Annual Report | 2022

MISTRA
CARBON
EXIT

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Contents

1. Introduction

2022 – A year of war and high energy prices, but also progress in green tech and climate policy

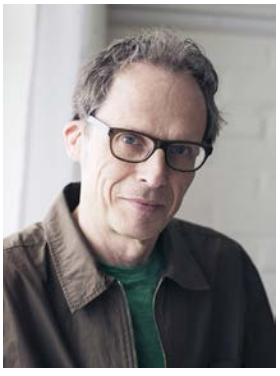
The year 2022 will be remembered as the year when Russia invaded Ukraine. The appalling invasion has altered the European security landscape dramatically. This has ramifications for the European economy, as well as for the transformation of European economies to climate neutrality. The invasion has led to an energy crisis in Europe with increased costs for fuel and electricity. Europe's response should be to accelerate the roll-out of renewables in order to cut free from Russian energy dependency. In addition, energy savings and efficiency measures are also important and the high energy prices have already resulted in decreased energy use, although the capacity to act is limited in the short term. The war has also put the light on Europe's dependency on metals critical for the green transition. Mistra Carbon Exit has examined the immediate and longer-term impacts from the war in Ukraine on the green transition in Sweden and in the EU, focusing on the energy systems, the supply of critical minerals, and policy implications. This is presented on page 6 of this annual report.

Indeed, the EU is accelerating the transition to a low carbon economy. In 2022 the EU institutions decided on a new climate package with the intention to increase ambition, sharpen the policy instruments and accelerate the transition. The original proposal includes a more ambitious emissions trading system (ETS), the introduction of a new EU emission trading scheme (EU ETS) for transports and heating (ETS2) and the introduction of a carbon border adjustment mechanism (CBAM). Yet, in the light of the energy crisis, EU policy makers were tempted to relax the level of ambition in order to not increase the burden on households and industry. But the EU institutions resisted this temptation and instead delivered an ambitious climate package. As we entered 2023, the price of emissions allowances reached over 100 EUR for the first time and future prices (2029) reached over 120 EUR. This sends a strong signal to industry to transform.

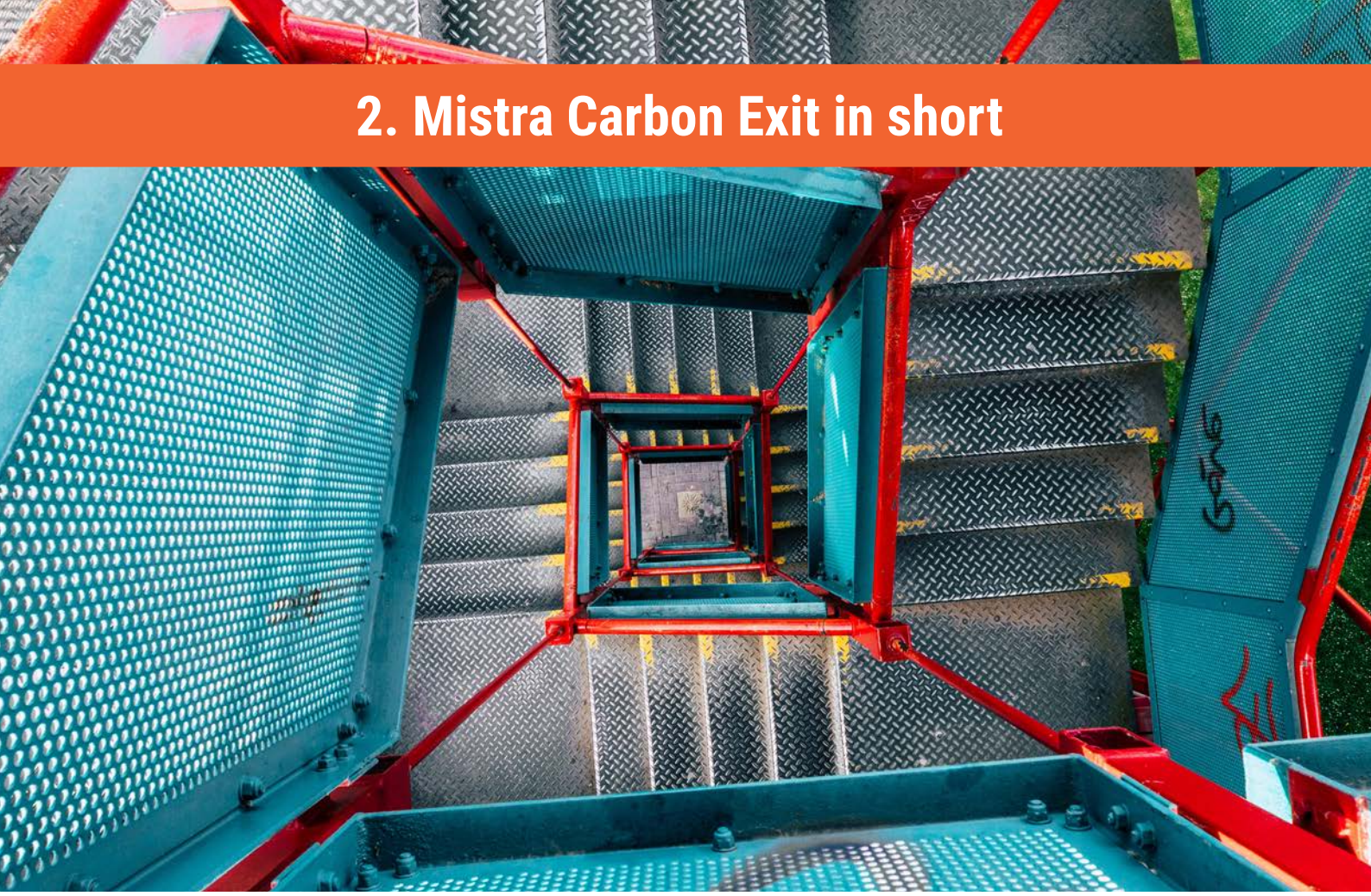
Many industries in Sweden are dedicated to de-carbonize and some have already started this transition. But they need firm support from the Government with ambitious policies that are sustained over time. Since the new Swedish government aims at rolling back some climate policies, most notably the reduction duty in vehicle fuels and possibly also support for wind power, EU's climate policy will be extremely important in supporting the green transition. Being forerunners in the climate transition should be a competitive advantage for EU countries and its companies, especially since the emission allowance prices are likely to increase further, and the free allocation will be phased out and replaced by CBAM.
The MCE consortium will follow the development with great interest, and we feel that our research is timelier than ever.

Finally, we of course hope that 2023 will see peace in Ukraine!

Lars Zetterberg and Filip Johnsson



2. Mistra Carbon Exit in short



About Mistra Carbon Exit

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

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

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

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

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

The Mistra Carbon Exit consortium includes a broad representation of researchers and actors 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 non-governmental organizations.

Impacts of the Russian invasion of Ukraine on the planned green transformation in Europe

LARS ZETTERBERG, FILIP JOHNSSON, MILAN ELKERBOUT

The Russian invasion of Ukraine in 2022 has altered dramatically the European security landscape. This will have ramifications for the European economy, as well as for the transformation of European economies to climate neutrality.

Politicians and policymakers across the EU, and at the national level in Sweden, have expressed that this new situation should be used to accelerate the transition of energy systems to comply with climate targets and to minimize dependency on fossil fuels in general, and on fossil fuels from Russia in particular. Yet, there are indications that decisions made during 2022 have not necessarily been in line with this ambition. A possible explanation is that Europe's dependency of fossil fuels from Russia is difficult to eliminate in the short term.

In a policy brief, we have examined the immediate and longer-term impacts on the green transition in Sweden and in the EU, focusing on the energy systems, the supply of critical minerals, and policy implications for the Green Deal and Fit-for-55 package. From our discussions on these issues, we draw the following conclusions:

Few technical measures can have a meaningful impact on EU fossil fuel use in the short term. Instead, the most important measure that can be taken, in our opinion, is to ensure that climate policies are not weakened, but instead strengthened so that the energy transition can be accelerated, such that the measures that can be expected to have effects in the medium and long terms will actually be implemented.

Only a few options constitute a short-term response to Putin's war with respect to decreasing dependency on Russian fossil fuels. These include a reduction of the indoor temperature, acceleration of the deployment of renewable electricity in the form of wind and solar power, and increased use of biofuels (provided in the form of drop-in fuels). Even so, it will most likely take at least a few years before these options have a significant effect. Clearly, the transition to renewables should, when possible, be prioritized over resourcing fossil fuels from suppliers other than Russia.

The green transition is dependent upon the availability of certain critical minerals, such as nickel, platinum, silver, cobalt, rare earth metals, lithium, neodymium, dysprosium, gallium, indium, tellurium, and silicon. There are concerns that the war will disrupt the supply chains for these metals and retard the green transition.

However, although Russia is one of several important producers of critical metals needed for the green transition, it does not dominate the world supply of any of these metals. Although Russia is not a dominant producer of these metals, the suppliers of many critical raw materials are highly concentrated in a few countries. For example, South Africa provides 72% of the world production of platinum, Congo is responsible for 71% of cobalt, China produces 60% of the rare earth elements, Australia produces 55% of lithium and Indonesia 37% of nickel. Therefore, in the longer term, Europe should increase efforts to secure its supply by diversifying the countries of origin; moving the processing of minerals to Europe; considering opening new mines in Europe; increasing recycling; and improving the metal efficiency in products. The potential for substitution is large and can be manifested in different ways, for instance by changing from one critical metal to another; substituting one technology for another (e.g., from batteries to hydrogen when possible); and switching from one service to another (e.g., from electric vehicles to public transportation).

The war in Ukraine provides further impetus to efforts to accelerate the energy transition and implement the EU climate package (Green Deal), especially in the mid-to-long term. In December 2022, the EU institutions agreed on the main elements of the package, including a reformed EU ETS, the implementation of the Carbon Border Adjustment Mechanism (CBAM) and the implementation for a second emissions trading system targeting transportation and heating, the "ETS2".

In the light of the energy crisis and the war, EU policy makers were tempted to relax the level of ambition in order to not increase the burden on households and industry. But the EU institutions resisted this temptation and instead delivered an ambitious climate package.

3. Examples from our research

Car sharing has potential to reduce carbon emissions

DANIEL JOHANSSON AND JOHANNES MORFELDT

Today, a car is generally only used a few percent of the time during the day. The potential for car sharing to reduce the environmental impact of passenger transport can therefore be substantial. However, the impact is hard to quantify because a shared car is used more and therefore may need to be replaced more often. Further, as more and more cars are electric, a greater proportion of emissions originates from the production of new cars rather than in the use phase.

In a country like Sweden, which has relatively clean electricity, most lifecycle emissions of an electric vehicle occur in the production phase, which largely take place outside Sweden. With this in mind, it is interesting to analyze how car sharing affects the number of cars in society, their lifetimes, and how often they need to be replaced. These factors would have large impacts on the production-related emissions of cars.

We have analyzed 450,000 cars that were scrapped during 2014-2018 in Sweden. We want to better understand the relationship between the vehicles' lifetimes and their driving intensity (so-called annual mileage). As expected, the more a car is driven per year, the shorter its lifespan.

Impacts of self-driving cars

We generalized the relationship that we found between vehicles' lifetimes and their annual driving intensity. A prospective life cycle analysis framework was then used to estimate the carbon footprint of future car-sharing systems under different future scenarios. The results indicate that the lifecycle CO_2 emissions in a system with shared cars are lower than those in a system with individually owned cars. Still, shared cars are used more intensely and replaced more often.

Cars will likely need to be self-driving (so-called autonomous vehicles) for car-sharing systems to take off at a larger scale. The technological and regulatory developments for self-driving cars have been slower than some analysts argued five to ten years ago. Still, the progress has been steady. More and more of the features necessary for autonomy are gradually included in new cars.

Our research points to that the environmental impacts of self-driving cars depend strongly on how they are adopted in society.

Reducing CO_2 emissions

If they primarily replace conventional cars owned by individuals – in which those individuals may sleep or work while traveling – the total car use may significantly increase. This would likely lead to large CO_2 emissions and resource use in the manufacturing of the cars and their batteries as the intensely used cars need replacements.

In an alternate future, multiple people share one that can drive itself, pick up passengers like a cab without a driver, and take care of its own charging. Such a scenario is more resource-efficient and can contribute to reducing CO_2 emissions compared with a system of individually owned cars.

Our analysis can provide input for better quantifying the environmental impacts of these different development pathways.

Literature

Morfeldt, J., Johansson, D.J.A. Impacts of shared mobility on vehicle lifetimes and on the carbon footprint of electric vehicles. Nat Commun 13, 6400 (2022).

The way forward – How to reduce embodied emission of Swedish roads and railways?

AARON QIYU LIU, JOHAN ROOTZÉN AND FILIP JOHNSON

The Swedish Transport Administration (STA) has pledged for all its infrastructures to be carbon neutral by 2040. This ambitious goal could be achieved if demand side strategies such as procurement policies can speed up the deployment of technologies like hydrogen direct reduction and carbon capture and storage (CCS) by creating a lead market for key materials like steel and cement.

In this study conducted within Phase 2 of Mistra Carbon Exit, we investigated the potential material flows and embodied emissions of Swedish roads and railways from 2020 to 2040 and how to reduce these emissions. Roads and railways are relatively long-live structures with approximately 20 to 30 years of lifetime and each road or railway needs to be maintained regularly for performance and safety reasons. The construction and maintenance require large quantities of asphalt, steel, concrete and gravel. The production processes of these materials are emission intensive, and these embodied emissions are a key challenge for the STA to reach its goal.

Material stock and flow analysis

The model used to estimate future material flows and embodied emissions has three parts. The first part is a material stock model that calculates the quantity of basic materials currently used in Swedish roads and railways. The second part is a Material-flow analysis (MFA) model that estimates the material flows associated with new construction and maintenance of the existing stock into the future using different scenarios. In the final part, which builds on earlier work in Mistra Carbon Exit, embodied emissions associated with the materials used for new construction and maintenance is estimated based on different assumptions on the technological development in the primary production of construction materials.

The basic materials considered in this study are asphalt, steel, concrete and gravels. The time horizon of the model is from 1950 to 2040. The starting year 1950 is chosen to capture historical maintenance dynamics, but the estimates of embodied emissions are reported from 2020. The future material flows are estimated using scenarios describing different rates of new construction rates and assuming different development pathways in the primary production of construction materials.

The results indicate that maintenance activities are responsible for around 90% of annual embodied emissions of roads and railways in Sweden. These results indicate that even if the rate of new construction slows down significantly in the future, deep decarbonization of the material production process is still required to reach the 2040 goal. For material flows, the results suggest that around 9 million tons of asphalt is needed to maintain and construct roads each year.

The model indicates that even in the scenario with the most ambitious emission reductions, only an 83% reduction of annual embodied emissions can be achieved compared to 2020. This is mainly due to the assumption that carbon neutral steel and asphalt will not be available in the construction sector until 2045.

Demand-side policy as the way forward?

Hydrogen-reduced steel has developed substantially since the first phase of Mistra Carbon Exit. The HYBRIT consortium has already delivered some high-quality fossil-free steel to customers like Volvo, but there are still uncertainty

surrounding prices and availability of these steel for the purpose of constructing railings and railway tracks.

For asphalts, there are some emerging technologies that promises to delivered carbon neutral products. For example, bio-based asphalts are being developed and tested using lignin from pulp mills. There is however no clear frontrunner as in the steel case. It is thus important to develop the market through a technology-neutral way.

Since the STA is a major purchaser of asphalt in Sweden, demand-side strategies like public procurement requirements on emission intensity of materials used in construction can be a good way to foster the market to develop carbon neutral asphalt. This can also facilitate the steel and concrete market, but to a smaller extent.

Effective implementation of demand-side policies like procurement requirements is required to reach carbon neutral by 2040. This will hopefully create a lead market for more carbon neutral products to emerge on the market for the whole construction sector in Sweden.

Literature

Q Liu, J Rootzén, F Johnson (submitted for journal publication). "The way forward – reducing embodied emissions of Swedish roads and railways"

4. Our PhD students

Our PhD candidates are key persons in Mistra Carbon Exit, developing new knowledge and competence for society. We are very impressed by our PhD candidates who all have contributed to new knowledge and published this in high ranked journals. Because of the focus on value chain analysis, they have produced new and valuable knowledge that can also be used as basis for decisions in industry and governmental organizations.

Two of our PhD candidates – Alla Toktarova and Ella Rebalski – are near completion of their PhDs. First out is Alla who will defend her PhD on May 8 and Ella will defend hers later this year.

In all, we are very proud of our PhDs and we think they are very good representatives for understanding the green transition of our energy and material systems!

Ella Rebalski joined Mistra Carbon Exit as a PhD student in 2018. She studies how connected and automated vehicles (CAVs) will affect carbon dioxide emissions in Sweden. Originally from Vancouver, Canada, Ella completed a master's degree in environmental management and policy at Lund University before moving to Gothenburg. Prior to joining Mistra Carbon Exit, she was a researcher at RISE, working with electromobility, CAV regulation, and mobility as a service. 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 two studies, one that uses an economic, quantitative method to model increased travel demand, and one will examine 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.

Alla Toktarova is part of Mistra Carbon Exit as a PhD student from February 2018, her research focus is on the electrification of energy-intensive industries and its impacts. The electricity generation sector is generally seen as having the largest potential for low-cost emission reductions among the energy sectors, as there exists a number of low-carbon electricity generation technologies, such as electricity generation based on Renewable Energy Sources (RES) in the form of wind, solar, hydropower and biomass, as well as the option to produce electricity from nuclear power. The findings of the case studies in Alla's work show that the electrification of the energy-intensive basic materials industry in the EU can increase the electricity demand by around 50%. Thus, there is an obvious need to accelerate the deployment of electricity generation technologies if to achieve the EU targets on climate neutrality by Year 2050.

One of the valuable aspects of being in the programme is that communication with other stakeholders involved in the programme allows for assessing solutions for reducing the emissions to net-zero emissions from different angles and filling knowledge gaps in a time efficient way.

Cecilia Hult joined Mistra Carbon Exit as an industrial PhD student as the 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 will focus on the interaction between technology and behaviour in the transport sector.

"After working with transport emission for years at IVL, I'm excited to look at transport from a systems perspective", says Cecilia. The latest report from IPCC Working group III tells us that demand-side options together with electric vehicles can reduce transport emissions in developed countries. I believe it is very important to study how technical innovations such as electric vehicles will impact the transport system and how we travel.

During her time at IVL, she has worked with transport air pollutants and mobility issues, and there are many potential co-benefits with the decarbonization of transport and other sustainable development goals. "Finally, it's great to be back at my alma mater".

Cecilia has a master's degree in Engineering Physics and Complex Adaptive Systems.

Aaron 'Qiyu' Liu 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 will focus on quantifying the embodied emissions in the Swedish built environment using a combination of Material-flow analysis and scenario-based modeling. This research aims to combine previous work done by fellow Mistra Carbon Exit PhD student Ida Karlsson with a national scale bottom-up model to simulate how the Swedish construction sector could aim to achieve net zero embodied emissions by the year 2045.

Aaron has finished his first analysis on embodied emissions of the transport infrastructures and will now continue on his work with a focus on buildings. Aaron is a strong believer in utilization of academic research, especially in sustainability related areas. Mistra Carbon Exit phase 2 offers a unique opportunity to work with stakeholders and government agencies to make a real impact on society.

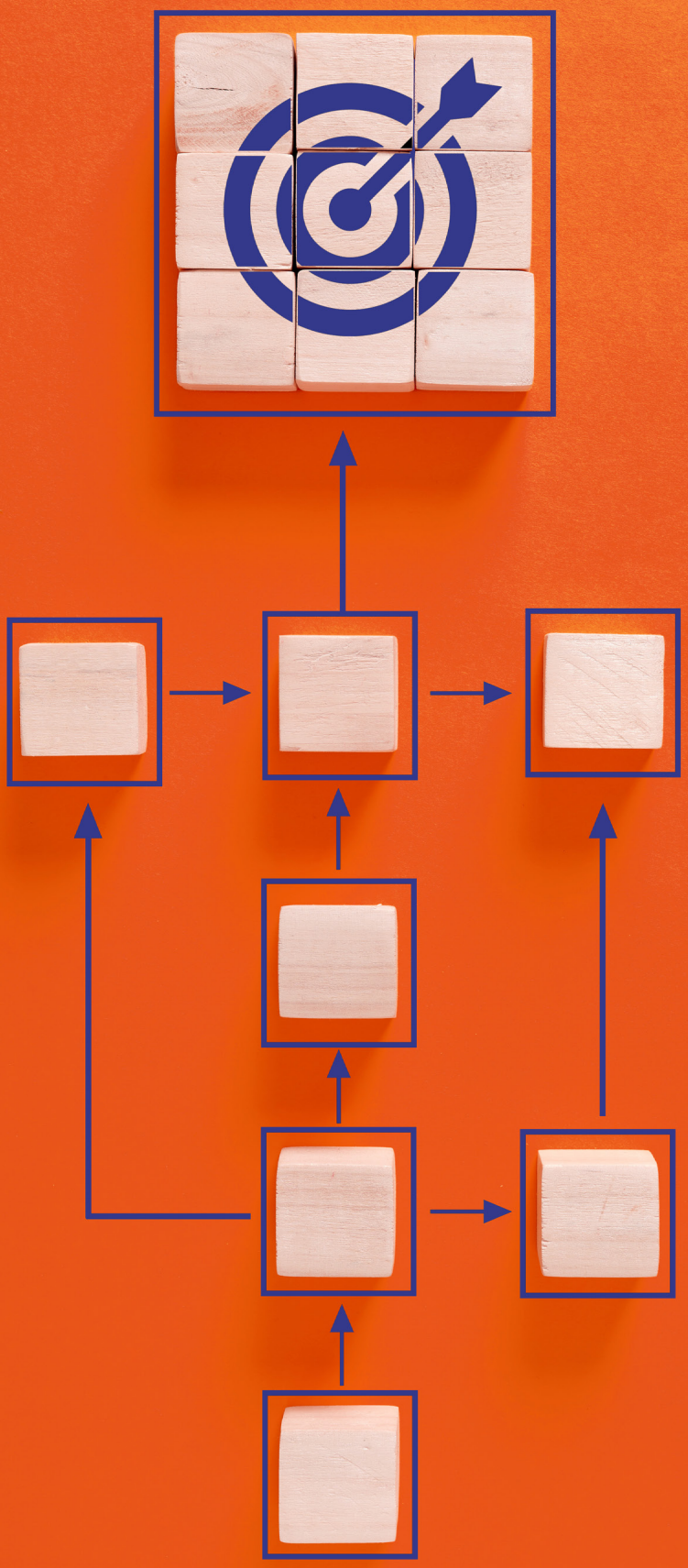
Ida Karlsson is currently working predominantly on the link between costs and climate optimization in building projects.

For this study, data is gathered on several building cases at different project stages in collaboration with various actors along the value chain, from architects and consultants to material producers, contractors and project developers.

Based on previous work within Mistra Carbon Exit, a framework has been developed for analysis of the supply chain and end-user abatement cost implications – taking into account costs linked to material substitution and material efficiency measures. It is my hope that this will provide evidence-based motivation for relevant actors to accelerate cooperation towards greater implementation of these types of abatement measures.

It is indeed the partnerships between academia, industry partners and governmental organization that I find so encouraging about being part of Mistra Carbon Exit. We now see clear examples of how partnerships are moving the entire playing field forward. While the climate transition is still moving too slowly, I see the momentum growing, ambition turning into action on the ground and targets being strengthened or moved forward.

5. Key deliverables 2022 – some highlights



Selected deliverables at programme level:

- **Programme conference**. Our main event was the program conference in Nynäshamn on 1-2 June. The conference consisted of presentations from all almost researchers in the program along with presentations from several of our partners from industry and authorities.

- **Ukraine report.** The report "Impacts of the Russian invasion of Ukraine on the planned green transformation in Europe" has been published.

- **PhD workshops.** In 2022, we started to have PhD workshops, in order for our PhD's to share experiences with each other and be informed about what is happening in the programme. Our plan is to have two workshops per year including all PhD student and representatives from the management group.

- **Communications strategy**. In 2022, we developed a new communications strategy in order to communicate our results more effectively.

Selected deliverables at work package level:

WP 1. Technology Assessment, Buildings, Transport infrastructure & Energy

- ***Task 1.2. Material use in the low-carbon transition***
  Completion of Material Flow; Analysis (MFA) in the construction sector (roads and railways.
- ***Task 1.3. Sectoral collaboration - system and sector perspectives.***
  Completed techno-economic modelling studies on the interaction between electricity systems and steel production and on thermochemical recycling of plastics.
- ***Task 1.4. Implementation - buildings and transport infrastructure.***
  Meetings in the Roadmap of the Building and Construction industry, a continuous process throughout the programme. Participation in workshops organised by InfraSweden and WSP.
- ***Task 1.6. Sectoral collaboration -the end-user perspective***
  The flexibility in electricity consumption on the end-use side has been implemented in the techno-economic models used in the programme.
- ***Task 1.7 Supply chain-specific sustainability indicators for stakeholder engagement and transparency***
  Workshop and meetings with Polestar Sustainability, Volvo Cars, and Volvo Construction Equipment, using the SDG Impact Assessment. Concept development: Collective Action for supply chains.

WP 2. Technology assessment, transportation

Several papers and reports have been published on subjects such as:

- Prospects for road, ocean, and air transport.
- Comparative assessment of the prospects for different biofuels and electrofuels from forest residues - strategies for drop-in and single-molecule fuels are both interesting options
- Impacts of shared mobility on vehicle lifetimes and the carbon footprint of electric vehicles.
- If electric cars are good for reducing emissions, they could be even better with electric roads.
- Improving future travel demand projections: a pathway with an open science interdisciplinary approach
- Too much pressure? Driving and restraining forces and pressures relating to the state of connected and autonomous vehicles in cities.

Modeling tools

- MetMob - a model for simulating mobility patterns and modal choice between car, public transport, biking and walking in the Swedish metropolitan areas of Stockholm, Gothenburg and Malmö.
- Semi-empirical vehicle lifetime-intensity model for estimating the lifetime of vehicles used more intensely in future mobility systems with high degrees of car sharing.
- Scenario Model for Consumption-based Emissions, for simulating greenhouse gas emissions related to consumption of products and services (Swedish case study)

WP 3. Governance and policy processes

- ***Task 3.1. Determinants of climate leadership.***
  Detailed research plan
- ***Task 3.2. Public acceptance of road tax reforms for electrification of the Swedish vehicle fleet***.
  Pilot study implemented.
- ***Task 3.3. The value of being a frontrunner***
  Manuscript submitted to peer-reviewed journal.
- ***Task 3.6. Governance, capabilities and incentives to enhance climate-friendly public procurement in the construction sector.***
  A guideline for how construction clients can drive innovation more systematically has been developed.
- ***Task 3.8. Quantitative assessment of the effect of public procurement.***
  Paper on economic assessment of policy needs for accelerating green public procurement adoption is still in progress. The task on the GPP handbook chapter is completed and has been published.
- ***Task 3.11 The financial sector and the transition to a net-zero economy.***
  Finalization of annotated data set on bank reports, training of AI model and preparation of manuscripts.

WP 4. Policy design options

- ***Task 4.1. Price-based and informative instruments for transformative changes.***
  Experimental design of experiment no 1 with industrial managers developed. Managers have been recruited.
- ***Task 4.2. Carbon pricing and coordination of investments***
  Progress has been made on a theoretical model that has been drafted. An extended abstract has been prepared for submission to conferences during 2023.
- ***Task 4.3. Flexible performance standards.***
  Progress in developing a model linking carbon markets with different emissions abatement opportunities.
- ***Task 4.4. Designing the EU ETS to accommodate companion policies.***
  Investigating what policies are appropriate for transformative changes and deep decarbonisation, analysing the role of emissions trading for transformative changes in the renewable energy and industry sector.
- ***Task 4.6. Policy packages and risk in hard-to-abate sectors.***
  Continued analysis of the so-called "coordination" barrier": Interviews with some key actors/industries within the programme have been conducted.
- ***Task 4.8 Designing policies for negative emissions.***
  In 2022, we advised the Energy Agency on designing a Swedish financial support system for BECCS (through reversed auctions), including ownership of credits, the size of auctioned lots and how to deal with the "winner's curse dilemma".
- ***Task 4.9 Understanding Electric Vehicle adoption – the cases of local and national policies.***
  Econometric modeling with 2021 adoption data finished.
- ***Task 4.10 Implementation – parking as a policy instrument in VGR.***
  Parking policy surveys to all 49 municipalities in Region Västra Götaland have been performed

WP 5. Synthesis, implementation, and integration

- In a collaboration between WP1 and WP2 researchers from the programme have developed Consumption based GHG emission scenarios Basis for discussing Sweden's future climate policy, in general, and consumption-based climate targets, in particular.
- Researchers involved in Tasks 1.1-1.5 have been involved in the BETCRETE 2.0 project aimed at contributing to decarbonizing the cement and concrete value chain. The project involved F Johnsson, I Karlsson, S Uppenberg, J Rootzén (CTH, WSP, IVL) NCC, ByggVesta, WSP and several other partners (Lead by RISE)
- During 2022, L Zetterberg, Filip Johnsson, Möllersten have had several workshops with the Energy Agency with the purpose of developing a financial support system for BECCS in Sweden. These discussions have been advised by research in Task 4.8
- At the end of 2022, we started advising the Swedish Public inquiry of incentives about potential consequences for Swedish industry if Sweden fails to develop new electricity production.
- F. Johnsson and Aaron Qiyu Liu have had several meetings with the Swedish National Road Administration on the MCE analysis on embodied emissions in roads and railways. The work was also presented in a Nordic workshop arranged by the Nordic Road Administrations.
- Updated and continuous mapping of existing and potential new collaborations across work packages and tasks.
- Two Mistra Carbon Exit PhD workshops have been organized throughout the year. The whole group of five PhD students and senior researchers from WP4 (RFF and CEPS) have been involved in the workshop.

6. Key communication in 2022

Programme conference

The main event 2022 was the Programme Conference in June, the first physical meeting within the programme since the pandemic hit us in early 2020. The conference consisted of presentations from researchers and from several of our partners from industry and authorities.

Publications

The programme has produced 33 publications (peer-reviewed papers, policy briefs, working papers and other reports), most of which are specific to Mistra Carbon Exit, and some co-funded by Carbon Exit and other programmes. See Chapter 7 for List of pubications.

Communications strategy

In 2022, the programme developed a new communications strategy in order to communicate research results more effectively.

Media exposure

Mistra Carbon Exit and its scholars have been visible in the media with over 350 unique hits. We have also participated in a couple of podcasts.

Here are some examples:

- Billigt för konsumenterna att klimatanpassa industrin. Opinion piece, Dagens Nyheter, January.
- Podcast "Energistrategipodden", March, explaining what is needed for the green transition.
- Sverige kan bli en exportör av negativa utsläpp - med hjälp av en sund marknad. Ny Teknik, April.
- Med fler elbilar och ökad biodrivmedelsanvändning kan de klimatpolitiska målen nås i tid. Dagens infrastruktur, June.
- Trafikverket tar tag i utsläppen. Byggindustrin, June.
- Låt inte Rysslands krig öka klimatutsläppen. Opinion piece in over 35 newspapers, July – September.
- Klimatpolitikens mål är inte en fråga för vetenskapen. Opinion piece, Dagens Nyheter, September.
- Premiär för betong med växtaska. Byggvärlden, September.
- EU vill stötta energiomställningen med utsläppsrätter från framtiden. Dagens Industri, October.
- Podcast "Hela Kedjan", November. Podcast about how we can reach the goal of net zero emissions in civil engineering by working together across the "whole chain" and pushing each other to dare to change.
- Energiutmaningen. Agenda Special (SVT) November.

Outreach – events and webinars

Mistra Carbon Exit has organised or participated in a number of physical seminars and workshops throughout 2022. A few examples:

- Seminars organized by Mistra in Almedalen, July.
- "The US Inflation Reduction Act", seminar, September-.
- "The way forward for the building and infrastructure sector, workshop, October.
- "What are the impacts of the Russian invasion of Ukraine on the planned green transformation in Europe", seminar, October.
- "West Sweden's Industry's use of green carbon atoms", seminar, October.
- Two Mistra Carbon Exit PhD workshops have also been organized throughout the year.

In 2022, we produced the following webinars:

- Konsumtionsbaserade scenarier för Sverige , February.
- Project zero: The making of a zero-carbon footprint car , March.
- The where and the who of the fossil free transformation, May.
- Roadmaps for zero and low energy and carbon buildings worldwide, June.
- Impacts of the Russian invasion of Ukraine on the planned green transformation in Europe , October.
- Understanding the resistance to carbon taxes, November.
- Impacts of shared mobility on vehicle lifetimes and the carbon footprint of electric vehicles, December.

7. List of publications

Peer-reviewed articles 2022

WP 1. Technology assessments for buildings, transport infrastructure and energy

Toktarova, A., Walter, V., Göransson, L. et al (2022). Interaction between electrified steel production and the north European electricity system. Applied Energy, 310.

Toktarova, A., Göransson, L., Thunman, H. et al (2022). Thermochemical recycling of plastics – Modeling the implications for the electricity system. Journal of Cleaner Production, 374.

WP 2. Technology assessment, transportation

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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) is a multidisciplinary research program that addresses and identifies 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 takes 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 covers the supply chains buildings, transportation infrastructure and transportation. These selected supply chains allow us to capture at least 75 percent[1] of Sweden's CO_2 emissions. The program has 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: four universities: Chalmers, University of Gothenburg, Linköping University and the Royal Institute of Technology (KTH), three research institutes: IVL Swedish Environmental Research Institute, Resources for the Future (RFF) and The German Institute for Economic Research (DIW), The Centre for European Policy Studies (CEPS) and 23 companies, authorities and non-governmental organizations.

Our partners in Phase 2 include Volvo Cars, Volvo Construction equipment, Cementa, Thomas Betong, PEAB, JM, NCC, Skanska, Byggvesta AB, Skandiafastigheter, Riksbyggen, Vasakronan, Trafikverket (The Swedish Transport Administration), Outokumpu, Fortum Sverige, Energiforsk, Danske Bank, Västra Götalandsregionen (West Sweden Region), Hagainitiativet, FORES, Voestalpine,. Naturvårdsverket (The Swedish Environmental Protection Agency) and Sweco.

[1]This is an approximate value, based on the production-based emissions within the Swedish borders.

Programme participants

Akademic centers

IVL Svenska Miljöinstitutet
Chalmers - Energiteknik
Chalmers - Fysisk resursteori
Göteborgs universitet - Handelshögskolan
Göteborgs miljövetenskapliga centrum
Linköpings universitet
KTH
Resources for the Future (RFF)
Centre for European Policy Studies (CEPS)
German Institute for Economic Research (DIW Berlin)

Industry

Thomas Betong
Cementa
JM
NCC
Peab
Skanska
Byggvesta
Skandiafastigheter
Riksbyggen
Vasakronan
Outokumpu
Voestalpine
Volvo Cars
Volvo CE
Polestar
Energiforsk
Fortum
Danske bank
Sweco

Municipalities and regions

Skellefteå kommun
Västra Götalandsregionen

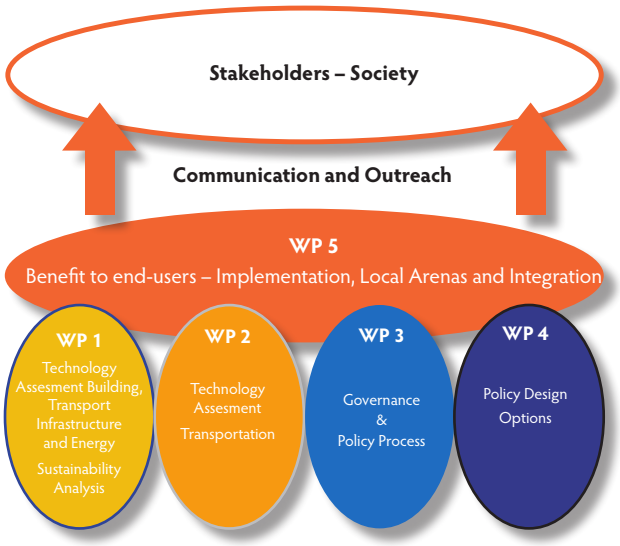
Public authorities

Naturvårdsverket
Trafikverket

NGOs

FORES
Hagainitiativet

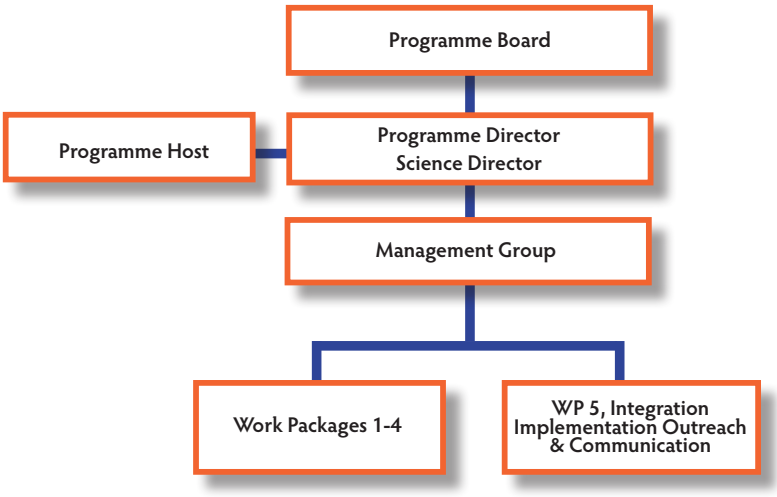
Programme structure and organization



The work is divided into four work packages plus an implementation package (WP5) and a communication package. The academic work packages investigate and define transformative pathways, technology assessments along supply chains, changing market institutions and behaviors towards Swedish Leadership, policies and governance, and integration and sustainability implications.

The Programme Board has overall responsibility for the programme and is appointed by the programme host (IVL) in consultation with Mistra. IVL Swedish Environmental Research Institute acts as the Programme Host. The responsibilities of the host include the administration of the funds awarded, the signing of contracts with all consortium partners, and the preparation and submission of administrative and communicative reports to Mistra. The Programme director is responsible for the coordination of the programme and for ensuring that the programme is fulfilling its objectives in terms of overall performance and deliverables, including programme administration and relations with the Programme Board and Mistra. The Programme Director is also responsible for the outreach activities. The Scientific Director is responsible for monitoring and enhancing the scientific progress of the programme, including organizing meetings and activities for scientific exchange and integration.

The Management Group consists of the Programme Director, the Scientific Leader, the Work Package Leaders (from Chalmers, GU and IVL), the Communications Officer, the Programme Assistant, and one representative each from KTH, LiU and GMV. The responsibilities of the Management Group is to inform about the progress made in the work packages, to prepare the administrative and communicative 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 provides 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,
Sameko Management

Erik Eriksson,
(to Dec 2022) Head of department for Analysis and Policy,
Formas

Paula Hallonsten,
(from Jan 2023) Head of department for Policy Analysis, Swedish Energy Agency

Anna Denell,
Head of Sustainability,
Vasakronan

Kristina Sundin Jonsson,
Municipal Director,
Skellefteå Municipality

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