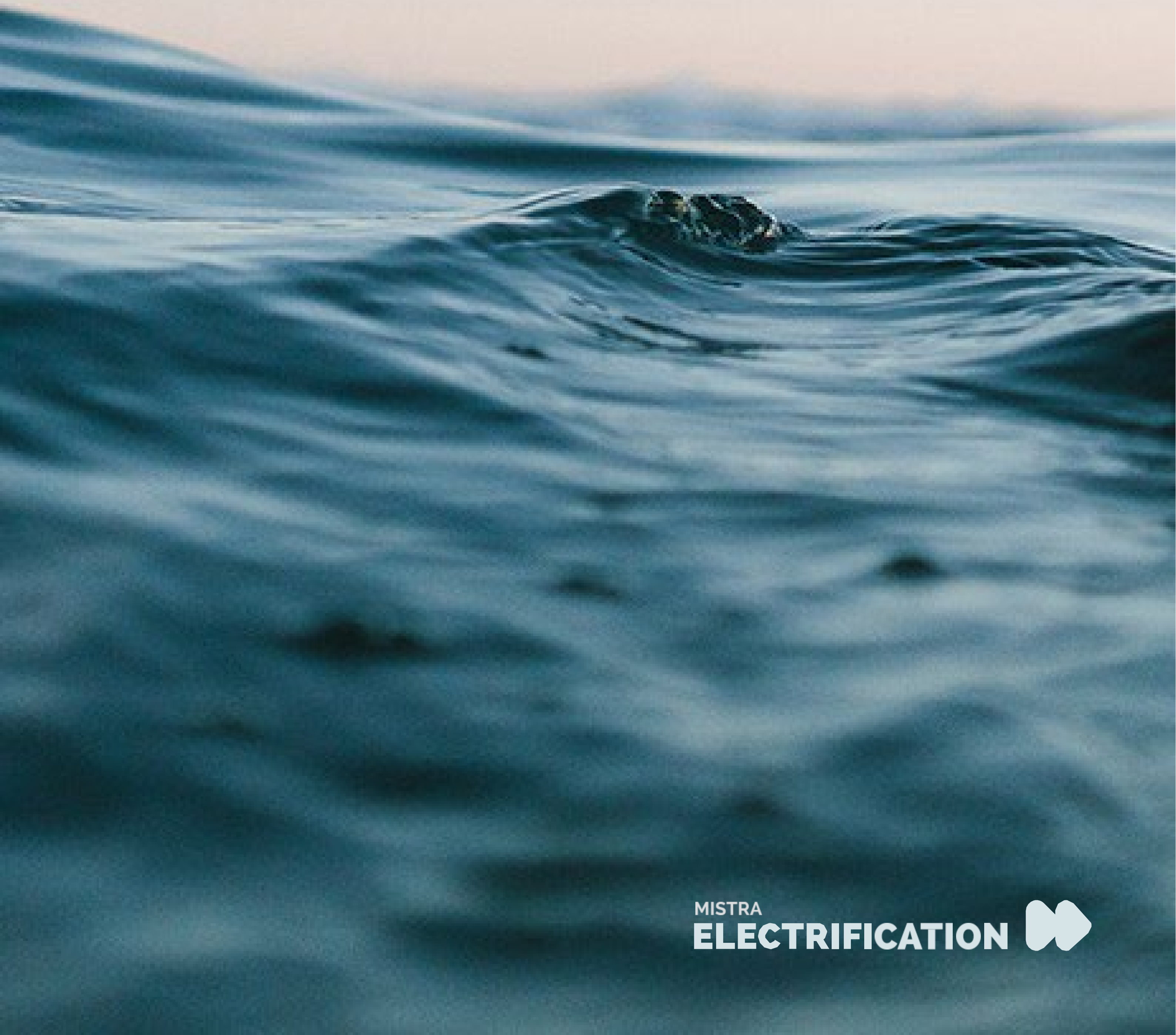
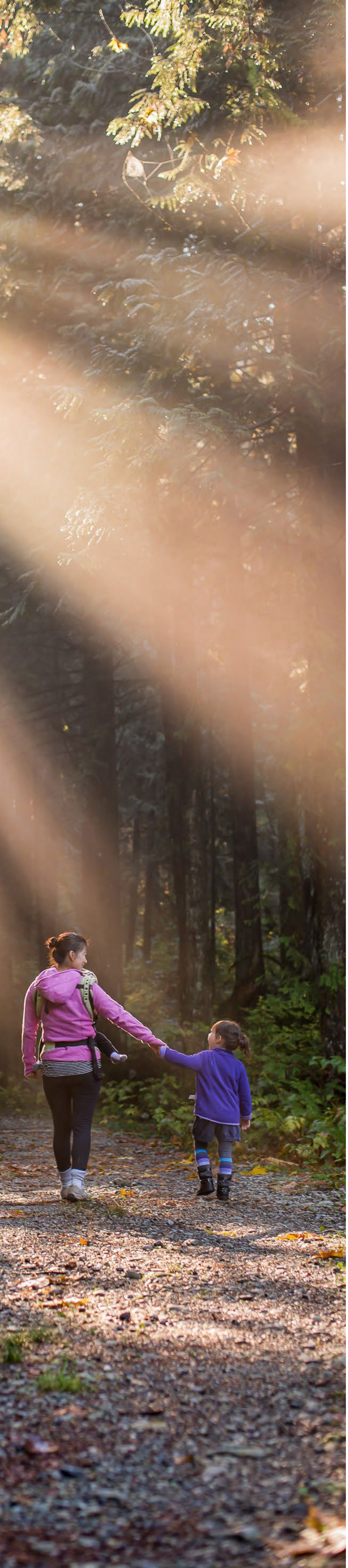
ANNUAL REPORT 2023

MISTRA ELECTRIFICATION
Programme Year Three



CONTENT

This is the third annual report from Mistra Electrification,
a reseach programme funded by
The Swedish Foundation for Strategic Environmental Research.



MISTRA
ELECTRIFICATION

The vision of the Mistra Electrification programme is to accelerate the transition to a sustainable and efficient energy system, through the creation of actionable knowledge for a feasible and fair transition.

PROGRAMME PARTNERS

Svenska kraftnät, Stockholm Exergi, Fortum, Nordion Energi, Göteborg Energi, Vattenfall, Hitachi Energy, Energiforsk, Kiona, Utilifeed, Chalmers, IVL Svenska Miljöinstitutet, Lunds universitet, University of Exeter, SLU

Filip Johnsson, Programme Director, and Karin Reuterskiöld, Chair of the programme board, at Vår Gård hotel outside Stockholm during the Mistra Electrification annual conference in October 2023.

Broad consensus on challenges facing the energy transition

While the researchers and stakeholders in Mistra Electrification agree on the main challenges regarding the energy transition, there is a need to initiate more research on the financial component of the energy transition. These are the two main take-away messages from the Mistra Electrification annual conference, which was held outside Stockholm in October, 2023.

More than 30 researchers and energy industry representatives met at the Vår Gård hotel outside Stockholm, during the Mistra Electrification annual conference, which took place on October 3–4, 2023. The conference had two themes: "How can we secure supply of electricity to large and small consumers" and "How can we secure efficient use of capacity and flexibility resources?"

Four of the most important conclusions from the conference are:

- The researchers and stakeholders in Mistra Electrification are in broad agreement regarding the main challenges for the energy transition and the measures that need to be taken to overcome the barriers to the transition. Thus, the main barrier is not whether we should strive for wind or nuclear power. Instead, the barriers are related to permitting processes, the gaining of social acceptance for siting new power plants, the supply availability of relevant competence, and the financial risks pertaining to investments in new power plants, especially for off-shore wind power and nuclear power.

- If Sweden wants to continue having a successful industrial sector, there is an urgent need to ramp up electricity generation to meet the goal of electrification as part of the energy transition for industry. In addition, in 2039, there will be no allocation of new emissions allowances in the EU Emissions Trading System (EU ETS). This means that industries that are covered by the EU ETS need to be fossil-free in 16 years from now, unless they can buy negative emissions or have saved, un-used allowances.

- Variable electricity generation from wind and solar power is expected to increase in northern Europe, which will affect the Swedish energy system. As variable electricity production increases, so will the need for flexible electricity consumption. There are several ways to achieve flexibility, including the un-tapped flexibility in already existing systems, such as smart control of heat pumps and charging of electric vehicles. Thus, several possibilities related to sector coupling could be used to reduce variability in the electricity system.

- Rapidly increasing electricity production and expanding the grid are crucial measures for Sweden to meet the expected demand for fossil-free electricity. A key element in ensuring increased electricity production is decreasing political polarisation in the energy policy debate. Reducing polarisation will lower the investment risk and stimulate new investments. Additional interdisciplinary research can help to speed up the transition, and this is part of the mission of Mistra Electrification, which covers a broad range of research fields.

Lively discussions during the annual conference.

Karin Reuterskiöld, who is Chair of the Mistra Electrification programme board, concluded the annual conference and pointed out the need for more research on financial issues related to the energy transition.

“Who is going to finance the transition, what kind of investors are willing to come up with the money needed?” asked Karin Reuterskiöld, adding that “There is money out there for the right projects, and I think it should be possible to address these questions in the programme and to derive what conditions are needed to make necessary investments come true.”

Filip Johnsson, who is Programme Director of Mistra Electrification, agreed that more research on the financial sector is important.

“We should do more research on market conditions and risks,” said Filip Johnsson. “I also see a need for more research on flexibility and sector coupling. It seems clear that there is much agreement on what the challenges and barriers are, despite that public debate sometimes is quite heated. I find the interdisciplinary approach of Mistra Electrification to be a strength, although I see a need for us researchers to improve communication.”

Jessica Jewell, Associate Professor, Chalmers University*, and Markus Wråke, CEO of Energiforsk.*

Mistra Electrification is about energy supply

Supporting vulnerable citizens and industries to manage the energy transition is essential. In particular, policy is needed to address the concerns of local communities that bear the costs of the transition. These were the messages presented by Jessica Jewell and Markus Wråke at an inter-parliamentary conference during Sweden's Presidency of the Council of the EU.

On April 23–24, the Committee on Industry and Trade of the Swedish Parliament hosted the inter-parliamentary conference *Challenges and opportunities for the EU's future energy supply*, as part of Sweden's Presidency of the Council of the EU. Mistra Electrification was represented by Jessica Jewell, Associate Professor at Chalmers, and Markus Wråke, CEO of Energiforsk.

In her speech, Jessica Jewell stated that the fastest deployment of power production in different countries is reflected in an increase of 1–2 percent per year, before the deployment rate slows down, according to research results. For Sweden, this is equivalent to 1.4–1.8 TWh per year.

"The reason deployment of new power production slows down is that there are opposing interests," said Jessica Jewell. "For instance, many local communities oppose the siting of wind power. So, increased power production benefits the whole Society, but the cost is borne locally."

To overcome barriers such as these, local communities need support. Research shows that compensation at the local level for the phasing out of coal increases support for the transition, and policy makers are beginning to experiment with similar schemes for renewables, according to Jessica Jewell.

"Therefore, we need political measures to remove local costs and concerns linked to the energy transition," said Jessica Jewell.

In his speech, Markus Wråke stated that the root cause of the energy crisis is fossil fuels.

"2022 saw eye-watering prices, strong policy leadership and an unprecedented rise in awareness around energy issues among the general public," said Markus Wråke. "Together, they made possible a drop in energy use. If we can save 10%–15% in just a few months, as we did this winter, imagine what we could achieve with a more structured strategy for energy efficiency".

His second message was that broad public support for the energy transition is critical. Thus, helping vulnerable citizens and industries manage the transition needs to be a key element.

"But high energy prices drive investments in energy efficiency and clean energy. In this sense European energy markets work as intended: high prices reflect supply and demand," said Markus Wråke.

On March 30 last year, Hitachi Energy closed a deal with TenneT, the Dutch-German transmission system operator, to supply multiple off-shore and on-shore HVDC converter stations that will connect off-shore wind farms to the Dutch and German grids.

Power electronics – science fiction or part of the energy transition?

Last year, Hitachi Energy signed the largest export order in Swedish history. The technology company is to deliver converters that will connect off-shore wind power to Germany and The Netherlands. How can power electronics play a role in the energy transition? Massimo Bongiorno, Professor at Chalmers University, claims that it already does.

The scene is the Mistra Electrification annual conference in 2022 and Massimo Bongiorno, Professor of Electric Power Engineering at Chalmers University addresses the delegates:

“Whatever you can do with mechanical systems, you can do with power electronics – and you can do it better.”

What did you mean by that?
“Ha-ha, I often say so,” said Massimo Bongiorno. “For example, a converter is an object that converts AC to DC power. But it can also release electrical energy to the grid. When it does, it acts in the same way as synchronous generators because it adds inertia to the grid. In that sense, power electronics can replace rotational mass.”

One of his goals is to find ways to maintain the overall stability of the power system. Historically, the power system was built on properties such as hydro power and later, nuclear power, where synchronous generators deliver the necessary inertia.

“But a system built on power electronics would be better and more effective, since it can add inertia, react faster when there are interferences, and enables optimisation. It is like having to brake a car if a child crosses the road: a driver needs to see the child, react, and then push the brake, while a self-driving car could stop faster,” said Massimo Bongiorno.

Today, wind power, solar power and batteries are all interfaced with power electronics to the grid. Since wind and solar power is increasing, we will see more of power electronics in the future, according to Massimo Bongiorno.

Hitachi Energy is one of the non-academic partners in Mistra Electrification. On March 30th last year, the technology company closed a deal with TenneT, the Dutch-German transmission system operator, to supply multiple off-shore and on-shore high-voltage direct current (HVDC) converter stations to connect off-shore wind farms to the Dutch and German grids.

[According to Hitachi Energy](), the deal confirms the opportunity to demonstrate how state-of-the-art technology can be deployed effectively and how new business models enable the scale needed for the green energy transition. The deal is worth 13 billion Euros, making it the largest export order in Swedish history, according to Dagens Nyheter.

The larger the share of renewable power in the power system, the lower the amount of inertia – if not supplied by power electronics. This is because the shares of hydro power and nuclear power using synchronous generators are reduced.

Massimo Bongiorno, Professor of Electric Power Engineering at Chalmers University, and Jan R. Svensson, Adjunct Professor at Chalmers University and Research Fellow at Hitachi Energy Research.

“Traditionally, transmission system operators (TSOs) have used synchronous condensers to stabilise the grids, aside from which synchronous generators and the synchronous condensers provide mechanical inertia” said Jan R. Svensson, Adjunct Professor at Chalmers and Research Fellow at Hitachi Energy Research. “However, when the electricity demand increases with the energy transition, the industry develops to meet the demand. This is what is happening now when it comes to power electronics. The TSO’s see they can buy services such as inertia from grid-connected converters.”

If power electronics can replace synchronous generators, why isn’t it used more frequently?
“Remember that this is a new area in which power electronics manufacturers have just launched their products,” said Jan R. Svensson. “As always, there are pros and cons. If a failure arises in the grid, the synchronous condenser is helping to stabilise the system by supplying inertia and high fault current. If a converter will supply the same level of fault current as a synchronous condenser, it needs to be over-dimensioned, which is costly. On the other hand, the controllability of the converter is much better, the flexibility is much greater, and it needs less maintenance. Moreover, the idle losses are lower.”

The research led by Massimo Bongiorno within Mistra Electrification is about how converters can be designed to minimise costs and optimise them for different applications.

“A converter can be combined in different ways; it is like building Lego. We are trying to find out how we can minimise active effect losses. They can be up to a percentage of the power, which doesn’t sound like much, but in the end is a lot of money spent on losses,” said Massimo Bongiorno.

Another challenge is the size of power electronics. A battery and converters that interface, for example, between a wind farm and the grid, can be the size of a building.

“If we could build power electronics more compactly, it would save cost. Furthermore, large appliances like that imply challenges if they need to be installed in urban areas”, said Massimo Bongiorno.

People might look upon power electronics as science fiction. What do you say when facing that?
“Research is very much in the forefront, so I can sympathise with that perception,” said Massimo Bongiorno. “But as I mentioned earlier, power electronics is already a part of the grid. Just because we once were dependent upon synchronous generators it doesn’t mean that we need or want a system like that in the future. In the end, it is a matter of cost, and minimising the cost is one part of our research. But it is a fact that we will see more of power electronics in the future,” said Massimo Bongiorno.

Aleh Cherp, Lund University, and Jessica Jewell, Chalmers University.

Phasing out coal is occurring too slowly – replication of the most-ambitious national plans is needed

The use of coal power is not being phased out rapidly enough. Keeping global warming below 2 degrees requires world-wide replication of the most-ambitious national plans for the phasing out of coal. However, the targets of the Paris Agreement seem to be already greatly exceeded, according to a report by Mistra Electrification.

Ending the use of unabated coal power is a key climate change mitigation measure to keep global warming below 2 degrees since the start of industrialisation. A report issued by Mistra Electrification analysed 72 national coal power phase-out pledges, which the magazine *Aktuell Hållbarhet* covered in: Forskarnas bedömning: vi går mot 2,5 till 3 grader Celsius.

The report shows that in the best scenarios, there is a chance that global warming can stay below 2 degrees, although this will require, amongst other measures, that both China and India start to phase out coal within 5 years. Furthermore, the phase out needs to be as rapid as it was in Great Britain, and faster than the time-frame pledged by Germany.

“More and more countries promise that they will phase out coal power, which is positive,” said Aleh Cherp, Professor at The International Institute for Industrial Environmental Economics, Lund University. “But their pledges unfortunately are not powerful enough. If we are to have a realistic chance of keeping global warming below 2 degrees, the phase out of coal needs to be faster, and countries that depend on other fossil fuels need to accelerate their transition.”

The report also shows the most-likely scenarios. They show that global warming of 2.5–3.0 degrees is likely.

“The pledges are not enough, not even amongst the most-ambitious countries,” said Jessica Jewell, Associate Professor in Energy Transitions at the Department of Space, Earth and Environment, Chalmers University.

Filip Johnsson, Professor in Sustainable Energy Systems, and Lisa Göransson, Associate Professor at Energy Technology, both at Chalmers University of Technology.

Flexibility is crucial for the future electricity system

Sweden can meet the increased electricity demand and reach the climate goals both with and without nuclear power. There will be no major differences in price of electricity regardless of the system used. Increased flexibility is key and is required regardless of the future of nuclear power, according to a report that has led to an intense public debate.

The report titled Ett framtida elsystem med och utan kärnkraft – vad är skillnaden? was published in July by Chalmers University of Technology and Mistra Electrification, and presented to a wider audience in the opinion piece Väderberoende är inget problem för elproduktionen, which appeared in *Dagens Nyheter* in August 2023.

The report analysed and modelled three future fossil-free electricity systems: a cost optimized system; a system in which 22 GW of off-shore wind power was prescribed; and a system with 9 GW of nuclear power, which is around the level of nuclear power that Sweden had in the 1990's.

Three main conclusions are drawn in the report:

1. It is possible to meet the increased electricity demand with a large amount of intermittent electricity production. By combining different flexibility measures, the demand can be met in all the modelled systems.

2. The price of electricity drives investments in new electricity production in a cost-efficient manner. The electricity price variations stimulate investments in flexibility measures, and investments in dispatchable generation occur when the cost is lower than non-dispatchable generation that includes flexibility measures.

3. The three modelled systems all reach the climate targets and meet the increased electricity demand arising from the electrification of industry. There are no major differences between the three modelled systems regarding either the price of electricity or the ability to meet the demand.

The report was presented to a wider audience in an opinion piece published in the leading Swedish newspaper Dagens Nyheter *and discussed in the energy web magazine* Second Opinion.

The report prompted reactions and public debate, both in social and traditional media. For instance, the energy web magazine *Second Opinion* discussed the report in the two articles: Erik Ek: ”Fysikens lagar kan inte simuleras bort” and Elsystem med och utan kärnkraft – ”Det finns tekniska lösningar”.

“Our conclusion is that politicians must stop polarizing between wind and nuclear power, and instead focus on removing barriers for more fossil-free electricity production regardless of technology”, stated the authors of the report, Lisa Göransson and Filip Johnsson, in the opinion piece in *Dagens Nyheter*.

DAGENS NYHETER. Nyheter Sverige Världen Ekonomi Kultur Sport Klimatet Ledare DN Debatt

Nya siffror: Högerpartiernas svängning stoppar vindkraft

M, KD och SD säger allt oftare nej när kommuner tar ställning till ny vindkraft. Det visar en ny rapport från Chalmers. Motståndet riskerar att allvarligt försena elektrifieringen, varnar professor Filip Johnsson.

– Det ser ganska mörkt ut, säger han.

Leading Swedish newspaper Dagens Nyheter *interviewed Professor Filip Johnsson about the report "Kommunala vetot – landbaserad vindkraft", which analysed how Swedish municipalities used their veto rights on new wind farms in the period of 2014–2022.*

Sharp increase in wind power vetoes by municipalities

Swedish municipalities vetoed 22 percent of new wind power applications during the period of 2014–2020. This figure rose to 48 percent in 2021–2022, according to a report by Mistra Electrification.

In the report "Kommunala vetot – landbaserad vindkraft" (The municipal veto – on-shore wind power), Mistra Electrification analysed how Swedish municipalities used their veto rights to stop new wind farms during the period of 2014–2022. The report shows that during this period, the municipalities vetoed 22 percent of all applications. During the period of 2021–2022, closer to the national election in 2022, such vetoes increased to 48 percent of applications.

All of the political parties, with the exception of the left-wing *Vänsterpartiet*, increased their share of vetoes. The conservative Moderate Party (*Moderaterna*), the Christian Democrats (*Kristdemokraterna*) and the Sweden Democrats (*Sverigedemokraterna*) increased their shares of vetoes the most.

Filip Johnsson, Program Director of Mistra Electrification and author of the report, interprets the development as part of the public debate concerning the energy transition.

"When the energy transition became part of the debate prior to the national elections in September 2022, the polarization between wind power and nuclear started, which I see is a pseudo debate," commented Filip Johnsson in Dagens Nyheter.

"This is because the challenge in the energy transition is not about wind power or nuclear power, but about removing barriers for all electricity generation and making the general public realize that we all have to compromise. The national debate spilled over to the politicians in the municipalities, and they started to use their veto more often than prior to the polarized debate," he continued.

Charlotte Paulie, SNS, Lars Zetterberg, IVL, Filip Johnsson, Chalmers, and Kenneth Möllersten, IVL, during the seminar in which the report "Mot nettonollutsläpp – hur kan koldioxid avskiljning bidra?" was presented. Photo: Allan Seppa, SNS.

Policy for bio-CCS can help to decarbonise hard-to-abate industries

Sweden has a strong potential to implement bio-CCS so as to abate carbon dioxide emissions, although some challenges remain. In the run up to the establishment of a mature market, the costs will be high. Moreover, the levels of credibility associated with CCS and bio-CCS hinge on a strong climate policy, according to a report that was co-written by researchers from Mistra Electrification and Mistra Carbon Exit.

The Swedish potential for CCS is close to 25 million tonnes of carbon dioxide per year at a cost of 130 Euro per tonne or less. This represents more than half of Sweden's yearly carbon dioxide emissions of some 40 million tonnes. A large share of the 25 million tonnes is captured from biogenic emissions sources. This means that there is strong potential not only to compensate for hard-to-abate emissions in Sweden, but also to export negative emissions to other countries, according to the report.

More than 200 people participated at the seminar where the report was presented, and the newspaper *Dagens Industri* published the opinion piece "Låt Sverige ta ledningen i arbetet med avskiljning av koldioxid".

The report identified three challenges related to realising the full potential of bio-CCS:

- **Financial threshold**. Bio-CCS is still an immature technology, so there will be higher initial costs than those estimated today, which are typically for so-called Nth-of-a-plant, i.e., assuming that a mature market has been established.
- **Lack of developed storage sites**. Current storage capacity is limited, and there is a risk of "Catch-22" situations in which investors in capture facilities are unsure as to when and where storage will be available, while investors in storage facilities are unsure as to whether they can get customers for their storage facilities.
- **Need for a credible policy for CCS and bio-CCS**. The credibility of CCS and bio-CCS (BECCS) relies on a strong climate policy. The choice should be between leaving the fossil fuels un-used or using fossil fuels together with CCS (albeit at a higher cost). There is also a need to develop a robust policy for bio-CCS.

The report presents and discusses five policy models for generating funding and creating demand for bio-CCS:

1. Governmental guarantees regarding the purchasing of bio-CCS outcomes.
2. The imposition on selected sectors of quota obligations to acquire BECCS outcomes.
3. Allowing bio-CCS credits to be used to compensate for hard-to-abate emissions within the EU's Emissions Trading System (EU ETS).
4. Other states acting as buyers of bio-CCS outcomes in order to meet their mitigation targets under the Paris Agreement.
5. Private entities compensating on a voluntary basis for their greenhouse gas emissions.

Based on these policy models, the authors present policy recommendations for the Government of Sweden:

With regard to BECCS, the policy should take a position on how large volumes of BECCS the Government should finance (according to Model 1). In addition, the Government needs to create conditions and funding for the total Swedish need for BECCS up to Year 2045, and beyond. At the same time, the policy instruments must encourage systems that create circular carbon flows.

Stimulation of BECCS can either take place through the introduction of a quota obligation (Model 2) at the Swedish level or Sweden can work towards the European Commission (EC) introducing a quota obligation at the EU level. Sweden can also press the EC to allow the use of BECCS credits within the EU ETS after Year 2030. Voluntary compensation (Model 5) could be an interesting alternative for companies, mainly those abroad, to climate-compensate their remaining emissions.

This is Mistra Electrification

The research programme involves a consortium of nine industry partners and five research partners. The consortium, which is funded by Mistra and the partners, is under the combined leadership of Chalmers University of Technology and Energi-forsk and reports to the Programme Board.

Programme Board

- **Karin Reuterskiöld** (Chair), Partner, Forever Sustainable
- **Lise Nordin**, Climate Coordinator at Västra Götalandsregionen
- **Åsa Pettersson**, CEO at Energiföretagen Sverige - Swedenergy
- **Karl Bergman**, Head of Research & Development, Vattenfall
- **Stefan Savonen**, SVP Energy & Climate at LKAB

Research Partners

- Chalmers University of Technology, three divisions/departments:
  - Energy Technology
  - Physical Resource Theory
  - Division of Electric Power Engineering
- IVL Swedish Environmental Research Institute
- University of Exeter
- Lund University
- Swedish University of Agricultural Sciences (SLU)

Industry Partners

- Svenska kraftnät (Swedish TSO)
- Stockholm Exergi
- Fortum
- Nordion Energi
- Göteborg Energi
- Vattenfall
- Hitachi Energy
- Kiona
- Utilifeed

Programme Period

June 2021 – May 2025

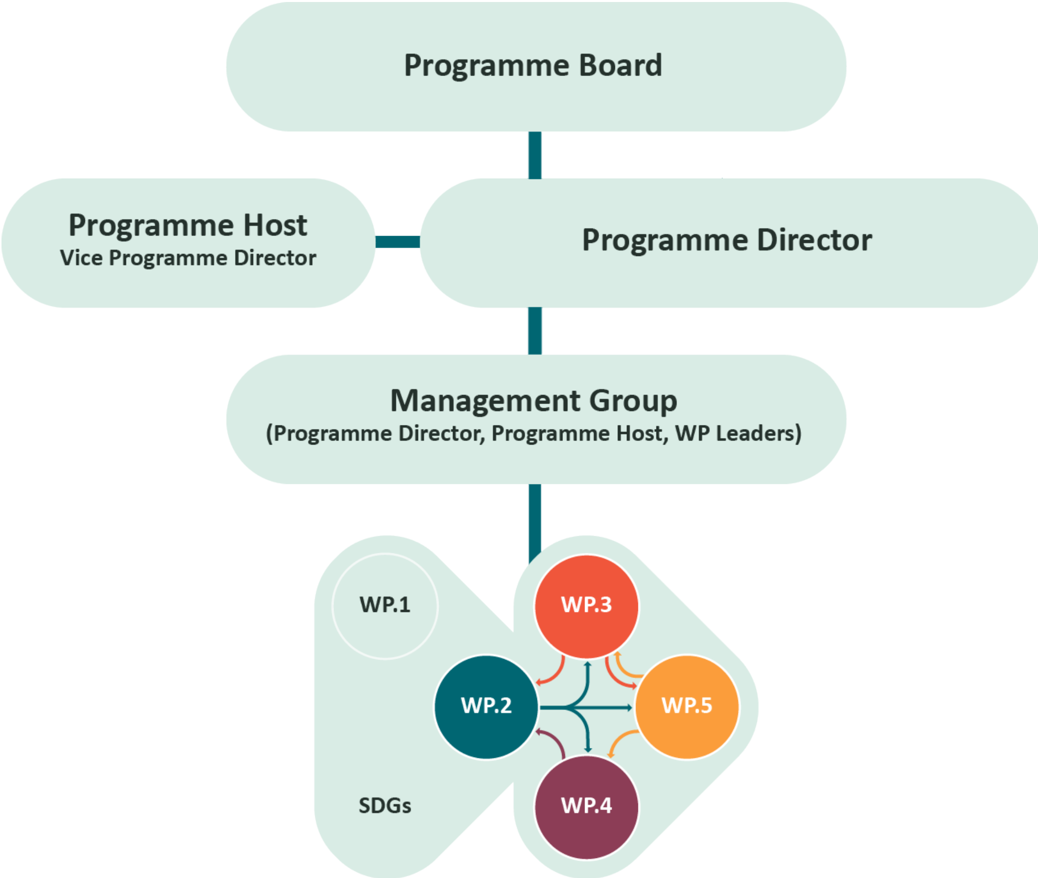
Budget and Funding

- In total, 67 MSEK, comprising:
- 50 MSEK from Mistra; and
- 17 MSEK as in-kind contribution from the research and industry partners

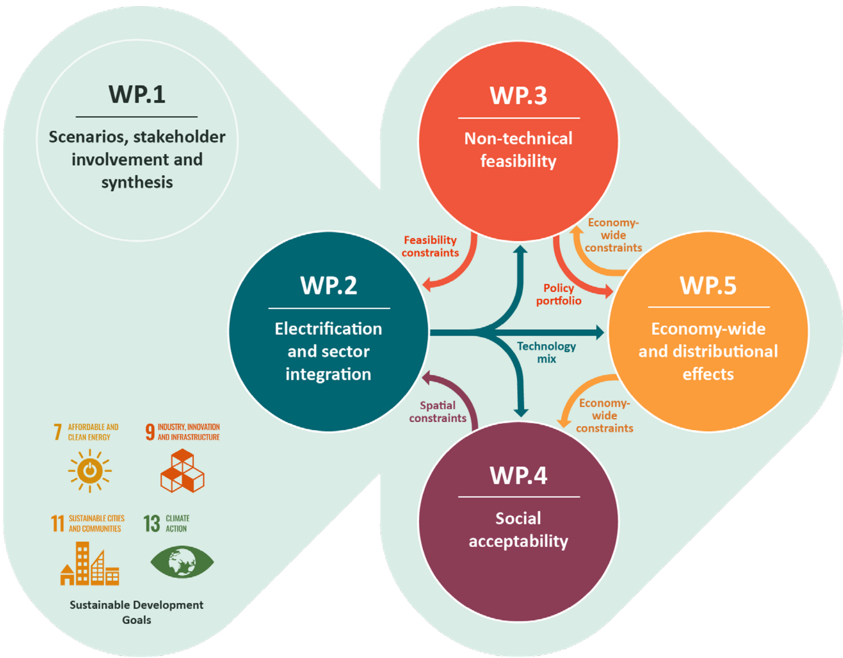
Work Packages

- **WP1** - Scenarios, stakeholder involvement and synthesis
- **WP2** - Electrification and sector integration
- **WP3** - Non-technical feasibility
- **WP4** - Social acceptability of energy infrastructure
- **WP5** - Economy-wide and distributional effects

Organisation of Mistra Electrification



Work packages and cooperation



WORK PACKAGE 1

Scenarios, stakeholder involvement and synthesis

The aim of WP1 is to provide a structured process for the interaction with stakeholders throughout the program, in order to formulate relevant scenarios and cases and to synthesize the results. An important novelty of the work is that it combines a relevant network of stakeholders with a participatory integrated assessment methodology.

Objectives of WP1

For the first 7 months of the programme, the main activities within WP1 have been to form the consortium and establish means of communication.

- To draw on the inputs of industry and societal actors (TSOs, DSOs, governmental agencies, Swedish EPA, NGOs) in developing scenarios for deep electrification and decarbonization.
- To explore key trade-offs and synergies between cost-efficiency, non-technical feasibility, social acceptance, and distributional and economy-wide impacts of the energy transition.
- To inform industry and societal actors as to the key trade-offs and how their actions can shape the unfolding energy transition.
- To synthesize the results from the research by means of outreach activities, such as a program web page, policy briefs, workshops, and social media including short video interviews (for e.g., YouTube channels).
- To arrange a yearly program conference, gathering academic and non-academic partners and invited selected external participants and fostering international networking (e.g., with visiting researchers).

WORK PACKAGE 2

Electrification and sector integration

The aim of WP2 is to analyze pathways for the Swedish and Northern European electricity systems that address the anticipated electrification of the transport and industry sectors and account for flexibility provision by sector coupling (including hydrogen production), as the basis for iteration with the other work packages.

Objectives of WP2

- To provide pathways for the Swedish and the Northern European electricity system, including electrification of industry and transport, infrastructure requirements and sector integration for different assumptions on external parameters (scenarios), including different target trajectories on carbon emissions towards zero emissions.
- To investigate the possibilities from distributed generation, including prosumer systems in urban areas, and the role of electric vehicles, including smart charging strategies.
- To develop novel approaches to integrating spatial constraints and political and institutional feasibility constraints in techno-economic modeling by means of a set of key indicators for quantifying the input and outputs from modeling with respect to quantities required for the subsequent analyses in WPs 3–5.
- To assess sustainability impacts, synergies, and trade-offs.
- To assess the potential role of IT as an enabler of sector integration, such as the role of virtual power plants (e.g., aggregated heat pumps bidding on electricity markets).
- To develop solutions to guarantee stable operation of the power systems when operated with a high penetration of non-dispatchable electricity generation (most notably, wind power), and compare them from the technical and economic points of view

WORK PACKAGE 3

Non-technical feasibility

WP3 aims to assess whether key elements of the electricity transition pathways, especially the rate of the transitions, modeled in WP2 are feasible. Whereas the models used in WP2 identify optimal electricity pathways based on technical constraints such as resource availability and intermittency challenges, WP3 draws on empirical material to identify non-technical constraints such as the rate of innovation, investment and institutional and social change. We will then go on to develop policy solutions, mixes and sequences that can relieve these constraints and enhance the feasibility of electricity transition pathways.

Objectives of WP3

Construct feasibility spaces for the rapid implementation of the most critical elements of the pathways, such as:

- Expansion of low-carbon power generation (onshore and offshore wind, distributed solar, the future of nuclear power).
- Expansion of hydrogen technologies, including production, supply, and storage.
- The phase-out of fossil fuels (coal and natural gas) in Northern Europe (e.g., coal phase-out in Poland).
- Translate the insights from first objective into benchmarks for interpreting parameters of the pathways produced in WP2, especially deployment rates, in order to identify, in collaboration with WP2, the feasibility constraints and trade-offs related to these key elements relevant for specific pathways and elaborating pathways that stay within these constraints.
- Identify and analyze policy mixes that can trigger the implementation of the transition pathways in the context of Swedish and EU energy and climate policies (e.g., the EU ETS) and strategies linked to the EU Green Deal.

WORK PACKAGE 4

Social acceptability of energy infrastructure

The aim of WP4 is to understand the social acceptability of the energy infrastructure solutions identified in WP2 as necessary to achieve climate neutrality.

Objectives of WP4

- To estimate future potential locations for wind power and levels of deployment density based on historical geospatial data (also to inform WP2).
- To identify the technological pathways and spatial locations for deployment that are expected by stakeholders and experts to be controversial with the public generally and local communities in particular.
- To investigate how the different technological solutions obtained in WP2 are represented and accepted by the public at the societal and local community levels and by officials and company representatives.
- To understand the roles that citizens are willing to play in enabling sustainable energy transitions, for example as prosumers or investors, and how these might vary across social groups, personal characteristics and spatial areas.
- To advance understanding of the socio-spatial aspects of technological pathways, specifically the compatibility between particular landscapes and specific technological solutions (e.g., large-scale wind power) using mapping methodologies.

WORK PACKAGE 5

Economy-wide and distributional effects

The effectiveness of Swedish measures and their effects on competitiveness, and ultimately welfare, depends on strategies chosen elsewhere and will, thus, influence Sweden's ability to be an early mover in decarbonization. The aim of WP5 is to shed empirical light on these issues, using the Comprehensive General Equilibrium (CGE) modeling approach and unique empirical data, a combination that makes this work novel and unique.

Through the iterative WP work managed by WP1, WP5 will inform WPs 3 and 4 on the overall distributional effects of the different transition pathways. As outlined in the description of WP1, this WP aims at incorporating stakeholder information knowledge to sharpen the analysis and place it in a realistic framework. The work in WP5 is novel in that we will contribute new theoretical results on the links between competitiveness metrics and exact welfare measures in a general equilibrium setting. This should be of great importance since, as mentioned in the introduction, the views in the public and political debates on the effect of the energy transition on the economy vary widely.

Objectives of WP5

- To quantify the effects on competitiveness of the energy transition pathways obtained from WP2–WP4, i.e., under different technology mixes and policy assumption in Sweden and internationally (cf. Figure 1).
- To quantify the distributional effects of the energy transition pathways obtained from WP2–WP4, i.e., under different technology mixes and policy assumptions.
- To understand the role of electricity trade with neighboring countries in the transition pathways, using inputs from WP1 and iteratively with WP2.

The results from the analysis will be iterated with WPs 2–4.

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