SDG Impact Assessment of Mistra Carbon Exit pathways

One plus 16 dimensions of sustainability

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MISTRA CARBON EXIT

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Summary

Finding political cohesion between ambitious climate goals according to the Paris Agreement and the wider sustainability framework of Agenda 2030 is to put the finger on one of the greater contemporary challenges – how can we reduce harmful anthropogenic impact on the climate without negatively affecting the prospects for Earth's ecosystems and human well-being? There is, however, no established framework that will provide clear guidance on how to compare different sustainability challenges against each other and resolve contradicting viewpoints. Still, the need for evidence-based scientific input to guide sustainable policy making is increasing.

Mistra Carbon Exit is an ambitious research programme with the aim to identify and describe technical, economic and political opportunities and barriers for Sweden to reach net zero emissions of greenhouse gases by 2045. The consortium involves relevant stakeholders to develop sectorial pathways that pinpoints technological options and efficient policy intervention across supply chains in buildings & transportation infrastructure, transportation, and energy carriers. The sustainability assessments carried out in the programme aims to identify potential impacts on the Sustainable Development Goals (SDGs) for climate neutral cement, wind power and electric vehicle batteries, as key components of the pathways. This is achieved through an approach called SDG Impact Assessment that refines expert opinions by structuring and reviewing information in a set of iterations, moving from open-ended questions to prioritizing risks and opportunities for the SDGs, domestically and as international spillovers.

From the sustainability assessments it is clear that reaching ambitious climate targets comes with opportunities and risks to the implementation of several SDGs. Achieving production of climate neutral cement, up-scaling of wind power and electrification of cars can bring competitive advantages to Swedish industry on global markets, and create synergies with the implementation of, for example, SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). Considering potential risks, SDG 15 (Life on Land) emerge as the goal for which most conflicts exists. These risks are mainly identified upstream in supply chains and are linked to the extraction of raw materials in other parts of the world. In countries with weak or non-existing environmental regulation, mining is oftentimes destructive to surrounding landscapes and can contaminate soil and fresh waters, thereby threatening biodiversity and ecosystems.

The 17 SDGs forms a complex web of connections, interlinkage and dependencies that proves a great challenge for analysis of impacts from specific activities or scenarios. Still, the SDG impact assessments confirmed that the SDGs need to be treated as a whole, with no room for presumptions and 'cherry picking' of only specific SDGs. As performed in this work, identifying impacts on the SDGs preferably starts as an open process of 'turning every stone', characterized by reflective and collaborative learning, that iteratively reduces complexity and pinpoints specific impacts on SDGs.

Aim

Mistra Carbon Exit is an ambitious research programme with the aim to identify and describe technical, economic and political opportunities and barriers for Sweden to reach net zero emissions of GHGs by 2045. The consortium involves relevant researchers and stakeholders from industry, authorities and civil society to develop sectorial pathways that pinpoints technological options and efficient policy intervention across supply chains in (i) buildings & transportation infrastructure, (ii) transportation and (iii) energy carriers. The sustainability assessments carried out in the programme aims to identify and describe risks and opportunities associated to the pathways, according to the Agenda 2030 framework and the SDGs. That is – putting the Swedish political target of net zero emissions of GHGs up front, what other sustainability perspective are relevant and in what way, in the transformation to zero emission supply chains?

Introduction – climate change and sustainability

Climate change and sustainable development have gradually been embraced by world leaders into mainstream ingredients of the global political discourse. Even so, global temperatures continue to rise, as are inequality, unsatisfactory human rights, loss of biodiversity and degradation of water, soil and air. Strengthened efforts are needed to address these challenges, and a sound understanding of the interlinkages between global warming and the Sustainable Development Goals (SDGs) is crucial.

The Paris Agreement, as agreed upon by all nations, stipulates that global temperature rise needs to be kept well below 2 degrees Celsius this century, compared to preindustrial levels. The agreement requires all parties to put forward their best efforts through nationally determined contributions. In Sweden, this contribution is defined in the Climate Act stipulating that by 2045 Sweden should have net zero emissions of greenhouse gases (GHGs). In parallel with the development and adaptation of the Paris Agreement in the United Nations Framework Convention on Climate Change (UNFCCC), the UN General Assembly put forward Agenda 2030 as a resolution to reach global sustainable development. At the heart of Agenda 2030 is 17 SDGs with 169 corresponding targets, which pinpoint efforts needed to reach sustainable development by 2030. The SDGs covers a wide range of aspects, spanning over the three dimensions commonly referred to as the 'three pillars of sustainability' – environmental, economic and social. In 2015, the Agenda 2030 was accepted by all the 193 UN member states. As in the case with the Paris Agreement, contributions to Agenda 2030 are expressed in bottom-up processes where nations develop their own plans and actions.

During the progress towards climate mitigation and adaptation, an increased awareness of associated risks and trade-offs has grown. Actions to reduce climate impact might come with costs of negative impacts on other sustainability perspectives. It is, for example, well known that large scale bio-energy production could be detrimental to biodiversity and compete with land-use for food production. Similarly, moving away from fossil fuels in favor of renewables will increase demand for new metals with potential consequences to global geopolitics, regional economic growth and local environmental degradation. Thus, finding political cohesion between ambitious climate goals according to the Paris Agreement and the wider sustainability framework of Agenda 2030 is to put the finger on one of the greater contemporary challenges – how can we reduce harmful anthropogenic impact on the climate without negatively affecting the prospects for Earth's ecosystems and human well-being?

With more attention devoted to this pivotal challenge, there is a growing need to pinpoint and describe risks and opportunities of climate action. That insight is far from new, however; already at the 1992 Rio Earth Summit, world leaders jointly confirmed the importance of sustainability assessments to aid governmental and business decision-making to monitor progress towards sustainability. The underlaying rationale was that "In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it." (United Nations, 1992). Ever since then a multitude of approaches, toolkits and methods have been developed. Due to sustainable development as a concept is (i) multi-dimensional and holistic (the three pillar conception: environmental, economic and social dimensions of sustainability), (ii) inter-generational (the needs of present and future generations) and (iii) value-laden (interpretation and actual meaning varies according to social and cultural contexts) a set of challenges to measure and evaluate sustainability exists. It is particularly tricky in situations involving trade-offs or dilemmas, i.e. when outcomes of actions may bring positive impact to one challenge and negative to others. There is no established framework that will provide clear guidance on how to weigh different impacts against each other and resolve contradicting viewpoints (Böhringer and Jochem, 2007), or how to handle the inter-generational perspective in a just way. Still, the call for evidence-based scientific input to guide sustainable policy making is growing, not the least in the context of combating global warming.

Mistra Carbon Exit sustainability assessment study objects

The Mistra Carbon Exit pathways of (i) buildings & transportation infrastructure, (ii) transportation and (iii) energy carriers describes options to mitigate carbon emissions along corresponding supply chains – from the input of raw materials to final products and services. The sustainability assessments have been framed to focus on key components that are central to the pathways of reaching net zero emissions in Sweden, as illustrated in figure 1. The components are equivalent to the study objects of performed SDG impact assessments, as presented below.

Wind power
In Sweden, wind power is key to future production of carbon-free electricity. Irrespective of different shares of electricity generating technologies in the predicted electricity mix, wind power in Sweden provides the lowest cost for carbon mitigation. Even though future consumer electricity prices are expected to increase, that seem to be the case for most scenarios no matter the share of wind power (Swedish Energy Agency, 2019). The scenarios developed in Mistra Carbon Exit for energy carriers respects the dynamics of future electricity demand generated from buildings & transportation infrastructure and transportation. Swedish wind power implementation can reduce costs for such implementation in other parts of the world, through learning curves and economy of scale, which have been considered as potential international spillovers. Both land-based and offshore wind power have been included in the assessment.

Climate neutral cement
Concrete is a major structuring building material globally with a considerable carbon footprint. Any ambitious climate agenda must rely on a shift away from conventional to climate neutral concrete. As outlined by Karlsson et al. (2020b), the greater part of climate impact from concrete stems from

the production of cement, an energy intensive industrial process. About two thirds of related emissions are due to the calcination process and one third from fuels used in cement ovens, so-called kilns. Options to mitigate climate impact are mainly to replace fuels in cement ovens, substitute cement as a binder in concrete, use less cement in concrete and introduce carbon capture and storage (CCS). Most of the raw materials for Swedish cement and concrete production comes from Sweden. Hence, the assessment does not include imports of these raw materials. SDG impacts associated with climate neutral cement are identified across the life cycle phases of production, use and end-of-life, where the latter two effectively focuses on concrete.

Electric vehicle battery
Electrification of vehicles is a crucial component in the transformation to reach net zero emission from transportation. There are several options to reduce climate impact from transportation – substituting fossil energy with renewable, increase energy efficiency and increase transportation efficiency. Current trends as digitalization, automatization and the servitization of transports (e.g. car sharing) will, no doubt, provide new opportunities to mitigate climate impact, although they might also bring about new challenges. Replacing fossil fuels with renewable electricity might, however, prove the most important of them all – a transformation relying on the development of high capacity batteries for vehicles. In support of making this transformation in a sustainable way, SDG Impacts of electric vehicle batteries were identified across life cycles of production, use and end-of-life, where the use phase is defined as use in an electric car.

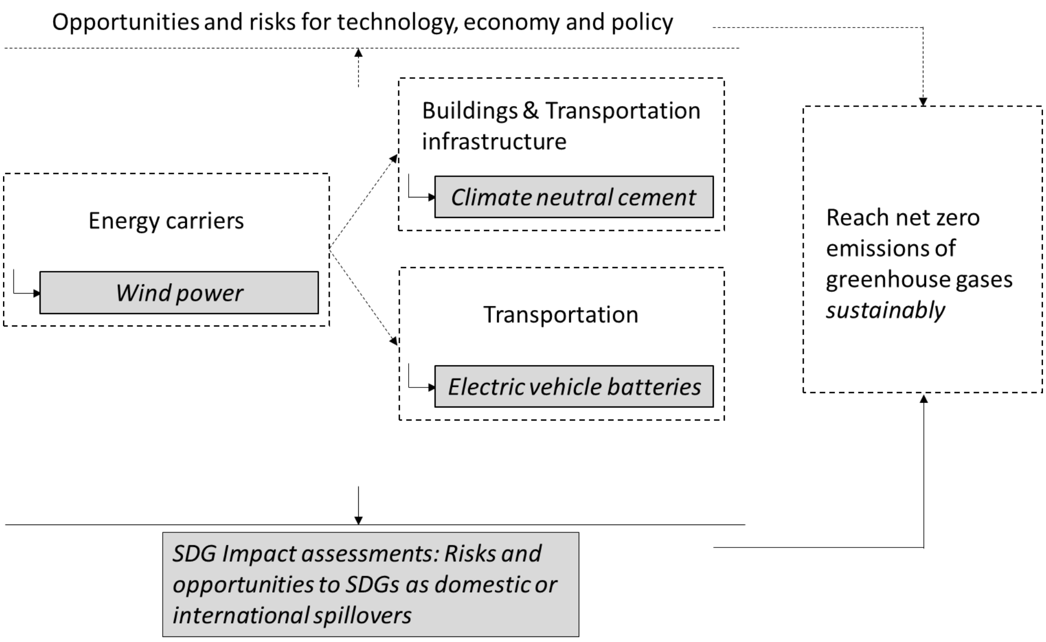

Figure 1. Mistra Carbon Exit pathways and corresponding key components in the sustainability assessments. Text in italics and grey boxes indicate work in the sustainability assessments.

The key components are studied based on their unique qualities and contributions, as part of the transition to net zero GHG emissions. The sustainability assessment uses Agenda 2030 and the SDGs as an analytical framework to identify risks and opportunities over the lifecycle phase of production, use and end-of-life, arising either in Sweden or as international spillovers.

Analytical framework – Agenda 2030 and the SDGs

There is no precise and unambiguous definition of sustainable development; rather, there are a set of aspirational statements which of the so-called Brundtland definition is the most commonly referred to, stating that sustainable development is a:

"development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

As highlighted in academic literature, the Brundtland definition and the three pillars of sustainability; the Environmental, Social and Economic, are open to different interpretations (Custance and Hillier, 1998, Ross, 2009). Especially the fundamental question of what is to be sustained or preserved for future generations. Consequently, there has been no actual agreement on how to measure and monitor progress within these pillars. The Agenda 2030 framework, even though it is a political resolution, could be viewed as a continuation and advancement of sustainable development as a concept. The 17 SDGs and 169 targets provides a more detailed answer to the question "What is sustainability?" or "What is a sustainable development?" compared to the three pillars concept and the intergenerational perspective. The latter two are still highly relevant, constituting the underlying principles for Agenda 2030, but the SDGs is a more suitable framework for evaluating progress in sustainable development. The SDGs frame specific challenges that needs to be considered in policy, strategy and planning with equal relevance to public and private stakeholders. They are agreed upon by the UN member states as "the action plan for people, planet and prosperity" (United Nations, 2015), thereby providing a common denominator to sustainable development that will guide international and national policy.

As emphasized in the Agenda, the goals are integrated and indivisible (UN, 2015), meaning that they should not be treated separately but instead as a holistic whole. The holistic nature of the 2030 Agenda and the SDGs has implications for sustainability assessments. The SDGs have contextual relationships where impacts on one SDG might have consequences for others. In practical terms, there is no room to on beforehand choose SDGs and put others to the side (so-called "cherry-picking") – a sustainability assessment needs to initially considered them all as relevant, to avoid ad hoc solutions and business as usual.
In practice it is possible for businesses, policy makers, innovators, researchers and other agents to form an understanding of how their operations affect the SDGs in terms of positive and negative impacts. The SDGs provides enough details to limit diverse interpretations of sustainable development and, thus, makes sustainability assessments attainable for a wide range of stakeholders. From an analytical viewpoint, however, challenges still remain as; how to integrate all SDGs (the holistic perspective), including inter-linkages in terms of trade-offs and synergies; quantitative and deterministic approaches versus qualitative and reflective; and useable knowledge versus complete science.

Environmental assessment is an established field to measure impact from human activities to the environment. Within this field, there are several approaches to describe impact in quantitative terms, of which Life-cycle assessments (LCA) is the most notable. LCA is a rigorous process of identifying and structuring data of energy and material use across a value chain for an object of study. The goal is oftentimes to compare various alternatives using a 'functional unit' to identify the least environmentally harmful option. In the context of sustainability assessments, quantitative approaches as LCA faces a couple of challenges.
Firstly, in what way could a functional unit for sustainability be defined as an aggregation of the 17 SDGs? Such a functional unit requires that normalization and weighting of all SDG-linked variables is feasible. As found by Böhringer and Jochem (2007) in their review of national and international

sustainability indicator sets and indexes – no approach had thitherto succeeded to develop a robust and scientifically sound method for normalization, weighting and aggregation.

Secondly, any quantitative methodology is obviously depending on the availability of data. LCA is usually a comparison between present options based on data derived from the recent past. Based on that, two problems arise. Agenda 2030 comes with a set of 232 indicators designed to measure progress of the 17 SDGs. The task ahead for national statistical agencies to match the indicators with data is described as of herculean nature. Currently only 93 are classified as Tier 1, meaning that the indicator is conceptually clear, has internationally established methodology and standards, and data are regularly compiled for at least 50 per cent of the countries (MacFeely, 2019). At the very basic level of data gathering for sustainability assessments, finding quality data sets to cover all 17 SDGs relevant to specific study objects would indeed prove challenging in practice, not the least when looking into the future as implied by sustainable development.

In contrast to quantitative approaches, qualitative draw more general conclusions based on expert options, literature reviews and practitioner experience. As argued by Mach et al. (2017), assessments of expert opinions or expert judgements is an important input to decision making in complex and contested issues, as done in the fifth assessment report (AR5) by the Intergovernmental Panel on Climate Change (IPCC) (2014). No doubt, “complex and contested” is a good description of issues in sustainability. Sustainability problem formulations and solutions are often characterized as ‘wicked’ in the sense that information may be incomplete, contradictory and changing, and might be inherently difficult to solve while maintaining consensus about what is the best solution. In qualitative assessments, complexity is reduced by identifying the most relevant issues, and solutions are suggested in a format that is comprehensible and usable to change agents in society. That is, rather than emphasizing precision in data gathering and handling, the output from qualitative approaches aims to pinpoint risks and opportunities as basis for decision making.

The implementation of Agenda 2030 needs actionable knowledge to avoid making progress on one SDG at the expense of others. The methodological premise for the sustainability assessments carried out in Mistra Carbon Exit is that synthesizing expert opinions in a structured way, to identify risks and opportunities for the SDGs, will provide valuable input to planning, strategic decision and policy making.

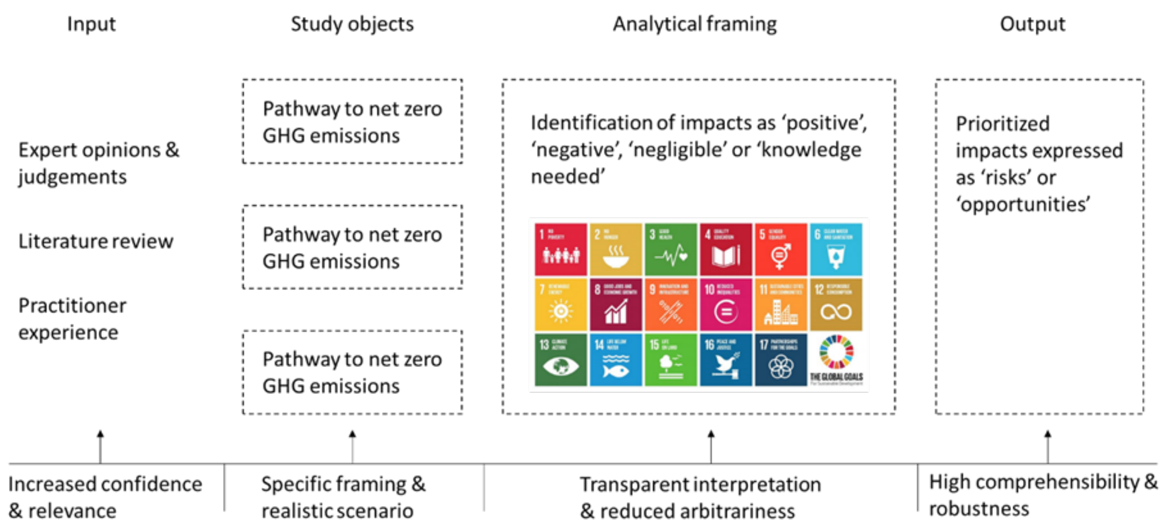

Figure 2. Conceptualization of Agenda 2030 and the SDGs as analytical framework for SDG impact assessment carried out in Mistra Carbon Exit.

As illustrated in figure 2, the framework suggests user input as qualitative and reflective with the aim of identifying impacts from a study object on the SDGs as either positive, negative, negligible or more knowledge needed. Although the focus here is on qualitative input/output, there are opportunities to complement assessments with quantitative approaches to estimate magnitude of impacts on a per SDG basis. Therefrom it is possible to prioritize among identified impacts to describe the most urgent ones as risks or opportunities from the realization of the study object in society. Along this process there are a set of challenges, highlighted at the bottom of figure 2, that needs to be considered. The confidence and relevance of input data ('data' used here in a loose sense) needs to be assessed. The specific circumstances of how the study object will be implemented and thereby have impact on the SDGs must be defined and framed. The interpretation of how the SDGs and their targets relates to the study object needs to be considered. Loose ends that give room for arbitrariness should be minimized; particularly so if the framing and scenario have uncertainties in terms of "what-ifs" and "it depends on". Moving from identified and characterized impacts to prioritized risks and opportunities is partly a value-laden exercise in which participating expert's judgement will be crucial. The success in producing a comprehensive but still comprehensible assessment will in the end determine the usability of the final output.

Methodology

The approach to the SDG impact assessments is based on the analytical framework outlined in figure 2 and is further refined into a series of steps, as indicated in figure 3. Together they form a process of iterations with the aim of moving from open-ended questions of identifying impacts on the SDGs (step 1), to increased confidence in prioritizing risks and opportunities at the end (step 4). The process is based on expert opinions in a Delphi-inspired approach (step 1 and 3), involving researchers and other stakeholders from the Mistra Carbon Exit program and, as a whole, facilitated by analysts that organize step 1 and 3 and refine and evaluate in step 2 and 4.

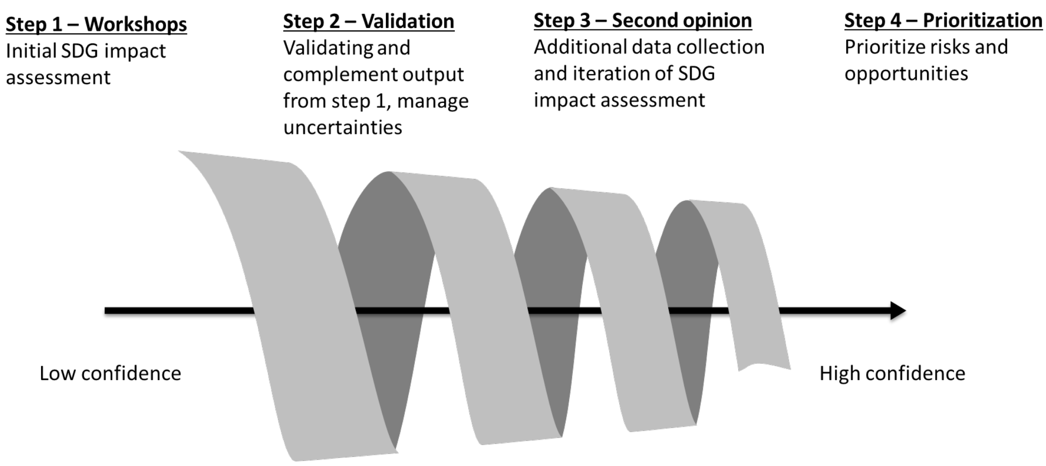

Figure 3. The overarching process of gathering input in a series of iterations with the aim to increase confidence in each step.

In the first step, the input to the initial SDG impact assessments is performed in workshop formats, gathering expertise linked to the Mistra Carbon Exit case studies. The workshops are characterized by exploration – "turn every stone" – and reflection on potential impacts on all 17 SDGs with respect to the study objects. As basis, the SDG Impact Assessment Tool (Gothenburg Centre for Sustainable Development, 2019), developed in conjunction with Mistra Carbon Exit, was used. The tool provides a simple but structured approach to assess impact on the SDGs. The common task of the workshops is to assign the impact from the study objects on each SDG in the categories of 'direct positive', 'indirect positive', 'negligible', 'indirect negative', 'direct negative', or 'more knowledge needed'. Every categorization is motivated by a short text to present reasoning and assumptions. Direct and indirect impacts are defined according to when, in a chain of events, they appear. Direct impacts appear as a direct consequence of the implementation of the object, whereas indirect impacts appear as a second consequence down the chain of events, *i.e.* as a result of the direct impact. The main reason behind this distinction is to help and guide reasoning of participants in the identification of potential impacts. This is also a way of pinpointing the interlinkages between SDGs. As noted earlier, impact on one SDG might give rise to impact(s) on other SDG(s) as a 'secondary effect'. Positive or negative impacts are defined as supporting or hindering, respectively, the implementation of an SDG.

For each SDG, the reasoning is guided based on three aspects as indicated in the flowchart of figure 4. The first aspect pertains the knowledge and confidence level – does the participants have enough knowledge to confidently assess how the object would impact the SDG? The next aspect is a binary perspective on magnitude or 'size of impact' – is the impact of significant magnitude or negligible? Finally, impacts are assessed as combination of direct or indirect and positive or negative. In the end, the tool (webpage) outputs a visualization of the impact assessment along with corresponding motivations.

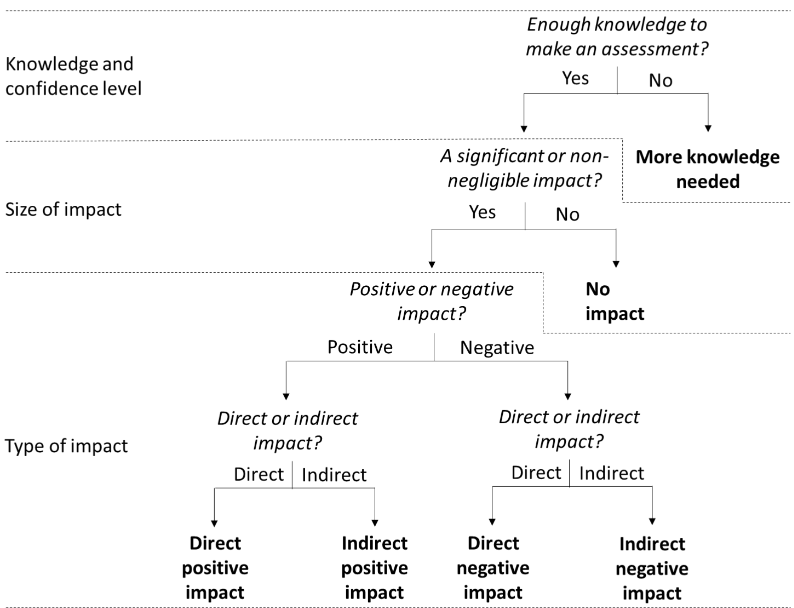

Figure 4. *Flow chart outlining the knowledge and confidence level, the size of the impact and the type of impact in the assessments.*

In the second step (Fig. 3), the output from workshops is refined by structuring the material according to (i) contextualization of impacts (highlighting the connections between SDG targets and the study object), (ii) describing the mechanism of impacts (the underlying rationale of an impact and the cause-effect relationships) and, (iii) verifying the categorization of impacts as 'negligible impact', 'positive impact', 'negative impact' or 'more knowledge needed'. With respect to the workshop output, the second step is a structuring, validating and, if necessary, complementing the SDG impact assessment, with the aim to prepare for the second opinion of the expert group in step 3 (Fig 3).

The third step invites participating experts to provide a second round of opinions in a Delphi methodinspired approach. That is, experts are encouraged to revise their earlier input after the information has been structured. Ideally, input at this stage will be complimented with references from relevant literature to provide confidence.

A final evaluation of the assessment is produced in step 4, prioritizing impacts by describing them as risks or opportunities, and keeping usability and comprehensibility in mind. Risk is defined as a combination of 'likelihood' and 'consequence' of an unsustainable outcome – an outcome that hinders the implementation of the SDG. Opportunities are also defined as a combination of 'likelihood' and 'consequence' but for a sustainable outcome – an outcome that supports the implementation of the SDG. Evaluating risks and opportunities for SDGs is, to some extent, dependent on the context of the object and on SDG-specific and value-laden issues (ethics).

To prioritize risks and opportunities is to deal with approximating magnitude of impacts and valuating their respective weight, with the aim to evaluate them as more or less important. The methodological approach is not developed to shy away ethics, but rather to find a structured way to gain common understanding of relevant sustainability perspectives in a specific context and offer input to decision and policy making.

Results and Discussion

Here follows a summary of results from SDG impact assessments carried out in the Mistra carbon exit program per study object. The results are presented as final output from step 4 (see figure 3), i.e. impacts on the SDGs expressed as prioritized risks and opportunities. Note that impacts affecting climate mitigation are here allocated to SDG 13 (Climate Action), although corresponding targets as such mainly considers aspects such as resilience and adaptive capacity, policy mainstreaming and education and awareness. Tables 1 to 3 in Appendix gives a summary of output from step 2.

Wind power

Driven by governmental support and sharp cost reductions, installed wind power capacity has expanded dramatically during the latest decades worldwide (International Energy Agency, 2019). Design improvements, economy of scale and learning by doing all have played their part to make wind power the lowest cost option in some parts of the world for new energy investments (Bloomberg New Energy Finance, 2019). In Sweden, relatively low costs due to favorable wind conditions position wind power as a key component for a future clean and fossil free energy system. In the production phase, opportunities were identified for SDG 8 (Decent work and economic growth), as production, large-scale construction and assembly of wind power plants brings employment. As construction and production of parts primarily occurs outside Sweden, expansion of wind power in Sweden creates positive spillover effects in countries where extraction of raw materials and production takes place. The employments for assembling the power plans will, however, be located in Sweden. In addition, jobs are not only created in the construction, production and assembly of the wind power plants themselves, but also in construction of supporting infrastructure (e.g. roads, telecommunication and electricity grids). New employment opportunities are also likely to appear in the use phase, since maintenance of these plants are necessary. Similarly, in the end-of-life phase, dismantling and recycling of wind power plants have the potential to generate additional employment.

Other opportunities in the use phase were identified for SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). As wind power to some extent replace fossil and bio energy, air pollution will be reduced with positive health impacts. Positive impact on SDG 7 (Affordable and Clean Energy) from wind power is confident since it is free from emissions.

SDG 13 (Climate Action), however, is vague in the Swedish context. The Swedish electricity mix is almost free from fossil energy, with a share of just about 1% (Swedish Energy Agency, 2020). Thus, positive impacts on SDG 13 (Climate Action) could only be motivated by that an expansion of wind power would force any potential future investments in fossil energy into obscurity, or as an international spillover in terms of bringing costs down (economies of scale and learning by doing). From a resource perspective, wind power reduces the need for fossil fuels and produce no waste in the user phase, motivating a positive impact on SDG 12 (Responsible Consumption and Production, most notably target 12.2). As an additional international spillover, it could be discussed weather Swedish investments in wind power would reduce CO2 emissions in a way that also reduce ocean acidification and hence positively impacts SDG 14 (Life Below Water, target 14.3).

Several risks of large-scale wind power expansion were also identified. In the production phase, negative spillover effects were identified for SDG 3 (Good Health and Wellbeing), SDG 6 (Clean Water and Sanitation) and SDG 15 (Life on Land). The mining and extraction of rare earth elements (mainly neodymium and dysprosium) for wind turbine components may contaminate soil and drinking water as well as give rise local air pollution. These impacts require that special attention should be given to the sustainability in the production of wind turbine components in exporting countries.

In Sweden, a risk for SDG 15 was found in the production phase as construction of infrastructure needed for the wind power installations might affect wildlife and biodiversity in otherwise pristine areas. The use of wind power plants also entails a risk to SDG 15, since elevated mortality of birds and bats have been observed (Rydell et al., 2017). These SDG 15 impacts are mostly of local significance and highlights the importance of making thorough environmental impact assessments of wind power installations.

There are still knowledge gaps associated with wind power. The most significant relates to SDG 12 (Responsible Consumption and Production, target 12.5) and recycling. For example, how can wind turbine blades, made of composite materials, be recycled and is the use of the non-renewable rare-earth elements in wind turbines sustainable. The question whether noise from wind power plants impacts human wellbeing (SDG 3 Good Health and Well-being) is still not entirely resolved, but as it is assumed that large wind parks will be built in remote areas, potential risks are assessed as negligible.

Table 1. Identified and prioritized Opportunities, Risks and Knowledge gaps over the life cycle phases Production, Use and End-of-life from scaling up Wind power in Sweden. Solid and dotted frames around the SDG icons indicate impacts in Sweden and as international spillovers, respectively. For a full list of opportunities, risks and knowledge gaps, see Appendix, Table 1.

	Production	Use	End-of-life
Opportunities	8 DECENT WORK AND ECONOMIC GROWTH	3 GOOD HEALTH AND WELL-BEING; 7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	8 DECENT WORK AND ECONOMIC GROWTH
Risks	3 GOOD HEALTH AND WELL-BEING; 6 CLEAN WATER AND SANITATION; 15 LIFE ON LAND; 15 LIFE ON LAND	15 LIFE ON LAND	
More knowledge needed	12 RESPONSIBLE CONSUMPTION AND PRODUCTION		12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Climate neutral cement

The UN has estimated that more than half of the urban infrastructure that will exist in 2050 is yet to be built and the total global floor area of buildings will double within the next three or four decades (UN Environment and International Resource Panel, 2019). Concrete is a heavily used construction material all over the world, and cement is an important component in concrete as produced today. Cement is a major source of greenhouse gas emissions. In Sweden, cement production represents 6 % of all greenhouse gas emissions (Karltorp et al., 2019). Although existing concrete structures acts as a sink for CO_2 - in Sweden it has been estimated to take up 17 % of the emissions from the production of new cement (Andersson et al., 2013) and at a global scale modelling efforts have estimated that 43 % of the cement emissions are offset by the uptake in concrete (Xi et al., 2016) - a transformation to climate neutral concrete production is crucial to reach net zero emissions of GHGs. That will require substantially reduced emissions in cement production, which could be achieved by replacing fossil fuel with renewable in cement ovens, reduce cement contents of concrete through substitution or efficiency measures, and carbon capture and storage (CCS) of process related emissions (Karlsson et al., 2020a). A successful transformation of the cement production would thus positively contribute to SDG 13 (*Climate Action*) and, in case of increased use of renewable energy and efficiency measures, also contribute to SDG 7 (*Affordable and Clean Energy*, target 7.2 and 7.3).

Moving towards climate neutral cement would, however, not necessarily eliminate risks associated with conventional cement and concrete production, and could potentially add new through the introduction of CCS. Most relevant are negative impacts on SDG 14 (*Life Below Water*) and SDG 15 (*Life on Land*) from exploitation of marine sand deposits and storage of CO_2 in aquifers, and limestone quarries, respectively. If future demand for concrete increases, exploitation of marine sand and limestone quarries deposits may affect local marine and terrestrial ecosystems negatively. Risks connected to the exploitation of marine sand are categorized as an international spillover from imports, as current Swedish concrete mainly uses natural gravel and crushed rock as raw materials. The use of machinery and explosives in quarries and cement production emits NO_x, dust and generates noise with potential adverse effect on local wildlife and surrounding ecosystems. Continued use of cement will have a negative impact on SDG 12 (*Responsible Consumption and Production*) as extraction of limestone is a natural resource and contributor to material footprint, as expressed in target 12.2. Cement production in areas with water scarcity could pose a threat to the availability of fresh water, thus negatively impacting SDG 6 (*Clean Water and Sanitation*, target 6.4). The latter is, however, a risk deemed as low in a Swedish context but might be highly relevant in other parts of the world.

Given that climate neutral cement can be realized, continued use of concrete as a dominating building material will provide an opportunity for actors in the Swedish concrete and cement industry to continue their operations and provide jobs, thus contributing to SDG 8 (*Decent Work and Economic Growth*). Innovative actors succeeding in producing climate neutral cement could gain first mover advantages on global markets, thereby further reinforcing positive impact on SDG 8. As noted, however, climate neutral cement can be achieved through various mitigation options with various degrees of innovativeness. A strong reliance on CCS could spur less innovation in the cement industry itself compared to the substitution of fuels and raw materials. Thus, to which extent this shift would create opportunities for SDG 9 (Industry, innovation and infrastructure, targets 9.2, 9.3 and 9.5 specifically), remains to be seen.

Future sustainable cities, as targeted in SDG 11 (*Sustainable Cities and Communities*), will heavily depend on the availability of climate neutral cement and concrete, if not to jeopardize SDG 13 (*Climate Action*). Increased demand in China, India and Africa are expected to force global annual cement production above 4 billion tons in 2050, an increase of some 30% compared to the levels at 2010 (Schneider *et al*, 2011). The main driver is the expansion of cities with its related buildings and transport infrastructure. Here, Swedish production and know-how could have a positive impact on

SDG 11, not only in a Swedish setting but as a positive spillover, assuming that Swedish actors will be at an international forefront. The same is true for SDG 9 (*Industry, Innovation and Infrastructure*), where the availability of climate neutral cement is an enabler for sustainable infrastructure (target 9.1), given that additional costs will be kept low.

SDG impacts from climate neutral cement in the end-of-life phase are judged as mostly negligible. Concrete is a long-lived but non-renewable material with low potential for genuine recycling, *i.e.* creating a feedback of used concrete to produce new cement and/or concrete. The most likely end-of-life application is to crush concrete constructions into rubbles that could be used as *e.g.* road gravel, revetments and retaining walls. Put into practice, the reuse of concrete will reduce the need for natural resources as stone and gravel, thereby creating an opportunity for SDG 12.

Table 2. Identified and prioritized opportunities, risks and knowledge gaps over the life cycle phases Production, Use and End-of-life from scaling up Climate neutral cement production in Sweden. Solid and dotted frames around the SDG icons indicate impacts in Sweden and international spillover effects, respectively. For a full list of opportunities, risks and knowledge gaps, see Appendix, Table 2.

	Production	Use	End-of-life
Opportunities	8 DECENT WORK AND ECONOMIC GROWTH; 13 CLIMATE ACTION; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES; 11 SUSTAINABLE CITIES AND COMMUNITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Risks	14 LIFE BELOW WATER; 15 LIFE ON LAND; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION		
More knowledge needed	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE		

Electric vehicle batteries

Globally, the electrification of cars has picked up pace during the latest decade. 2018 was a record year, raising the worldwide stock to above 5 million units (International Energy Agency, 2019). Assuming that new electric vehicles are powered with renewable electricity and replace fossil fuels, this trend will have a considerable contribution to combat climate change and raise demand for new electricity generation technologies, thereby creating opportunities for SDG 13 (*Climate Action*) and SDG 7 (*Affordable and Clean Energy*). Accelerating electrification brings increased demand for batteries and its associated components and raw materials. In current battery designs (lithium-ion), lithium and cobalt are crucial elements to achieve competitive efficiency and energy storing capacity. Lithium is predominantly mined in South America and Australia, whereas a vast majority of global supply of cobalt originates from small-scale mines in Congo.

Following an electrification of passenger vehicles in Sweden, mining and extraction of crucial metals might create negative spillover in exporting countries. Most notable are risks connected to the quality of fresh water and adverse effects on landscapes and surrounding ecosystems. There is evidence of how the use of water in the extraction and refining of lithium and cobalt contaminates water reservoirs and, consequently, disrupt fresh water supply of local communities (SDG 6 *Clean Water and Sanitation*, target 6.1) (Wang et al., 2020). Hazardous chemicals used during refining puts the health of workers and ecosystems at risk, negatively impacting SDG 3 (*Good Health and Well-Being*, specifically target 3.9), SDG 6 (target 6.3) and SDG 15 (target 15.5). Increasing cobalt extraction in unstable conflict regions and states could increase tensions and worsen conflicts as the competition over mineral trade increases, thereby hindering the implementation of SDG 16 (*Peace, Justice and Strong Institutions*, targets 16.1, 16.4, 16.5 and 16.6).

Some estimates indicate that about a fifth of the Congo population is directly or indirectly involved in small-scale mining of minerals (Garrett, 2007). Much of the mining in is small-scale, artisanal and unregulated, involving child labor (SDG 8 *Decent Work and Economic Growth*, target 8.7 and SDG 16 *Peace, Justice and Strong Institutions*, target 16.2) and with common occurrences of work injuries and health issues (SDG 3 *Good Health and Well-Being*, target 3.9 and SDG 8 *Decent Work and Economic Growth*, target 8.8). In addition, workers in and around mining areas have been subjected to violence, corruption and human trafficking (Garrett, 2007), negatively impacting SDG 16 *Peace, Justice and Strong Institutions*, specifically target 16.2, 16.5 and 16.10.

On the other hand, wide scale electrification will bring jobs and economic growth opportunities to regions rich in cobalt, lithium and other associated elements. Assuming that corruption, institutional capacity and working conditions will improve, new streams of income from export could potentially bring welfare with numerous indirect opportunities. Swedish industrial actors active in car and battery manufacturing will accordingly bring opportunities to implement SDG 8 (*Decent Work and Economic Growth*) and SDG 9 (*Industry, Innovation and Infrastructure*) in these regions by meeting both domestic and international demand for electrified vehicles.

Electrification of cars in Sweden will bring improved air quality through the reduction of nitrogen oxides (NO_x) and particulate matter (PM), increasing the environmental performance of cities as expressed in SDG 11 (*Sustainable Cities and Communities*, target 11.6). That will contribute human health and SDG 3 (*Good health and Well-being*, target 3.9), with reduced costs for medication and health care. Additionally, improved air quality will decrease weathering and erosion of buildings with potential positive contribution to maintaining cultural heritage, as expressed in SDG 11 (*Sustainable Cities and Communities*, target 11.4).

Looking ahead, the reuse or recycling of electric vehicle batteries will be a growing concern. Establishing functioning recycling systems for *e.g.* lithium and cobalt will bring down the need to use virgin metals, thereby somewhat lessen a negative impact on SDG 12 (*Responsible Consumption and Production*, target 12.2). In Sweden and Europe, it is likely that such systems will be further developed, considering current environmental regulations. How these systems will be organized and perform is, however, still uncertain and requires more knowledge.

Table 3. Identified and prioritized opportunities, risks and knowledge gaps over the life cycle phases Production, Use and End-of-life from scaling up Electric vehicle batteries in Sweden. Solid and dotted frames around the SDG icons indicate impacts in Sweden and international spillover effects, respectively. For a full list of opportunities, risks and knowledge gaps, see Appendix, Table 3.

	Production	Use	End-of-life
Opportunities	8 Decent work and economic growth; 9 Industry, innovation and infrastructure	3 Good health and well-being; 7 Affordable and clean energy; 11 Sustainable cities and communities; 13 Climate action; 8 Decent work and economic growth	
Risks	3 Good health and well-being; 6 Clean water and sanitation; 8 Decent work and economic growth; 15 Life on land; 16 Peace, justice and strong institutions		
More knowledge needed			12 Responsible consumption and production

Conclusions and final remarks

From the sustainability assessments of the key components to reach net zero emissions of greenhouse gases in Sweden by 2045, it is clear that ambitious climate targets come with opportunities and risks to the implementation of several SDGs. Achieving production of climate neutral cement, up-scaling of wind power and electrification of cars can bring competitive advantages to Swedish industry on global markets, and create synergies with the implementation of, for example, SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). Swedish know-how to realize changes at system level could be exported, as well as commercial products and services. Economy of scale and learning curves could bring down costs of climate mitigation in other regions and countries. However, actual contributions from Swedish companies on international markets will likely be relatively small. Particularly so as more and more nations are expected to act on global warming, thereby bringing relative market shares for Swedish industry down. Still, Swedish actions might prove important to support sustainable climate action elsewhere, resulting in potential positive spillovers on several SDGs. Such a development, however, will rely on the existence of strong and fair institutions that keep corruption and other unjust market barriers in check, which emphasize the importance of global implementation of SDG 16 (Peace, Justice and Strong Institutions).

Considering potential risks, SDG 15 (Life on Land) emerge as the goal for which most conflicts exists with the net zero greenhouse gas emission target in Sweden. These risks are mainly identified upstream in supply chains and are linked to the extraction of raw materials in other parts of the world. In countries with weak or non-existing environmental regulation, mining is oftentimes destructive to surrounding landscapes and can contaminate soil and fresh waters, thereby threatening biodiversity and ecosystems. Even though negative impacts on SDG 15 are mostly local, the consequences to communities and wildlife could be dire. The mining of cobalt as a crucial element in lithium-ion batteries is of a particular concern. The vast majority of global supply of cobalt stems from Congo – a country struggling with conflicts and unjust human development. The mining is characterized as small-scale and artisanal, and apart from its impact on SDG 15, is associated with child labor, work injuries and human trafficking, posing risks to SDG 3 (Good health and Wellbeing), SDG 8 (Decent work and Economic Growth) and SDG 16 (Peace, Justice and Strong Institutions).

As globalization has developed more and more complex value and supply chains, it is not a trivial task to minimize negative spillovers. It requires clear regulations, transparency of business operations and responsibility and authority to act on negative impacts both in businesses and regulation. These are crucial issues to sustainable development but oftentimes neglected in global supply chains. Furthermore, the question of who should act for a given concern, and how, is contextual and general recommendations are rarely specific enough to be effective. Achieving sustainable development requires broad cooperation along the supply chains with relevant policy makers, regulators and international institutions. To obtain an ethical and sustainable approach without negative spillovers, Swedish companies, policy makers, regulators and Swedish representation in international institutions need not only to be involved but also to be pro-active. In an international comparison, the Swedish society has environmental regulations in place, a high degree of transparency, and decision making is generally based on accountability. Hence, pro-activity of Swedish actors is both appropriate and important.

The SDG impact assessments developed and employed in Mistra Carbon Exit has proved functional in pinpointing risks and opportunities linked to scenarios for net zero greenhouse gas emissions, using expert opinions as starting points. In order to align with the holistic intentions of the 2030 Agenda, the impacts from the scenarios need to be assessed on all the SDGs. Together the SDGs form a complex web of connections, interlinkage and dependencies that requires further investigations to be described in detail. The assessments presented here points to future work where specific operations in supply chains is further investigated. Involving even more stakeholders would enable a higher precision to describe specific barriers and risks and to formulate suitable actions and strategies to advance sustainability performance of a given supply chain. We recommend to advance the analyses by developing specific indicators for the supply chains identified as important for the set of SDGs highlighted in this report.

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Appendix

Table 1. Identified SDG impacts in Sweden and international spillovers, including their mechanisms, over the life cycle phases Production, Use and End-of-life from scaling up Wind power in Sweden.

SDG	Impact	Sweden or spillover	Lifecycle phase	Mechanism
1	Indirect positive	Spillover	Use	Per capita income level and energy use is positively correlated. Nordic wind power installations can decrease corresponding costs in other regions.
2	No impact			No significant mechanism identified.
3	Direct positive	Sweden	Use	Replacing air-polluting and hazardous power generation.
3	Indirect negative	Sweden	Use	Increased stress by noise pollution
3	Indirect negative	Spillover	Production	Mining and extraction of elements (e.g. mainly neodymium and dysprosium) for wind turbine components may be hazardous and contaminate drinking water
4	No impact			No significant mechanism identified.
5	No impact			No significant mechanism identified.
6	Indirect negative	Spillover	Production	Mining and extraction of elements (e.g. mainly neodymium and dysprosium) for wind turbine components may contaminate drinking water
7	Direct positive	Sweden	Production & Use	Relatively low cost, clean and renewable energy source.
8	Direct positive	Sweden & Spillover	Production, Use & End-of-life	Improves resource efficiency in consumption and production. Construction and maintenance of wind power plants generates employment.
9	Direct positive	Sweden	Use	Stimulates sustainable, resilient and inclusive infrastructures, sustainable energy use in industry, and innovation.
10	Indirect positive	Sweden	Use	Decentralized energy systems can promote social, economic and political inclusion in society.
10	Indirect negative	Sweden	Use	Can create conflicts between cities, needing electricity, and rural areas where wind power plants need to be built.
10	Direct negative	Spillover	Use	Wind resources vary between regions. Wind power can make some regions more import dependent.
11	Direct positive	Sweden	Use	Can reduce environmental impact of electricity generation for cities.
11	Indirect positive	Sweden	Use	Can support sustainable transport systems in cities.
12	Direct positive	Sweden	Use	Reduced use of fossil fuels for electricity generation and sustainable use of natural resources.
12	Direct negative	Spillover	Production	Increased mining and use of non-renewable rare metals.
12	More knowledge needed	Sweden	End-of-life	Wind turbine blades hard to recycle.
13	Direct positive	Sweden	Use	Replace electricity generation from fossil fuels.
14	Indirect positive	Spillover	Use	Reduced ocean acidification from reduced use of fossil fuels.
14	Direct negative	Sweden	Use	Local effects from building and maintenance of offshore wind parks.
14	More knowledge needed	Sweden	Use	Potential negative impacts on marine life from noise pollution.
15	Direct negative	Sweden	Use	Construction and use of wind parks threaten biodiversity and natural terrestrial, freshwater and mountain ecosystems and habitats.
15	Direct negative	Spillover	Production	Mining and extraction of elements (e.g. mainly neodymium and dysprosium) for wind turbine components threaten biodiversity and natural terrestrial, freshwater and mountain ecosystems and habitats.
15	More knowledge needed	Sweden	Use	Potential negative impacts on terrestrial life from noise pollution.
16	Indirect negative	Spillover	Production	Mining and resource extraction may have a negative effect on human rights in regions with fragile governance.
17	Direct positive	Spillover	Use	Can stimulate partnerships through electricity trading at local, national and regional levels.

Table 2. Identified SDG impacts in Sweden and international spillovers, including their mechanisms, over the life cycle phases Production, Use and End-of-life from scaling up Climate neutral cement production in Sweden.

SDG	Impact	Sweden or spillover	Lifecycle phase	Mechanism
1	No impact			No significant mechanism identified.
2	No impact			No significant mechanism identified.
3	No impact			No significant mechanism identified.
4	No impact			No significant mechanism identified.
5	No impact			No significant mechanism identified.
6	Indirect positive	Sweden	Production	Concrete may ensure continued access to water and sanitation as the underlying infrastructures are built using it.
6	Indirect negative	Sweden	Production	Extraction of limestone used in cement could have negative effects on local water resources.
7	Indirect positive	Sweden	Use	Concrete is an important building block when installing many renewable energy technologies, such as wind and solar power. Climate neutral concrete would further limit climate impact from energy technologies.
8	Indirect positive	Sweden	Production	Cement, being one of the most used materials in the world, has spurred economic development and will likely continue to do so.
9	Direct positive	Sweden	Production	Making cement climate neutral will support sustainable industrialization and sustainable infrastructure development.
9	Direct positive	Sweden	Use	Making concrete climate neutral will support sustainable industrialization and sustainable infrastructure development.
9	More knowledge needed	Sweden	Production	It's unknown if implementation of Carbon Capture and Storage (CCS) will be successful and if it will hamper innovation in substitution of fuels and raw materials in cement production.
10	No impact			No significant mechanism identified.
11	Indirect positive	Sweden & spillover	Use	Climate neutral cement and concrete will contribute to reduce climate impact of built environment as many urban centers continue to grow.
12	Indirect positive	Sweden	End-of-life	Concrete can be used instead of gravel and sand and thereby increase resource efficiency.
12	Direct negative	Sweden	Production	Cement production extracts limestone, which is a natural resource, and thereby impacts material footprint, as expressed in target 12.2.
13	Direct positive	Sweden	Production	In Sweden, the cement industry is the second biggest emitter of GHGs of all industries in Sweden. Making cement climate neutral would therefore contribute significantly to lowering emissions.
14	Indirect negative	Spillover	Production	Harvesting of natural sand deposits for cement production will affect local and regional marine ecosystems.
14	Indirect negative	Spillover	Production	Climate neutral cement will likely require CCS, which in turn could affect marine environments if carbon is stored at ocean floor.
15	Indirect negative	Sweden	Production	Extraction of resources for cement production will affect local terrestrial ecosystems negatively, with effects such as resource depletion and noise pollution.
15	More knowledge needed	Sweden	Production	Using climate neutral cement and concrete could lower pressure on wood, and thereby forests, though the evidence is inconclusive.
16	No impact			No significant mechanism identified.
17	No impact			No significant mechanism identified.

Table 3. Identified SDG impacts in Sweden and international spillovers, including their mechanisms, over the life cycle phases Production, Use and End-of-life from scaling up Electric vehicle batteries in Sweden

SDG	Impact	Sweden or spillover	Lifecycle phase	Mechanism
1	No impact			No significant mechanism identified.
2	No impact			No significant mechanism identified.
3	Direct positive	Sweden	Use	Reduced emissions of hazardous substances to air from fossil fuels.
3	Direct negative	Spillover	Production	Adverse health risks during extraction of *e.g.* cobalt in some regions.
4	Indirect positive	Spillover	Use & End-of-life	No significant mechanism identified.
5	More knowledge needed	Spillover	Use & End-of-life	Electrification may relieve many women from *e.g.* time-consuming household chores. More research into how batteries may support this is needed.
6	Direct negative	Spillover	Production	Lithium extraction and refining can contaminate water resources.
7	Direct positive	Sweden	Use	Clean energy and increased energy efficiency for transportation.
7	More knowledge needed	Sweden	End-of-life	EVBs may be used for a second time elsewhere where energy infrastructure is lacking.
8	Indirect positive	Sweden	Production & Use	Battery and car manufacturing bring employment to Swedish companies.
8	Indirect negative	Spillover	Production	Mining and extraction of minerals is small-scale, artisanal, unregulated and involves child labor (target 8.7).
9	Direct positive	Sweden	Use	EVBs will likely stimulate development of electricity infrastructure and adoption of clean and environmentally sound technologies.
9	Indirect positive	Spillover	Use & End-of-life	Batteries may enhance the electricity infrastructure in some regions, spurring industrialization.
10	More knowledge needed	Sweden	Use	Higher price for electric vehicles may lead to inequalities regarding mobility.
10	More knowledge needed	Spillover	Use	Electrification of transportation could lead to a shift in power between some economies, though how this could unfold requires more research.
11	Direct positive	Sweden	Use	By replacing fossil fuels, and thereby reducing air pollution, the environmental performance of cities in increased. Less noise pollution by replacing combustion engines.
12	More knowledge needed	Spillover	Production	EVB will give lower demand for fossil fuels, but to which extent is currently unknown.
12	More knowledge needed	Spillover	Production	More knowledge is needed about how EVBs can be reused or recycled, and potentially reduce the need for extraction and use of rare earth elements.
13	Direct positive	Sweden & Spillover	Use	No emissions of GHGs from passenger vehicles due to energy production in Sweden.
14	Indirect positive	Sweden & spillover	Use	Less ocean acidification by replacing fossil fuels. Less extraction of oil at sea.
14	More knowledge needed	Spillover	Production	Risk of deep mining of cobalt, which could affect marine ecosystems.
15	Direct negative	Spillover	Production	Increased mining and resource extraction will affect terrestrial landscapes and ecosystems.
16	Direct negative	Spillover	Production	Increased demand and competition for "conflict minerals" could worsen conflicts, increase corruption, violence and human trafficking, and weaken institutions.
17	Indirect positive	Sweden & spillover	Use	Increased knowledge sharing, cooperation and trade.

About Mistra Carbon Exit

Mistra Carbon Exit is a research programme that identifies and analyzes the technical, economic and political opportunities and challenges for Sweden to reach the target of net zero greenhouse gas emissions by 2045. We will identify pathways and policies for how Sweden and Swedish companies can become frontrunners in transforming society and industries, providing low carbon products and services while at the same time dressing market risks. This will make Sweden an important international example for other countries to follow.

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