Technology) 03 June 2024.
- **Framväxten av nya fossilfria värdekedjor från malm till fordon** – styrmedel som möjliggör omställningen – Lars Zetterberg m.fl. (IVL/Luleå tekniska universitet) 08 Oktober 2024.
- **Stöd för och attityder till klimatpolitik i Sverige** – Naghmeh Nasiritousi (Linköpings universitet och Utrikespolitiska institutet), Sofia Axelsson (Göteborgs Universitet) 3 December 2024.
- **Industrial Policies, Green Reindustrialization and Its Discontent** – Viktor Skyrman (European University Institute) 14 May 2025.

8. The Programme in Detail

Background

This research programme was formulated in response to Mistra's research call "Transformative changes in society to achieve challenging climate goals". In response to this a consortium was formed during spring 2016 and a proposal was written by lead authors (Lars Zetterberg, IVL, together with Filip Johnsson and Daniel Johansson at Chalmers). The proposal was approved by Mistra on December 9, 2016 (Mistra protocol DIA 2016/12).
In 2020, Mistra invited the consortium to submit a proposal for a second phase of the programme, covering four years. This proposal was evaluated by an external evaluation committee who also evaluated the first four years of the programme. In December 2020, the proposal was approved by Mistra. On April 1st, 2021 the second phase of Mistra Carbon Exit started.

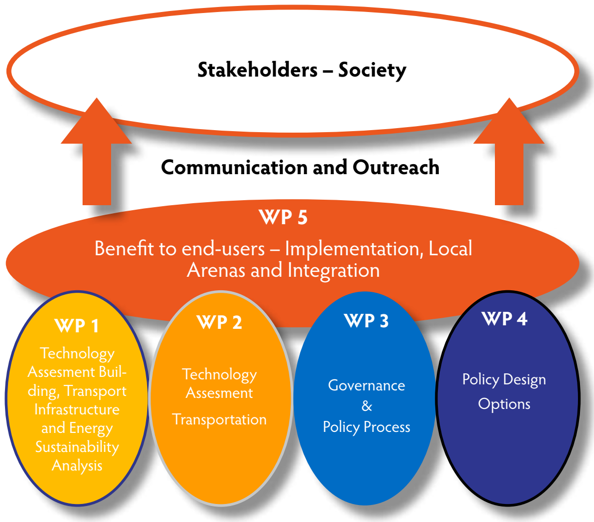
The Scope of the Programme

The Mistra Carbon Exit programme (Phase 2) was a multidisciplinary research programme, it addressed and identified the technical, economic and political challenges for Sweden to reach the target of net zero greenhouse gas emissions by 2045. This target will require transformative pathways with respect to virtually all industrial processes and their associated products and services. Mistra Carbon Exit took a novel approach to address this problem by focusing on opportunities and barriers for mitigating carbon emissions along the industry supply chains from the input of raw materials, over primary and secondary activities, to final products and services demanded by the end user. The programme covered the supply chains in buildings, transportation infrastructure and transportation. These selected supply chains allow us to capture at least 75 percent of Sweden's CO_2 emissions. The program has had a substantial component of implementation, working closely to companies, authorities and non-governmental organizations.

Programme Participants

The Mistra Carbon Exit consortium includes a broad representation of researchers and actors 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 (programme host), Resources for the Future (RFF), The German Institute for Economic Research (DIW), and the Centre for European Policy Studies (CEPS), and more than 20 companies, authorities and nongovernmental organizations. See page 72.

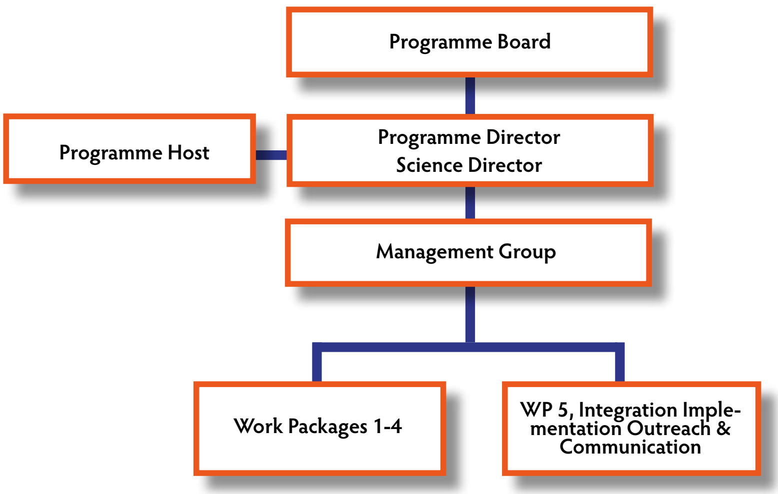
Programme Structure and Organisation



The work was divided into four work packages, an implementation package (WP5) and a communication package. The academic work packages investigated and defined transformative pathways, technology assessments along supply chains, changing market institutions and behaviors towards Swedish leadership, policies and governance.

The programme board has been responsible for the programme and was appointed by the *programme host* in consultation with Mistra. IVL Swedish Environmental Research Institute has acted as the programme host. The host's responsibilities included administrating the funds awarded, signing contracts with consortium partners, and preparing and submitting administrative and communicative reports to Mistra. The *programme director* has been responsible for the coordination of the programme and for ensuring that the programme would fulfill its objectives in terms of overall performance and deliverables, including programme administration and relations with the programme board and Mistra. The programme director was also responsible for the outreach activities. *The scientific director* has been responsible for monitoring and enhancing the scientific progress of the programme, including organizing meetings and activities for scientific exchange and integration.

The management group has consisted of the programme director, the scientific leader, the work package leaders (from Chalmers, GU and IVL), the communications officer, and one representative each from KTH, LiU and GMV. The responsibilities of the management group have been to inform about the progress made in the work packages, to prepare the reports to be submitted to Mistra, to take initiatives for improving exchanges between researchers and integration across the programme, and to plan outreach activities, such as seminars, conferences and publications. The management group members also provided the programme director with input for the board meetings.

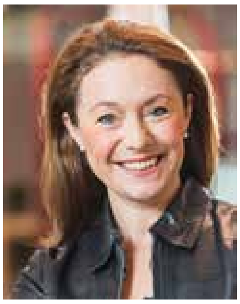


Programme Board

Peter Nygårds (Chair)
Industrial Advisor,
H2 Green Steel

Birgitta Resvik,
Senior Advisor Climate
and Energy,
Lumo Advice

Paula Hallonsten,
Head of Shipping and
Industry,
The Swedish Gas
Association



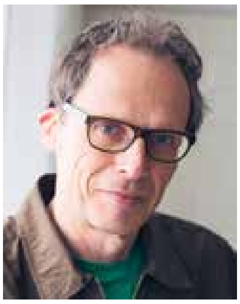
Anna Denell,
Head of Sustainability,
Vasakronan

Kristina Sundin Jonsson,
Municipal Director,
Skellefteå Municipality

Stefan Nyström,
Head of Climate Unit,
Swedish Environmental
Agency

Management Group

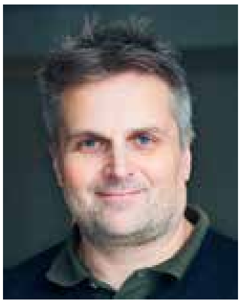
Lars Zetterberg, IVL Swedish Environmental Research Institute



Filip Johnsson, Chalmers University of Technology

Daniel Johansson, Chalmers University of Technology

Åsa Löfgren, University of Gothenburg



Magnus Hennlock, IVL Swedish Environmental Research Institute

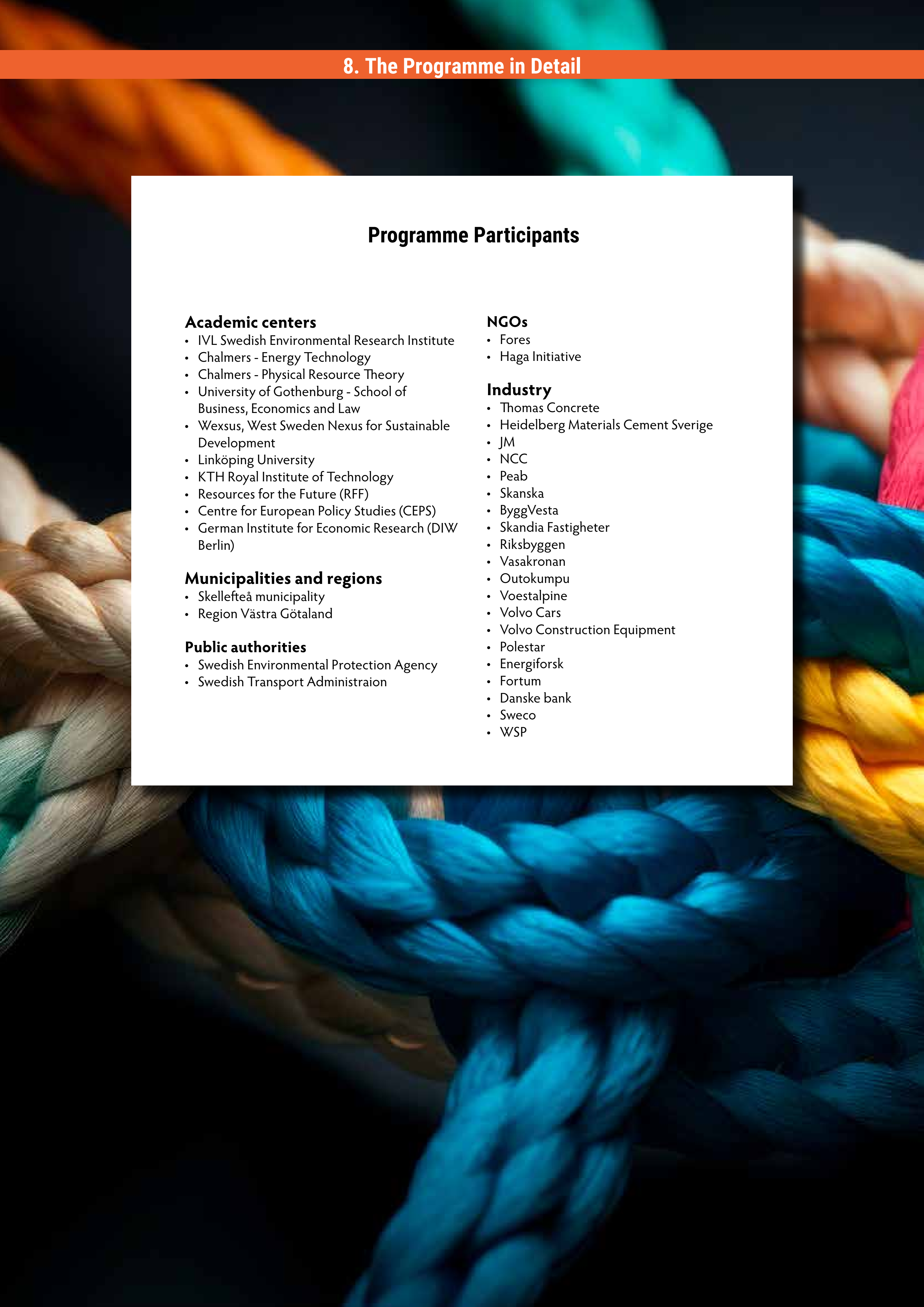
Johan Rootzén, IVL Swedish Environmental Research Institute

Anders Ahlbäck, Wexsus, West Sweden Nexus for Sustainable Development

Victoria Wibeck, Linköping University

Anna Kadefors, KTH Royal Institute of Technology

Maria Ljung, IVL Swedish Environmental Research Institute



Programme Participants

Academic centers
- IVL Swedish Environmental Research Institute
- Chalmers - Energy Technology
- Chalmers - Physical Resource Theory
- University of Gothenburg - School of Business, Economics and Law
- Wexsus, West Sweden Nexus for Sustainable Development
- Linköping University
- KTH Royal Institute of Technology
- Resources for the Future (RFF)
- Centre for European Policy Studies (CEPS)
- German Institute for Economic Research (DIW Berlin)

Municipalities and regions
- Skellefteå municipality
- Region Västra Götaland

Public authorities
- Swedish Environmental Protection Agency
- Swedish Transport Administraion

NGOs
- Fores
- Haga Initiative

Industry
- Thomas Concrete
- Heidelberg Materials Cement Sverige
- JM
- NCC
- Peab
- Skanska
- ByggVesta
- Skandia Fastigheter
- Riksbyggen
- Vasakronan
- Outokumpu
- Voestalpine
- Volvo Cars
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