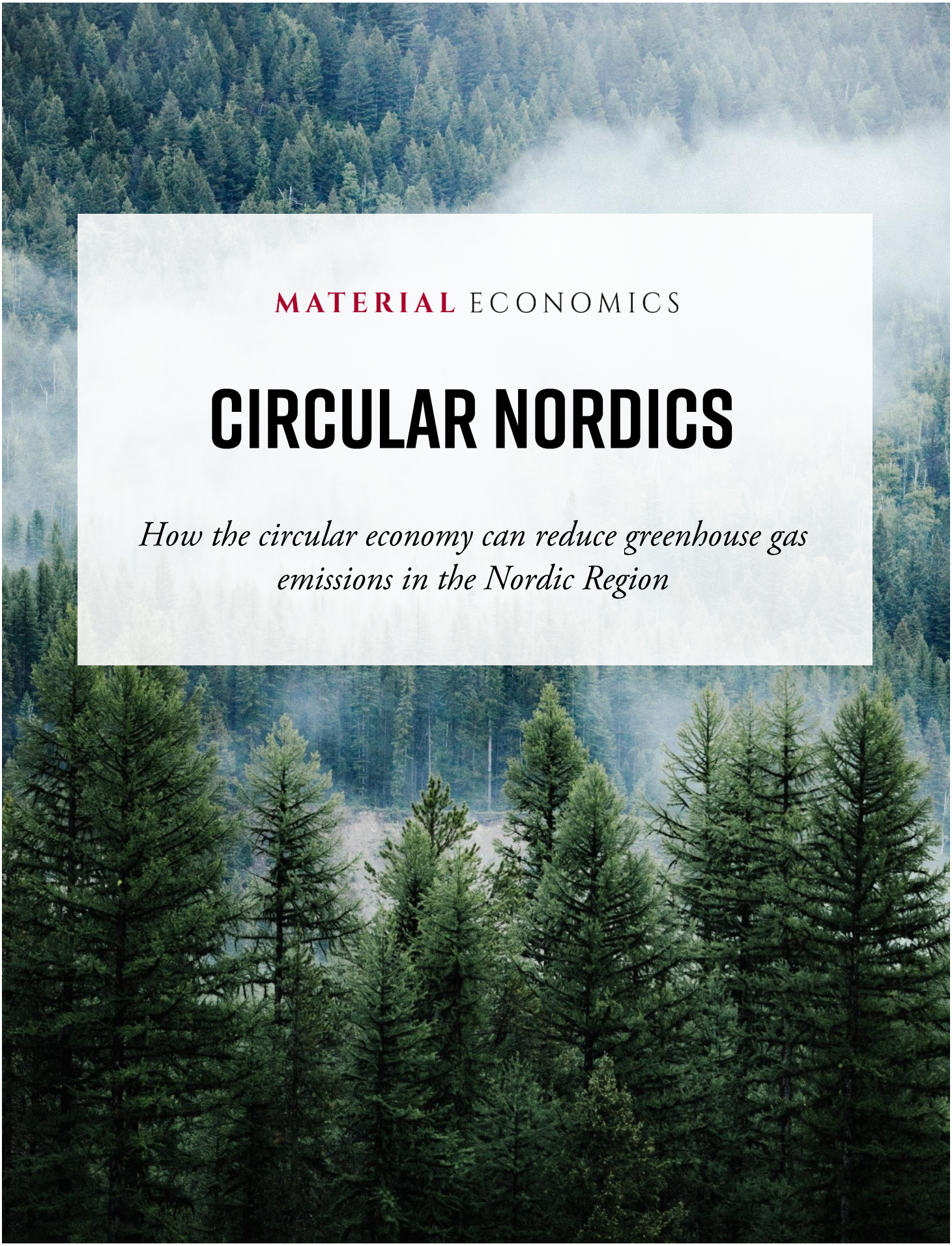

MATERIAL ECONOMICS

CIRCULAR NORDICS

How the circular economy can reduce greenhouse gas emissions in the Nordic Region

DANISH BUSINESS AUTHORITY

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PREFACE

The Nordic countries have been among the global leaders in the fight against climate change for many years.[1] They have set strict national emission targets, introduced strong domestic decarbonization incentives, and been consistent advocates for more ambitious international action.

So far, these climate efforts, in the Nordics and elsewhere, have largely focused on energy-related emissions: increasing energy efficiency and reducing fossil fuel use. That approach had a lot of merit, since fossil fuel represents a major share of the greenhouse gas (GHG) emission problem and cleaner technologies have become available over the last decade.

However, over the last few years an increasing body of evidence has shown that addressing energy-related emissions is not enough to reach the ambitions set forth in the Paris agreement. Additional strategies are needed to address emissions from the production of food and of materials such as steel, cement, plastics and aluminium.

The circular economy brings such strategies. Material-related emissions are reduced through recirculation, reduced waste, lightweighting, extended lifetimes, new sharing business models, and more. At the European and global level, circular opportunities to cut GHG emissions have been explored by Material Economics, the Ellen MacArthur Foundation, and others, in reports such as *The Circular Economy – a Powerful Force for Climate Mitigation*, *Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry*, and most recently, *Completing the Picture*.[2] These reports have been heavily leveraged, and their perspectives adapted to a Nordic context.

This report aims to provide first answers to two questions:

- To what extent can circular strategies contribute to reducing GHG emissions and reaching climate goals in Denmark, Finland, Iceland, Norway, Sweden, Greenland, Åland and the Faroe Islands?[3]
- What role can Nordic cooperation play in realizing such opportunities?

The report was commissioned by the Danish Business Authority in preparation for Denmark's presidency of the Nordic Council of Ministers starting in 2020. It was developed by Material Economics in a short effort during November and December 2019, and as such can only provide initial answers to the questions above. Deeper quantitative analyses are required as a basis for robust policy decisions. Material Economics is grateful for the guidance and insights provided by the reference panel and the interviewed policymakers and business representatives. Partner organizations and their constituencies do not necessarily endorse all findings or conclusions in this report. All errors and omissions are the responsibility of the authors.

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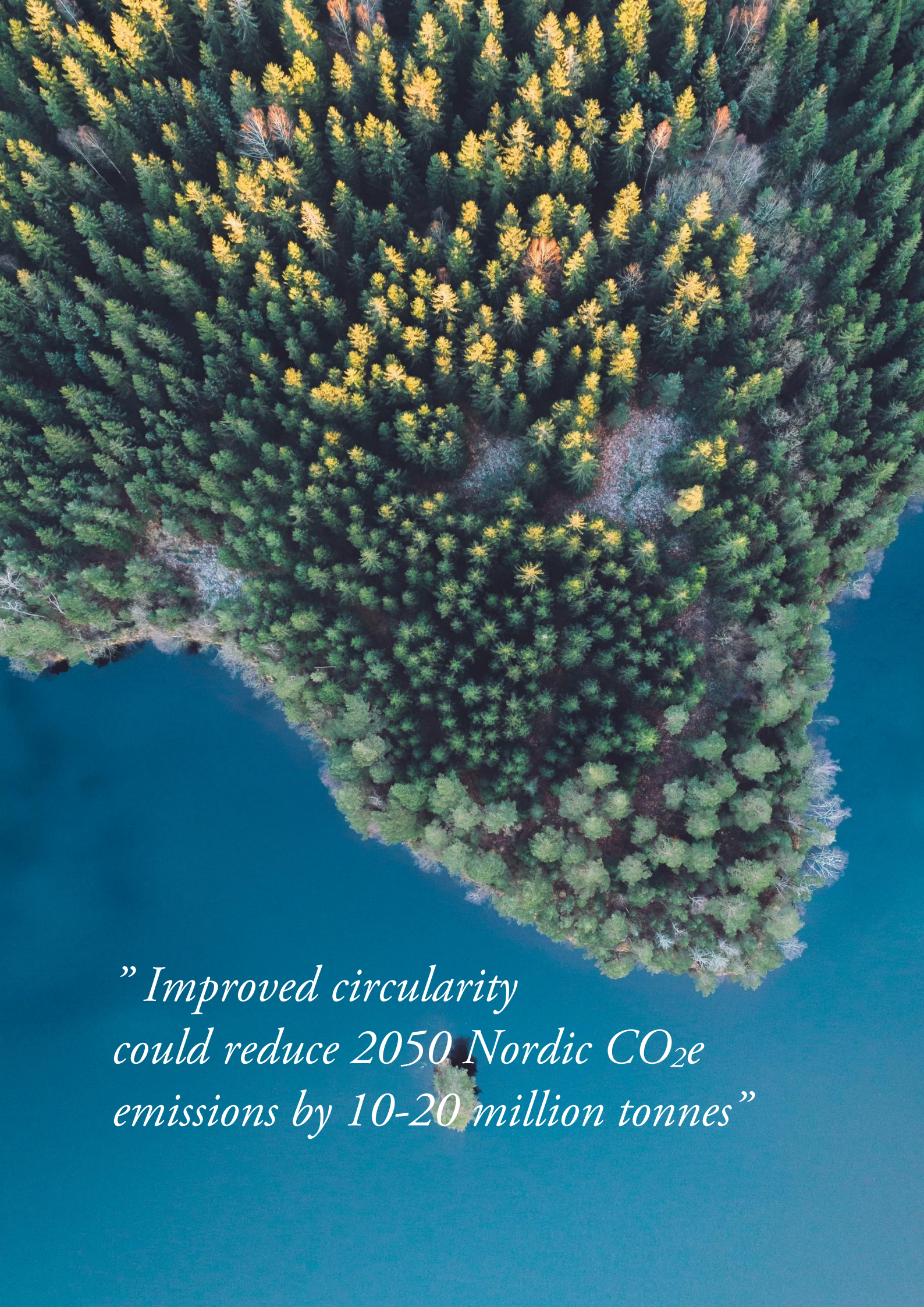


” Improved circularity could reduce 2050 Nordic CO_2e emissions by 10-20 million tonnes”

EXECUTIVE SUMMARY

This report explores whether circular approaches have the potential to further accelerate GHG emission reductions in the Nordic countries, and if circularity is a suitable area for Nordic cooperation. *The central conclusion of the report is that the circular economy could indeed help speed up the Nordic region's transition to a low-carbon economy, and several areas look suitable for Nordic cooperation*. In more detail:

1. BETTER CIRCULARITY MEANS LESS EMISSIONS

Circularity helps reduce GHG emissions in three ways (see exhibit 1): Increased material recirculation, improved product material efficiency and new circular business models. These are all powerful emission reduction levers. For example, production of recycled steel, aluminium and plastics emits 5-20 times less CO_2 than virgin production.[4] As another example, one shared car can replace trips in five privately owned cars, with the corresponding savings in materials per passenger kilometer.[5] This report focuses on exploring such opportunities in steel, plastics, aluminium, cement and food, which make up 74% of Nordic material-related emissions.

2. CIRCULAR OPPORTUNITIES ARE OFTEN ADDITIONAL TO CURRENT POLICY

In practice, current CO_2 and waste policy provide only weak to moderate incentives for companies to improve circularity. For example, under current policy regimes, product design and recycling practices for steel, aluminium and plastics are still such that the materials are downgraded in every use cycle. In the case of plastics, this downgrading is so significant that the used plastics in many cases is literally worthless. Recycled steel and aluminium also typically have distinctly different application areas than virgin materials. The result is a need to produce more virgin, CO_2-intensive materials than would otherwise be necessary. As for circular business models such as car sharing, house sharing and re-manufacturing, they are often not thought of as GHG emission reduction opportunities.[6] As a result, they are not promoted as they would be if their total societal benefits were appreciated. Again, the result is a need to produce more virgin, high-CO_2 materials. Hence the report's claim that increased circularity is a promising GHG emission reduction opportunity, and one that is largely additional to today's policy. Climate targets of net-zero emissions are in sight only if these material-related emissions are addressed in parallel with the transition to carbon-free energy.

3. CIRCULARITY COULD REMOVE 10-20 MILLION TONNES CO_2E BY 2050

For small, open economies such as the Nordic countries, the GHG emissions impact of imports and exports needs to be considered in addition to the territorial emissions. This is no easy task: there are many examples of sound circularity actions the Nordic countries could take, but where the emission benefit would accrue to other countries, and vice versa. If, for instance, the Nordic countries were to improve its plastics recycling, only parts of the GHG emission reduction would be seen in the territorial emission statistics of the Nordic countries as they would incinerate less plastics and therefore emit less GHGs. The other part would be seen in the countries that produced and exported the plastics to us as they would produce less plastics, thus causing less emissions. Large opportunities impacting territorial emissions include plastics and aluminium recycling, food waste reduction, car- and building-sharing and reduced over-specification in construction. The report's initial estimate is that the Nordic countries could take circularity action that would reduce

their own territorial emissions covered by the Paris agreement by 10-20 million tonnes of CO_2e per year by 2050, corresponding to 4-9% of total Nordic emissions in 2017. In addition, circular economy could reduce emissions from imported materials and products by another 20-30 million tonnes of CO_2e per year by 2050. This apparent 'mismatch' between who acts and who receives the benefit is a consequence of the global UNFCCC GHG negotiation framework that is centered around territorial emissions.

4. THERE IS A ROLE FOR NORDIC COOPERATION

Much of today's product regulation is European, and waste regulation is largely national. Are there any meaningful roles for cooperation at the Nordic level, 'in-between' the EU- and national policy making? The conclusion of this report is that there are. Circularity is held back by scale disadvantages. Recycling plants are often at the scale of 10,000-100,000 tonnes per year, whereas primary production plant capacity often reaches 1-3 million tonnes per year. This implies a role for Nordic cooperation: If the Nordic countries aligned its waste management regulation and public procurement principles, this would create a market that is 2.5-5 times larger than any one of the larger countries by themselves.[7] This will make a meaningful difference to companies that invest in this market. The Nordic countries could also apply for intra-Nordic exemptions from the EU regulations on waste exports, which would create a true internal market for secondary materials. In addition, circular policymaking is a nascent field, and there are many cross-learnings to be had from cooperation between the Nordic countries. A number of other cooperation areas are outlined in the report.

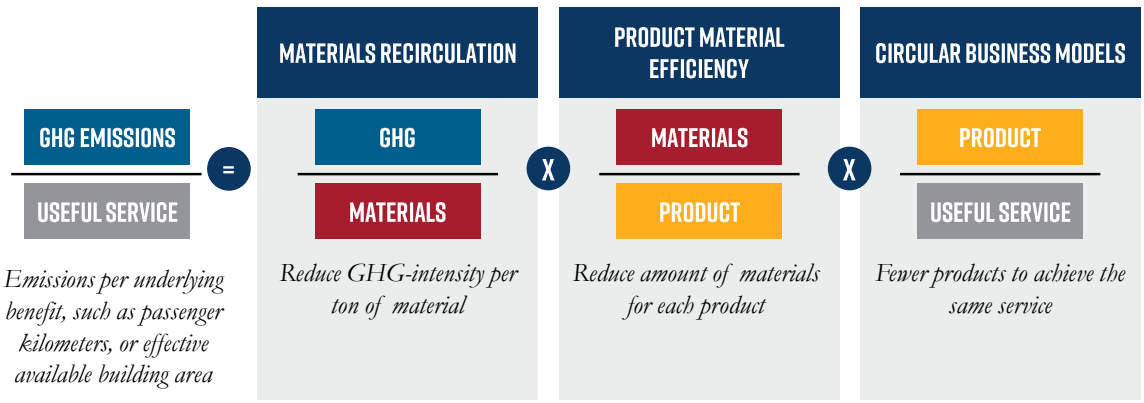
5. CIRCULAR POLICY OPPORTUNITIES TO BE EXPLORED FURTHER

The scope and time available for this report were not sufficient to fully quantify and validate the opportunity of a circular Nordic region. The results of this first quantitative investigation are promising enough to merit a deeper look. Conversely, the materials-related emissions are so large that it is hard to imagine the Nordic countries reaching their net-zero ambitions without heavily using circular solution strategies.

Finally, the Nordic countries can cooperate even more at EU level. In environmental questions, the Nordic countries are listened to and speaking with one voice will make a difference.

EXHIBIT I.

CIRCULAR ECONOMY REDUCES EMISSIONS FROM MATERIAL PRODUCTION AND CONSUMPTION



1. INTRODUCTION: COMPLETING THE PICTURE

The Nordic countries have set increasingly ambitious climate targets. Norway targets net-zero emissions by 2030, Finland by 2035, Iceland by 2040, and Sweden by 2045 – albeit with slightly different definitions. Denmark will have net-zero emissions by 2050 and achieve a 70% reduction by 2030 compared to 1990. Greenland and the Faroe Islands are covered by Denmark's targets, and Åland is included in Finland's goal.

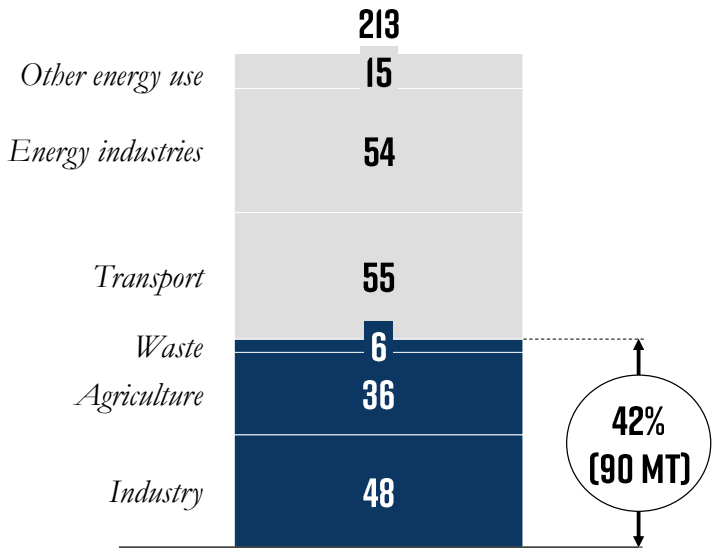
There is a strong political vision on how to reduce energy emissions globally, and businesses and investors try to deliver on that vision by changing the way energy is produced and consumed in large sectors including mobility and buildings. Energy use for electricity, heating, transportation, and other energy industries accounts for 58% of total Nordic GHG emissions, and the region demonstrates progress in addressing these emissions.[8] Renewable energy is an important part of the progress: hydropower in Norway and Sweden, biomass in combined heat and power plants in Finland and Sweden, and the world's highest share of wind power in Denmark. In 2017, 36-72% of energy consumption in Nordic countries came from renewable sources.[9] In addition, innovations including low-energy construction and district heating systems have cut GHG emissions from household heating systems to 75% below the average in OECD Europe.[10] Overall, this has led to a decoupling of production-related emissions from economic growth.

There is potential to reduce the remaining 42% of Nordic emissions that come from the material economy – industrial processes, product use, agriculture and waste[11].

EXHIBIT 2.[12]

42% OF NORDIC EMISSIONS COME FROM MATERIAL PRODUCTION

Greenhouse gases in the Nordic countries, million tonnes CO_2e 2017



Note: Emissions from energy use in agricultural and material production are included in the categories 'Agriculture' and 'Industry'. Emissions do not include land use, land-use change, Forestry, and memo items (CO_2 from biomass, Indirect N_2O, International aviation, and International water-borne transport.
Source: See endnotes.

This share is similar in the Nordics and the rest of the world, which might be surprising given the unique characteristics of the Nordic economies. Material-related emissions have been calculated based on UNFCCC data and include process emissions and energy emissions from the production of materials and agricultural products. In the Nordics, the above-mentioned low-carbon energy mix reduces energy emissions, leading to a larger share of material-related emissions. In parallel, the service sector is an important source of income in the Nordics compared to industrial and agricultural giants such as China, India, and Russia, which creates a counteracting effect and reduces the Nordic share of material-related emissions.[13]

Climate targets of net-zero emissions are in sight only if these material-related emissions are addressed in parallel with the transition to carbon-free energy. Fortunately, industrial companies that process materials such as steel, aluminium, plastics and cement are covered by the European Union's Emissions Trading Scheme and therefore have clear incentives to reduce territorial emissions from material production.

2. CONTEXT: NORDIC MATERIAL USE AND EMISSIONS

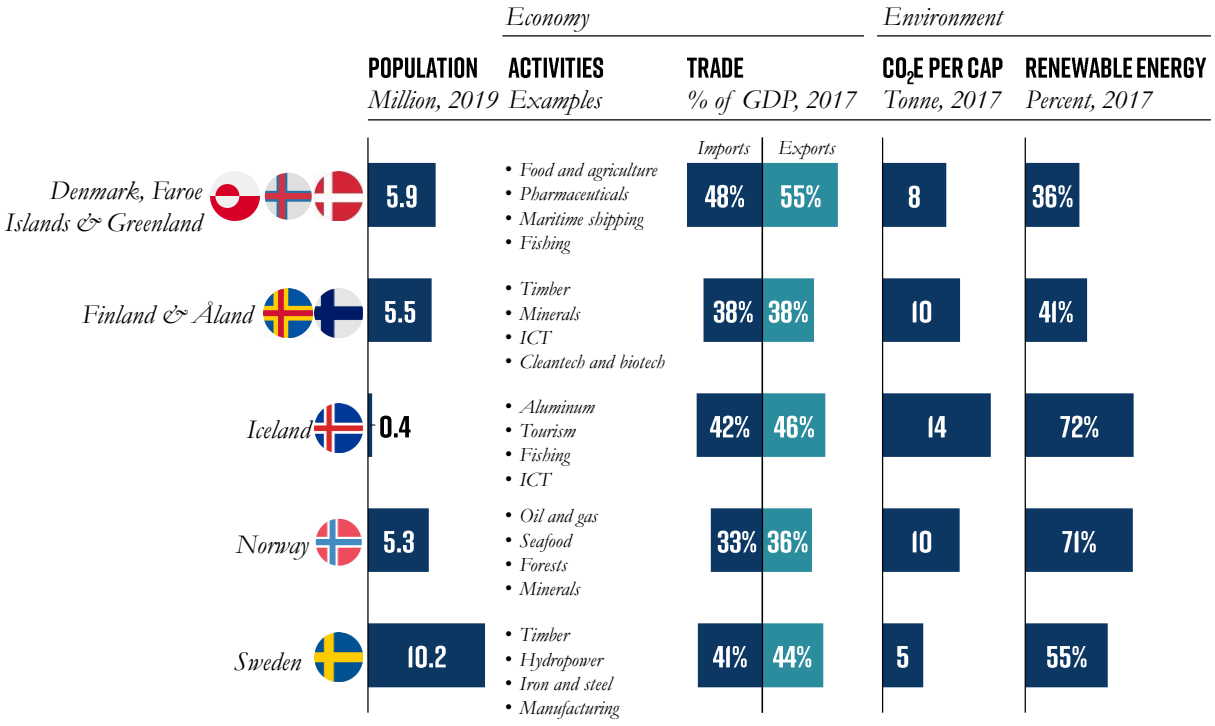
Thus far, most climate discussions have focused on the supply side: the need to develop and deploy new industrial production processes, turn to non-fossil feedstock and fuels, and use carbon capture and storage to offset any remaining emissions. Climate and industrial debates often lack a demand-side discussion on how to make better use of the materials already produced in order to reduce the need for new production.

The Nordic region is well positioned to address material-related emissions. There are large trade flows among the Nordic countries and to the rest of the world. The open Nordic economies impact global emissions both through their own production and through imported goods and materials. There is a strong willingness to reduce emissions and an emerging interest in circular economy strategies among businesses and policymakers.

The region produces significant volumes of key materials and food, and economic activities vary across countries. Finland and Sweden have historically produced paper, pulp, and steel from raw materials such as timber, iron and other minerals, and have become an important supplier of information and communication technology. Denmark is a major producer and exporter of pharmaceuticals, food and other agricultural products, and a global leader in maritime shipping and renewable energy. Norway is a major producer and exporter of seafood, oil and gas. Greenland and the Faroe Islands are large fish exporters, and Åland derives income from tourism, shipping and food processing.

EXHIBIT 3.

THE NORDIC COUNTRIES ARE SMALL, OPEN ECONOMIES WITH A STRONG FOCUS ON REDUCING ENVIRONMENTAL IMPACT



Source: Eurostat, Nordic Statistics database

SELECTED MATERIALS IN THIS REPORT

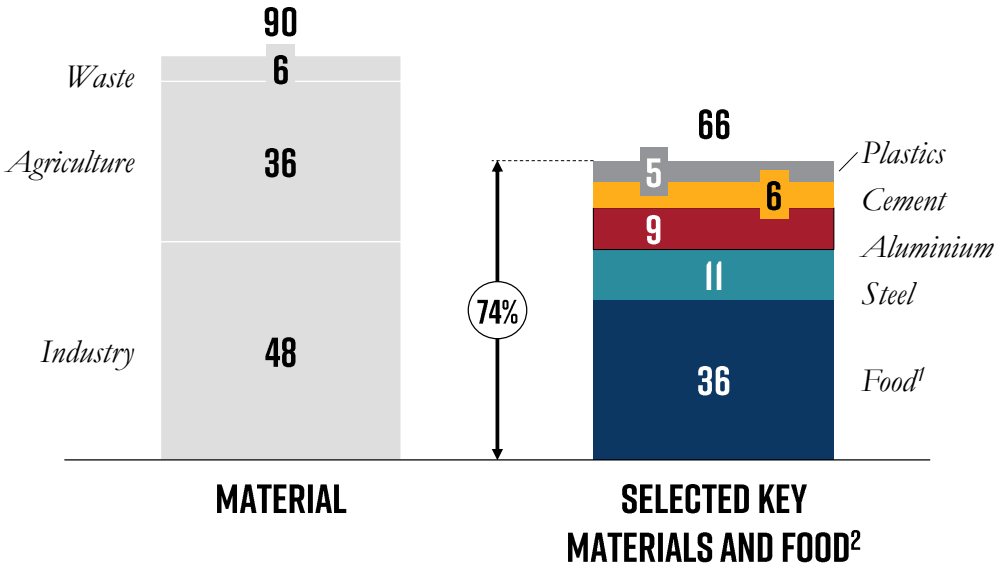
Four key materials – steel, aluminium, cement and plastics – and food are crucial for the discussion on CO_2 and circularity. They make up 31% of total Nordic emissions and 74% of material-related emissions, and are the focus of this report. They are also critical for businesses and consumers in the Nordic countries, so careful trade-offs must be made in all discussion about how to reduce emissions.

The Nordic region is a producer and consumer of all four materials, and production varies by country. Sweden and Finland are major steel producers with companies like SSAB and Outokumpu and have an annual output of 8.7 million tonnes of steel. Iceland (Rio Tinto Alcan, Alcoa etc.) and Norway (Norsk Hydro, Elkem etc.) have most of the Nordic aluminium smelting capacity because of their access to green energy and produce 2.4 million tonnes of aluminum per year. Sweden is the largest producer of plastics with a total production of 1.2 million tonnes. Cement is produced in all larger Nordic countries due to transportation economics. All Nordic countries produce food. Denmark has a well-developed food and beverage sector with brands like Carlsberg, Arla Foods and Danish Crown. Norway, Iceland, the Faroe Islands and Greenland are large fish exporters. Sweden and Finland mainly produce food for self-sufficiency and are net importers.

EXHIBIT 4. [14]

PRODUCTION EMISSIONS FROM KEY MATERIALS AND FOOD MAKE UP 74% OF MATERIAL ECONOMY EMISSIONS

Emissions from material and food production in the Nordics, million tonnes CO_2e 2017



1. Agricultural emissions - this is mainly for food production. Value chain and end-of-life emissions from food are not included.
2. Not including waste.
Sources: Material Economics analysis. See endnotes.

A few other materials of importance to the Nordic economies have been excluded from this study. They deserve mentioning here and are of interest for follow-up studies. One of the most important is textiles. Each year, the Nordic countries use more than 400,000 tonnes of clothing made from carbon intensive fabric, leading to a global carbon footprint close to that of cement. The Nordic Council of Ministers, the Ellen Macarthur Foundation and others have investigated the clothing industry from a circular perspective.[15]

Also of importance are wood, pulp and paper, which have been excluded since they are short cycle products made from trees that capture CO_2 from the atmosphere. Production of these materials yield biogenic emissions that are canceled out by removals from new tree growth. Although sand and gravel are produced and used in large quantities, circular economy brings limited potential to reduce emissions from these materials since they have low emission factors of 0.01 and 0.0043 kg CO_2e per kg material respectively.[16] Additional metals such as copper and zinc are important in their own right and partly covered by this report as alloys in steel production.

NORDIC MATERIAL USE

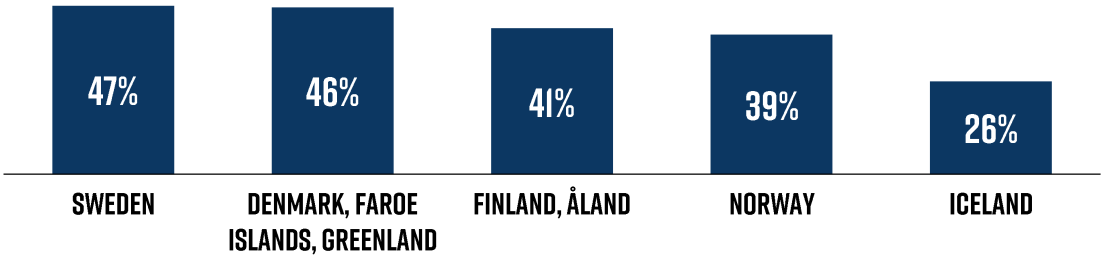
Production, use and end-of-life flow of materials make up the Nordic materials system: a set of intertwined production processes, products, business models, infrastructures, and end-of-life handling involving large economic values – and large GHG emissions. To reduce these emissions, change across the Nordic material system is possible and necessary to reach net-zero GHG emissions.

The Nordic countries are already among the best recyclers in the world and can strengthen their role as some of the world's most environmentally friendly economies by further improving their use of materials. For example, municipal waste recycling rates approach 50%, but are still below the EU target of 65% to be reached by 2035.[17]

EXHIBIT 5.

THE NORDIC COUNTRIES ARE SMALL, OPEN ECONOMIES WITH A STRONG FOCUS ON REDUCING ENVIRONMENTAL IMPACT

Recycling rate of municipal waste, percent 2017



Source: Eurostat

The Nordics also need to increase the quality and value preserved after each use cycle in order to reduce the demand for primary materials and their associated GHG emissions.[18] In Sweden, the value of materials that are lost or downgraded each year amounts to 1.2% of GDP.[19]

THE IMPORTANCE OF TRADE AND CONSUMPTION

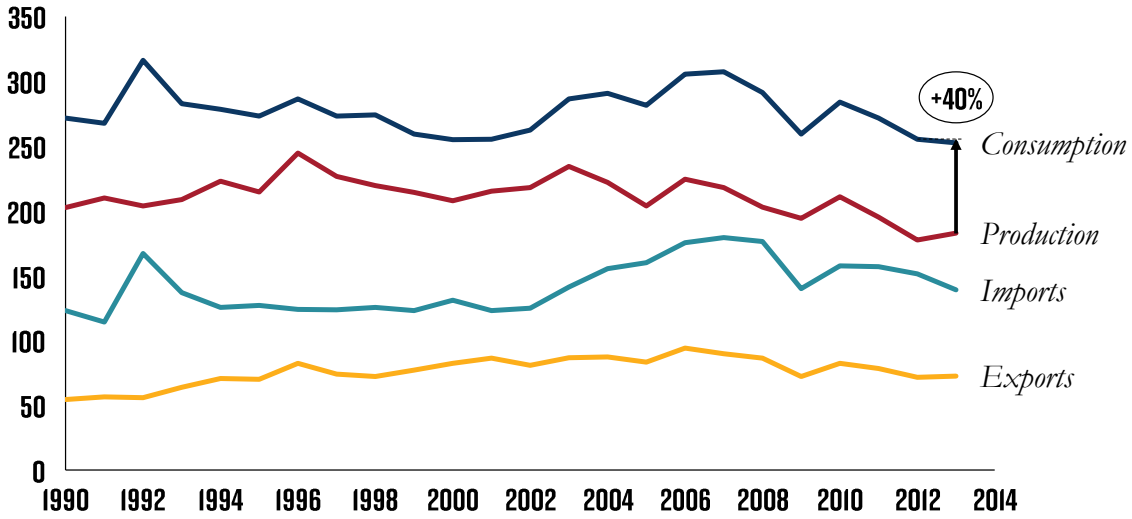
National targets and policies tend to focus on territorial emissions from domestic production. However, the Nordic countries not only impact global GHG emissions through domestic production but also through their consumption of materials and goods produced abroad. In high-income economies with large service sectors and moderate raw

material extraction and production, emissions from consumption tend to be higher than production emissions and the Nordic region is a net importer of emissions.

EXHIBIT 6.

THE NORDIC COUNTRIES ARE NET CO_2 IMPORTERS – EMISSIONS FROM CONSUMPTION ARE HIGHER THAN PRODUCTION

GHG emissions in the Nordic countries, million tonnes CO_2



Note: Contrary to the other data in this report, this data shows CO_2 emissions excluding other greenhouse gases.
Source: Nordic Council of Ministers (2016), GTAP-TSTRD with UNFCCC (Le Quéré et al., 2015)

The globalization of the world economy and the growth of industrial production in low income countries impact indirect GHG emissions from consumption in the Nordic region, but such indirect effects are not reflected in official climate data.[20] Emissions from Nordic consumption are 40% higher than territorial emissions. The share of imported emissions is fueled by for examples chemicals, primary and secondary metals, machinery, and electronic products from China, Russia, Brazil and India.[21]

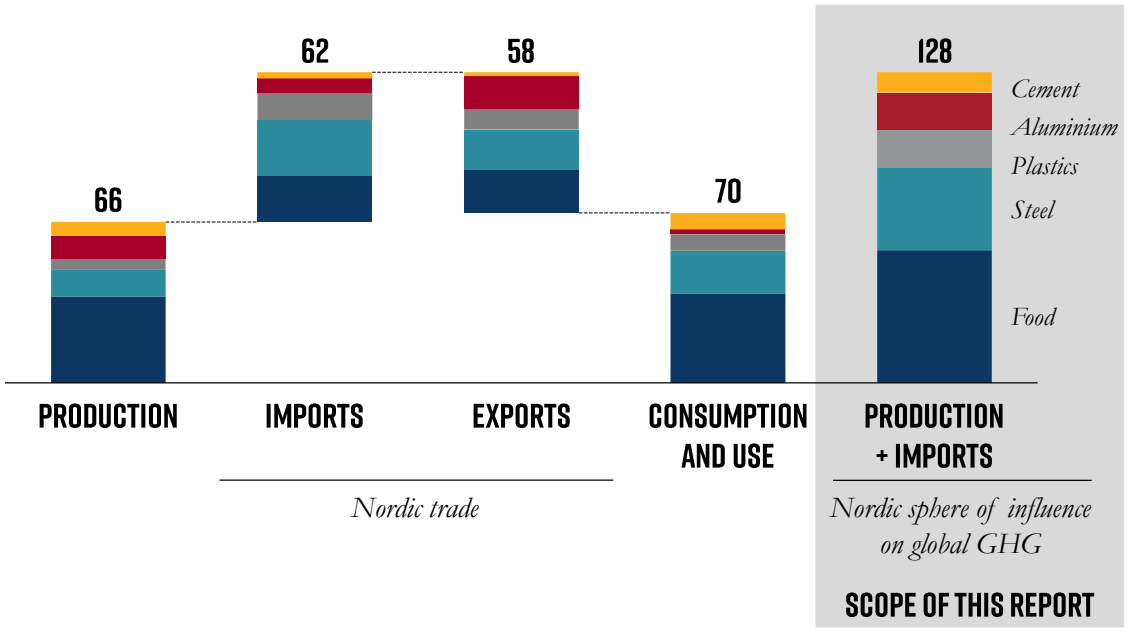
This global perspective is highly relevant also for the emissions in scope for this report: steel, plastics, aluminium and food are all part of international value chains with large trade volumes. Steel consumed in the Nordics are mostly imported while most of the Nordic production is exported.[22] Cement, on the other hand, is to a larger extent produced for local consumption with less imported emissions.

Nordic production of these materials leads to 66 million tonnes of CO_2e per year, and imports to another 62 million tonnes of CO_2e. The Nordic countries consume and use steel, aluminium, plastics, cement and food corresponding to emissions of 70 million tonnes of CO_2e per year.

EXHIBIT 7.[23]

THE NORDIC COUNTRIES INFLUENCE MATERIAL EMISSIONS THROUGH WHAT WE PRODUCE – AND USE

Nordic emissions from material and food, million tonnes CO_2e 2017



Note: Production is only material production (e.g. crude steel). Imports and exports include both trade of materials and products containing the material.
Source: Material Economic analysis. For data sources see endnotes.

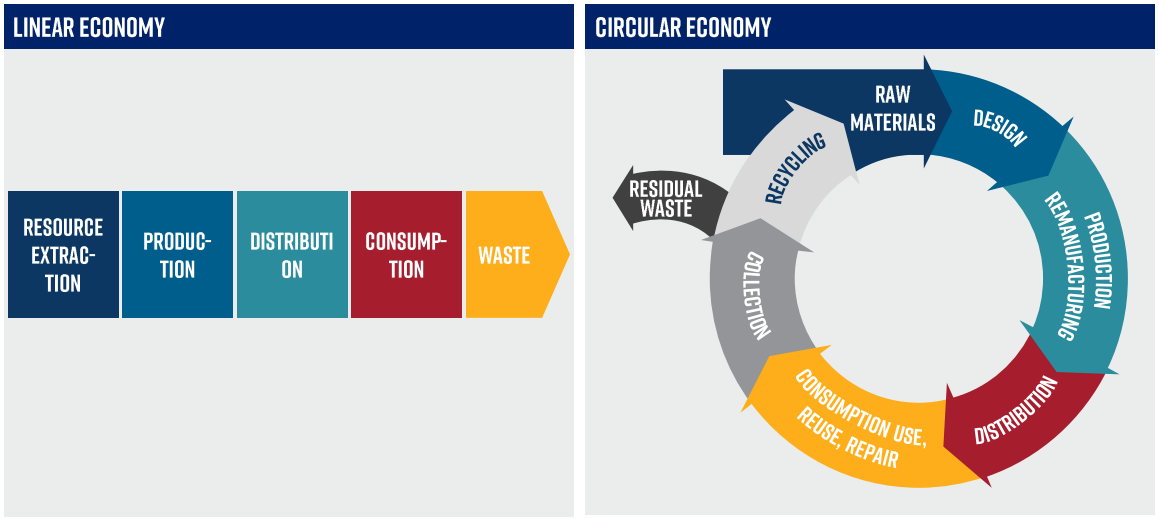
Although the Nordic countries are not obliged to address their imported emissions according to UNFCCC's set up, these emissions will need to be eliminated to reach the global 1.5℃ target. Given ambitious Nordic aspirations to mitigate climate change, it is reasonable for the Nordic countries to explore their role and potential in reducing imported emissions in parallel with territorial. Consequently, to capture the full potential of the circular economy, this report considers emissions from Nordic production and consumption of materials. More specifically, we use data on Nordic production and add imports to arrive at the Nordic countries' full sphere of influence on global GHG emissions.

3. POTENTIAL: LEVERAGING THE CIRCULAR ECONOMY

The circular economy transforms the way products are designed and used. It moves away from today's 'take-make-waste' linear model towards an economy that is regenerative. Natural systems are renewed, materials come from renewable sources, and waste is avoided through better design of materials, products, and business models.

EXHIBIT 8.

MOVING TOWARDS A MORE CIRCULAR ECONOMY



HOW THE CIRCULAR ECONOMY REDUCES EMISSIONS

The circular economy can reduce emissions from materials that are produced or consumed in the Nordics and is essential to reaching climate targets. It reduces GHG emissions in three ways: increased material recirculation, improved product material efficiency and new circular business models.

- *Materials recirculation:* Recirculating materials cuts GHG emissions since secondary material production is less carbon intensive and replaces primary production. However, current practice does not facilitate high replacement rates of primary production. An influx of new materials is required both to replace metals and plastics that are lost, and to compensate for downgrading of quality. For steel, the key is to ensure cleaner scrap flows that allow for higher-quality secondary steel, and less pollution of steel with copper. For aluminium, smaller losses and less mixing of different alloys will be crucial. Mixing and downgrading effects are particularly serious problems for plastics, making a large share of used plastics literally worthless. Changed product design and end-of-life disassembly is needed to enable high value recovery. Substitution to inherently renewable materials is another promising opportunity.

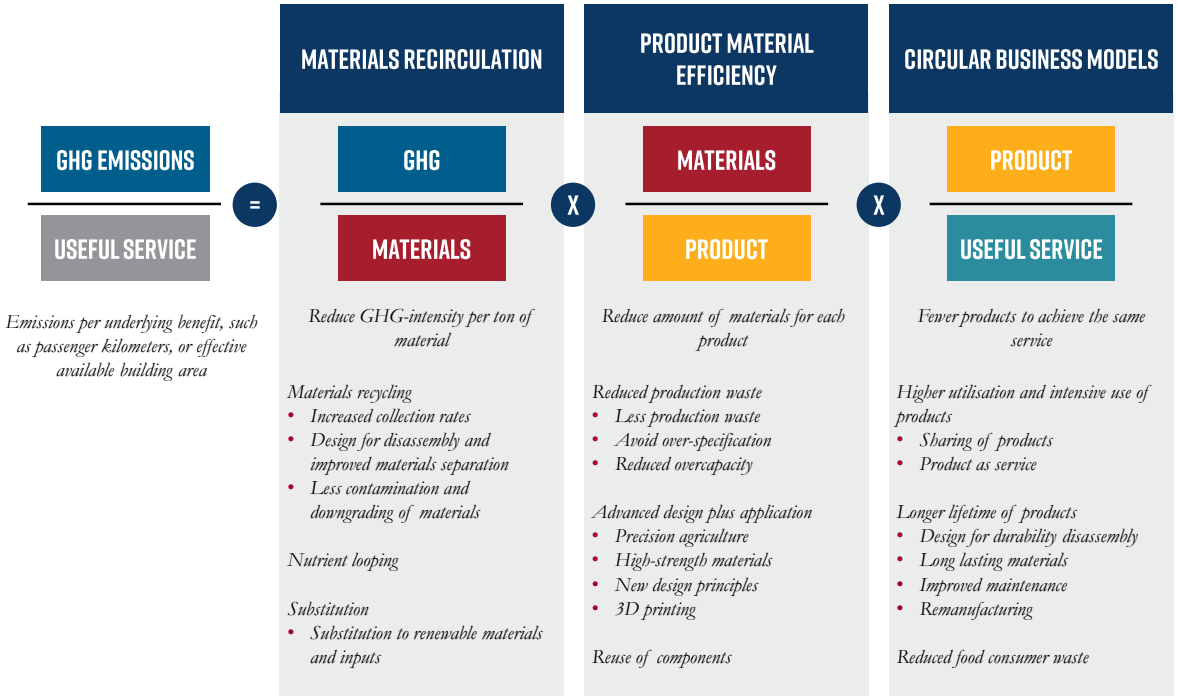
- *Product material efficiency:* Product material efficiency reduces the volume of materials required to make a product. It can be achieved by reducing the amount of materials that is lost in production, improved product design or more advanced materials and construction techniques. There are also opportunities to reduce over-specification, such as the overuse of steel in buildings, or tailor products to specific uses such as one- or

two-passenger cars for city-use. Many opportunities in the mobility and buildings value chains become more economic with greater digitization.[24] In principle, companies are already incentivized to optimize their material use. However, in practice, such opportunities are often uncaptured due to out-of-date building codes, established industry practices, or sheer inertia.

- *New circular business models:* Circular business models increase the use of each product, for example through sharing or prolonged lifetime. The result is a self-reinforcing loop of incentives for higher utilization, lower-carbon energy, and less materials use. Sharing and product-as-a-service models are taking root by themselves, but more could be done to accelerate their growth, and to find ways to resolve the concerns that have arisen with some early versions of such business models.

EXHIBIT 9.

CIRCULAR ECONOMY REDUCES EMISSIONS FROM MATERIAL PRODUCTION AND CONSUMPTION



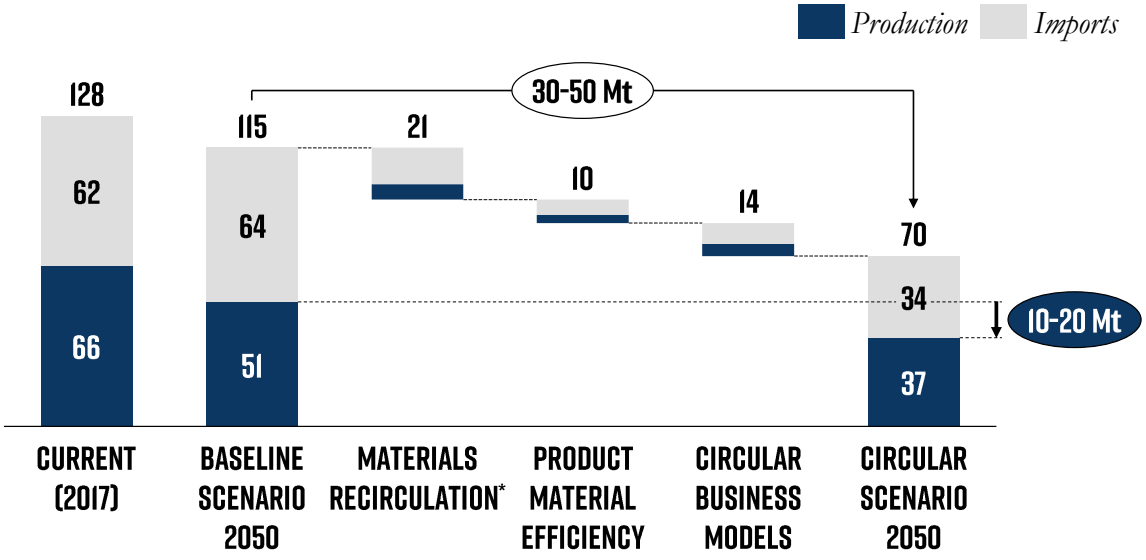
CIRCULAR ECONOMY'S POTENTIAL TO REDUCE NORDIC EMISSIONS

These circular strategies can reduce emissions from Nordic industrial and agricultural production. An initial estimation shows that circular Nordic territorial emissions from steel, aluminium, plastics, cement and food can be reduced by 10-20 million tonnes of CO_2e per year by 2050. This corresponds to 4-7% of total Nordic emissions in 2017 and is expected to represent an even higher share of total emissions by 2050, given anticipated progress to reduce energy emissions.[25]

EXHIBIT 10. [26]

CIRCULAR ECONOMY WILL CUT TERRITORIAL EMISSIONS BY 10-20 MILLION TONNES CO_2E – AND IMPORTED EMISSIONS EVEN MORE

Nordic emissions from production and imports, million tonnes CO_2e



* Impact from nutrient looping excluded in improvement potential since emissions from fertilizer production is excluded in baseline.
Source: Material Economics modelling. For data sources see endnotes.

The estimated potential to reduce territorial emissions related to materials can for example be captured through increased recycling, reduced food waste, improved use of construction materials, and sharing of transport and buildings.

- *Materials recirculation.* Emissions are reduced when production of primary material is replaced with secondary material with lower emission factors and when incineration is decreased. Only a part of these emission reductions will be counted towards the Nordic countries' territorial targets, namely those that either mean less incineration in the Nordics and those with local supply chain where less Nordic consumption also mean less Nordic production. Examples include further increasing the recycling of plastics and paper, anaerobic digestion of organic matter, and recirculation of cement and concrete. In total, such opportunities could mean 4-7 million tonnes less CO_2e annually by 2050.

- *Product material efficiency.* A key lever is food waste reduction. In the Nordics, 10 million tonnes of food is wasted each year.[27] Part of these losses are inevitable. Estimating that 5-10 percent of food losses could be reduced, Nordic territorial emissions would be reduced by approximately 2-4 million tonnes CO_2e per year by 2050. Another key lever is improved use of construction materials, where an estimated 1-4 million tonnes CO_2e of Nordic territorial emissions could be saved by 2050 through minimized over-specification of key materials (cement, steel, plastics, and aluminium).

- *Circular business models.* Sharing of buildings and cars means less materials (cement, steel, ...) for every unit of useful service, and prolonged life-times through re-use and re-manufacturing have the same effect. We have estimated a total opportunity of 4-7 million tons CO_2e per year by 2050, with the majority in the construction and building value chain, where the link between consumption and territorial emissions is strongest.

The circular economy's potential is even higher for materials and products that are imported to the Nordics from countries with more carbon-intense energy and less progressive climate policies. These imported emissions could be reduced by half, or another 20-30 million tonnes of CO_2e per year by 2050, resulting in the total reduction potential of 30-50 million tonnes of CO_2e per year by 2050 shown in exhibit 10.

This is a preliminary analysis in need of further validation. It is based on an estimation of the circular economy's potential to reduce emissions from steel, aluminium, plastics and cement at a European level, which has been adapted to the Nordic context and applied to the Nordic baseline of material production and imports discussed in chapter 2.3. The potential to reduce food is based on national data on avoidable food waste.
Important to note is that the business-as-usual scenario in 2050 has been adjusted for ongoing improvements that are expected to reduce emissions, such as a transition to low-carbon energy, electrification and new processes for steel production. The circular potential to reduce emissions from steel is limited by ongoing efforts, which will drastically reduce the emission factor for steel. However, plans to reduce emissions from cement production through carbon capture and storage (CCS) have not been included given the uncertainty and competing interests for CCS.

Circular economy could thus bring the Nordics – and the world – closer to a future with net-zero emissions.

BUILDING CIRCULAR MOMENTUM AT THE EUROPEAN AND NORDIC LEVEL

There is nascent momentum at the European level to capture the potential of the circular economy. The report *The Circular Economy – a Powerful Force for Climate Mitigation*,[28] showed that circular economy approaches has the potential to reduce European emissions from heavy industry by 56%. The European Union's last circular economy action plan was launched in 2015, and led to higher recycling targets and later to a ban on single-use plastics. More ambitious measures are now gaining traction among European policymakers and the European Commission is preparing a new circular economy action plan expected to be published in 2020. In her *Political Guidelines for the Next European Commission 2019-2024*, incoming President of the European Commission Ursula von der Leyen, states that the European Union "will be a world leader in circular economy and clean technologies",[29] and the circular economy is reassured to be of high priority in the upcoming European Green Deal.

There is also growing interest from both the public and private sector in the Nordic region. In line with the United Nations' call for member states to target a circular economy when developing national plans and policies, Nordic governments produce whitepapers, set up advisory boards and delegations, and develop strategies on circular economy. [30] Finnish innovation agency SITRA published the world's first national circular economy roadmap in 2016. In Sweden, VAT on repairs of bicycles, clothing, textiles and leather goods has been reduced from 25% to 12%. Norway has published a strategy for sustainable and circular consumption in Oslo and announced plans to launch a country-wide strategy.[31] The Norwegian government has signed an agreement to halve food waste by 2030. The Danish Ministries of Environment and Food and of Industry, Business and Financial Affairs launched Denmark's *Strategy for Circular Economy* in 2018, which was followed by a political agreement to initiate 16 financed initiatives for more circular Danish businesses and society. The strategy was based on recommendations to the government from an Advisory Board for Circular Economy of 12 business leaders. The Nordic Council of Ministers has published several reports on circularity in the Nordics and included circularity in recommendations for a Nordic sustainable public procurement policy.

There are also several pan-Nordic initiatives on circular economy, including the following:

- *Circular Economy Integration in the Nordic Industry for Enhanced Sustainability and Competitiveness*

(CIRCit) is a joint initiative from NordForsk, Nordic Energy Research and Nordic Innovation that creates science-based tools and approaches in order to: investigate and conceptualize circular business models, develop circular products, services and solutions, and close the loop of materials through remanufacturing, recycling and reuse.

- *Nordic Working Group for Circular Economy (NCE)* contributes to activities and exchanges of information that will promote the transition to a circular economy in the Nordic Region. The group also aims to influence the EU and global players, for example by helping to identify solutions that will reduce consumption of raw materials, waste, emissions and energy by recycling products.

- *Coalition to Accelerate Nordic Circular Economy* is co-financed by Nordic Innovation and is establishing a new platform – Nordic Circular Hotspot – to increase knowledge sharing about circular economy between the Nordic markets, while exploring needs and opportunities for specific circular economy projects in the Nordics.

- *Circular Economy Business Models in the Nordic Manufacturing Industry* aims to enable the creation of unique Nordic value chains, competence building in ecosystems, and collaboration between Nordic companies, and is supported by Nordic Innovation and SITRA.

- *LOOP – Ventures for the Circular Economy* builds a circular economy ecosystems in the Nordics and pilots circular business models by matching the challenges of larger companies with the solutions and working methods of start-ups.

In addition, Nordic businesses are beginning to adopt circular strategies that increase material re-circulation, improve product material efficiency and launch new ways of delivering value through sharing and extended product lifetime. There are quite a few examples. Swedish recycling company Ragn-Sells captures nitrogen from municipal sewage treatment plants to be used for plant nutrition and reduce the need for mineral fertilizer in food production. Norwegian crop nutrition producer Yara has partnered with Veolia to make use of food surplus and waste for production of organo-mineral fertilizers and soil improvement solutions. In 2018, Danish Carlsberg launched its snap-pack design to reduce plastic packaging, and Arla uses excess cheese resources for production of infant formula – at a profit. Swedish H&M's customers can rent clothing by the week,[32] and Danish toy manufacturer Lego considers launching a rental offering – "Lego as a service".[33] Waste and residues account for 70% of the raw materials in renewable diesel produced by Finnish oil refiner Neste. At least 25% of the plastic in all new Volvo cars will be made from recycled material by 2025.

Going forward, this emerging momentum on circular economy can be leveraged to reduce GHG emissions. Both emissions and circularity are climbing higher on the agenda of producing companies in the Nordics. The link between the two now needs to be widely recognized and policies must be coordinated and integrated to avoid conflicting goals. Nordic business, academia and policymakers alike agree that most of the circular economy's potential to reduce GHG emissions, foster innovation and create and maintain value remains untapped, and that little of this potential is captured in Nordic national climate plans. To date, these climate plans mostly focus on energy for electricity, transports and buildings, and waste gets some minor attention. Circular economy is not yet linked to GHG emissions and only mentioned in passing as an area that deserves more attention. Finland's climate plan explicitly states that circular economy will play an increasingly important role but that its impact on emissions has been limited to date.[34]

The unrealized potential to reduce Nordic emissions is positive news. Circular economy provides an additional solution for the Nordic countries to meet their climate goals and completes the picture of a carbon-neutral Nordic.

4. DEEP DIVES: BUILDINGS AND MOBILITY IN THE CIRCULAR ECONOMY

Material-related emissions can be reduced by altering how products are designed, assembled, used, collected and dissembled. The construction and mobility sectors make up a large part of Nordic material demand and offer major circular opportunities in terms of recycling, product design, material efficiency and, fundamentally, business models.

This chapter provides an early quantification of how much these opportunities can reduce GHG emissions. While previous chapters include Nordic material production and imports as the region's full sphere of influence, the following deep dives describe how the circular economy can reduce emissions from materials in buildings and cars that are used in the Nordics.

Food is another sector with a significant carbon footprint and great circular potential, as recognized in *Completing the Picture* and other reports by the Ellen Macarthur Foundation. It has not been included as a deep dive in this report but merits more attention in future efforts.

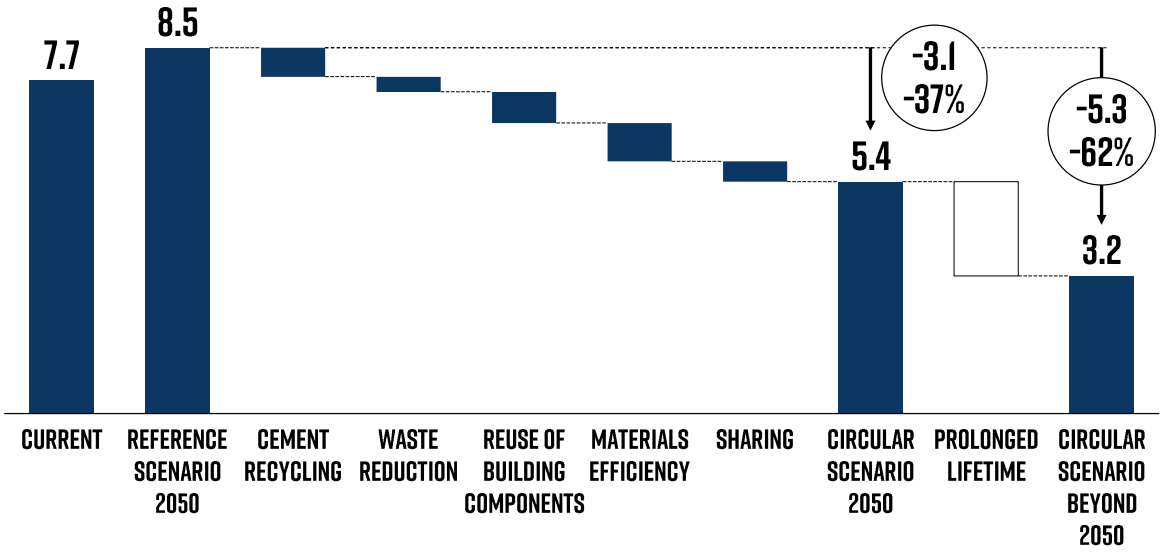
BUILDINGS – MATERIAL BANKS DESIGNED FOR SHARING, REUSE AND RECYCLING

The construction sector is a major user of materials. As the Nordic countries improve energy efficiency and decarbonize heat, construction will account for more than half of the lifetime GHG footprint of a building.[35]

EXHIBIT II.

A CIRCULAR SCENARIO REDUCES CO_2 EMISSIONS FROM BUILDING MATERIALS BY APPROXIMATELY ONE THIRD BY 2050

Emissions from materials used in buildings in Nordic countries, million tonnes of CO_2e per year



Note: Emissions from aluminium, cement, plastics, and steel used in buildings.
Source: Material Economics analysis based on Material Economics, "The Circular Economy – A Powerful Force for Climate Mitigation" (2018) and scaled for Nordic region.

A circular scenario for the built environment could increase material circularity, improved product material efficiency, and new business models, and thereby reduce demand for steel, aluminium, cement, and plastic. This would cut CO_2e emissions from building materials used in the Nordics by 37% or 3.1 million tonnes of CO_2e in 2050. There is additional potential to prolong building lifetimes, which would reduce emissions in the long run, beyond 2050.

- *Material circularity:* Materials can be designed for disassembly and high-value reuse and recycling to ensure that they serve as inputs for new production when they reach end-of-life. This way, buildings have the potential to serve as material banks – predictable sources of materials that can be reused. To enable this, a high degree of traceability is required, for example through a digital building passport, so that a demolition contractor knows which material fall out of a building. Construction firm NCC, for example, has developed such material passports.

- *Product material efficiency:* Construction projects often use more materials than needed and building codes sometimes serve as barriers to more efficient material use. Sufficient structural strength can often be achieved with less cement and steel.[36] Increased standardization, improved planning, and appropriate storage and transportation could reduce waste. Improved design of building components, new construction techniques, and use of high-strength steel and concrete could reduce the materials needed for new buildings.

- *New business models:* Office buildings and homes are often underutilized. In the circular economy, service-based business models, such as sharing, increase the utilization of underused buildings, spaces, and construction components. Buildings that are built in a traditional way has an expected technical lifespan of 50-100 years but may be demolished earlier.[56] In the circular economy, the economic value of a building is maintained by extending its 'functional' lifespan. Longevity in buildings can be stimulated through modular, flexible, and durable designs. Modular design typically reuses 80% of the components in a building's exterior so that it can stand for 100 years or more, coupling modularity with durability.[57]

Increased digitalization of the construction process will be a key factor for the adoption of circular opportunities, though building information modelling, and the gradual automation of more of the construction process.

MOBILITY – SHARED, ELECTRIFIED, MODULAR, AUTONOMOUS AND INTERCONNECTED

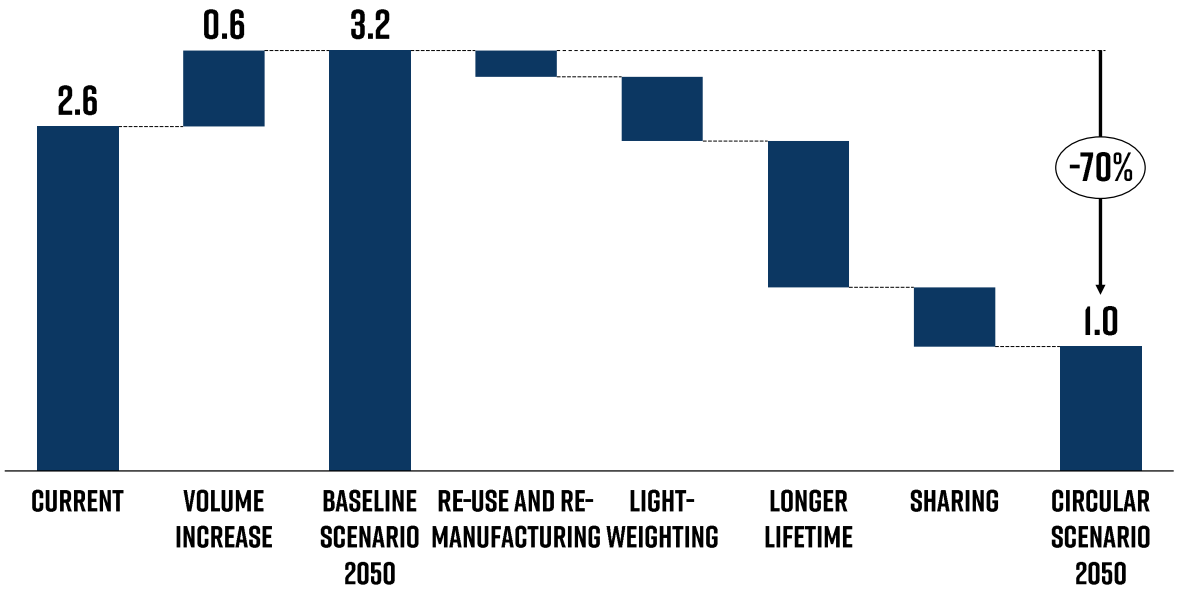
Today, energy for transportation contributes to 26% of Nordic GHG emissions. However, over time, the increased penetration of hybrid, plug-in hybrid and fully electric vehicles will reduce emissions from the use of vehicles, and emissions from the manufacture of cars could increase due to the production of batteries. The latter will become the dominant source of life-cycle emissions for new cars in only 5-10 years. With electrical vehicles in sight, how we design, produce, and use vehicles will matter greatly if we are to meet future climate targets.

Our use of cars today is resource inefficient. Most cars are owned and operated by a single household, and this results in overcapacity: five-seat cars used mostly for one-passenger trips, and vehicles that are stationary 92% of the time.[37] Vehicles today are not designed and managed for reuse. This means that valuable components and materials are downgraded at end-of-life. In a circular economy, vehicles are designed for high utilization, recycling, and remanufacturing to prolong the life of assets.

EXHIBIT 12.

CO_2 EMISSIONS FROM MATERIALS USED IN PASSENGER CARS FALL BY 70% IN A CIRCULAR SCENARIO

Emissions from materials used in passenger cars in Nordic countries, million tonnes of CO_2e per year



Source: Material Economics analysis based on Material Economics, "The Circular Economy – A Powerful Force for Climate Mitigation" (2018). International Energy Agency, "Energy Technology Perspectives - Transport" (2017) and scaled for Nordic region.

A circular scenario where passenger cars are shared, electrified, autonomous, and interconnected could reduce CO_2e emissions from materials included in passenger cars that are used in the Nordics by as much as 70% or 2.2 million tonnes CO_2e in 2050 – and reduce costs. It is important to note that this estimate regards cars that are used in the Nordics – territorial emissions for cars produced in the region is smaller given that most cars on Nordic roads are imported from abroad.

- *Material recirculation:* By separating materials from cars that are collected after use, a larger share of the material value could be preserved. Already today, a large share of vehicles is collected, but most are then dismantled and broken down into pieces in a mix of material categories and grades, with the risk of significant loss of value. Copper in steel is a particularly clear example, where copper components are mixed into the steel. As a result, the high copper content needs diluting with virgin material in order to be recycled. Plastics can be separated to a certain extent but largely end up in a mixed light fraction, known as "fluff", which goes to landfill or incineration. Small volumes of scarce metals are also lost as they are not separated by fragmentation. New recycling methods will address this problem by building recycling into the design stages for new cars and allow for greater disassembly of components after use. Note that recycling has not been modelled in the estimate above since the analysis focusses on the product level (cars).

- *Product material efficiency:* In a circular future, the average car would require less material, and be more durable and better maintained. The initial design and materials choices would be optimized for more intensive use, and with electrification, the lifetime kilometers could more than double. Light-weighting techniques that use advanced materials would be more economic than when applied to a privately-owned car. The same is true of using automation to reduce accidents and applying more advanced manufacturing

methods to reduce materials losses at the production stage.

- *New business models:* Public and private sharing services can increase the utilization of vehicles while offering convenient access to diverse forms of transport. The more passengers that ride a train, bus or car, the fewer vehicles are needed, and the lower the emissions per passenger per kilometer. Designing for durability is particularly beneficial for service-based business models where the cost of maintenance falls on the business and not the passenger. Vehicles designed to be modular and easily maintained and repaired help retain their value and allow for the direct replacement of broken or outdated single components, enabling fleets to last up to ten times longer.

6. RECOMMENDATIONS: AREAS OF NORDIC COLLABORATION

This report provides a high-level summary of the circular economy's potential in the Nordics and started by asking if the circular economy can contribute to further reduction of GHG emissions and the achievement of climate goals in the Nordics. The answer is yes. Nordic businesses recognize the value of the circular economy and show willingness to invest in a more sustainable and circular system.

Nevertheless, the transition to a circular economy is held back by complexity, fragmentation and a lack of scale. Linear supply chains fed with primary materials are global and have had decades or more to optimize processes, refine quality and cut costs. Recycling markets are local, abiding to different rules and systems across municipalities. Trade of secondary materials and circular products is impeded by differences in waste definitions and restrictions to border movements of waste. Consequently, secondary materials are available in smaller volumes, and at varying quality and often a higher cost.

The Nordic countries are uniquely positioned to scale circular solutions in a favorable environment with solid sustainability track records, business cultures of innovation and digital transformation, and strong public sectors that drive demand. There is already a well-established Nordic cooperation and shared interests across countries, which limits complexity.

EXHIBIT 13.

AREAS FOR COLLABORATION FOR A CIRCULAR NORDIC REGION

Develop a shared market for re-used and recycled materials	*Include circular economy in public procurement criteria*	*Align indicators and product standards for circularity*	*Encourage investment to scale up a shared circular infrastructure*	*Promote digital solutions for increased circularity*	*Serve as a strong voice in the European Union*

The Nordic countries can show to the rest of the world that the circular economy is achievable. With increased Nordic collaboration on circular economy, the Nordic region is large enough to serve as an attractive market for circular solutions. The following areas of collaboration need further work and provide initial ideas that could increase material recirculation, improve product material efficiency and promote new business models in the Nordics.

RECOMMENDATION 1: DEVELOP A SHARED MARKET FOR RE-USED AND RECYCLED MATERIALS

Access to secondary material is a barrier for Nordic businesses to invest in circular material use. Recycling companies experience low demand for collected and processed secondary material. Meanwhile, material buyers are reluctant to switching to recycled inputs since primary material can be procured in large volumes from international suppliers, whereas secondary supply come in smaller batches with varying availability, quality and price. Recycling markets are local and regulations are geographically fragmented.

This creates suboptimal material flows and handling. For example, Sweden and Norway have different rules for the handling of fly ash. Swedish incineration of household waste generates fly ash containing hazardous substances. In Sweden, the ash is considered waste for landfill and therefore taxed. Instead, the Swedish fly ash is transported to Norway, mixed with chemical waste and used to fill a limestone quarry, which is considered (low-value) material recycling according to Norwegian standards. Norwegian authorities are now exploring how to instead extract valuable materials from the fly ash to preserve larger material value.[38]

A Nordic inner market for waste and secondary materials would pool the Nordic streams of secondary material, create sufficient supply and economies of scale for processors and users, and encourage investments and innovation. This would be a major initiative that could take decades to implement in full. End-of-waste regulations and definitions would be aligned across the Nordics, as would incentives for incineration of waste and regulation of long-term destructive practices (e.g. copper, additives). Collection systems could be harmonized to make waste streams as similar as possible for efficient sorting, washing and processing. In the long term, Nordic policymakers and businesses could introduce take-back schemes for critical materials.[39]

RECOMMENDATION 2: INCLUDE CIRCULAR ECONOMY IN PUBLIC PROCUREMENT CRITERIA

The public sector buys a large share of material-intensive products, provides and uses mobility services, and owns or operates much of the built environment. Public procurement corresponds to 14-28% of GDP in the Nordic countries.[40] Nordic governments are well positioned to boost demand for circular solutions through their own investments and purchases.

If the total cost of ownership is considered, circular alternatives are often more cost effective than linear. That said, it may be difficult for municipality staff to know which alternative is the most circular and justify departing from existing procurement criteria. It is therefore important to create clear circular procurement criteria.

Criteria on circular economy and GHG intensity could be included in public procurement tenders alongside existing environmental criteria to incentivize circular economy market innovation and support research and pilots.[41] For example, European Green Public Procurement voluntary policy criteria include circular economy components such as design for disassembly and partial replacement of components.[42] The Danish national strategy on circular economy focus on including circularity in public procurement criteria and the Nordic Council of Ministers has already supported research exploring procurement rules that promote circular products, materials, services, business concepts and ecosystems.[43]

RECOMMENDATION 3: ALIGN ON INDICATORS AND PRODUCT STANDARDS FOR CIRCULARITY

Circular policy discussions often focus on recycling rates of materials falling out of use. This could lead to practices where secondary materials are used for purposes with a low value, such as road or construction fillers. Recycling rates increase, but the retained value may be low and demand for primary material remains high. It is worthwhile

exploring how the attention could move to the share, quality and recyclability of the secondary material that goes into new products and structures. Material value retention could be a better metric to close the material loop, leading to practices that increase the share of high-quality secondary material that is used again and again.

Product and material standards on recyclability, repairability, eco-design and labelling could create demand and allow scaling of high-value use of secondary materials. The Nordic countries already collaborate on circular economy standards with international standardization bodies such as ISO and CEN, and could explore if there are further opportunities to promote such standards at EU level and coordinate national standards in plastics and construction.[44] A possible option is a quota system for recycled content, similar to quotas for renewable energy and energy efficiency. For example, a minimum share of secondary material could be applied to sludge in agricultural fertilizer or metal to increase demand and economic viability for recycled material. Another example is for manufacturers to state product repairability as proposed in France's upcoming circular economy law.[45] Recovery, recycling and re-use could be facilitated through increased use of material passports declaring all the materials included in a product or construction. Materials efficiency metrics could be reported and tracked as an expansion of the Ecodesign directive. To avoid market distortions, the same standards would need to be applied to imports.

RECOMMENDATION 4: INVEST IN A NORDIC CIRCULAR INFRASTRUCTURE

Technological advances make the circular economy increasingly viable and companies that seize these opportunities can position themselves as leaders. Nordic actors have already developed platforms for car-sharing, autonomous vehicles, sensor technology for buildings, automation of manufacturing processes, recycling technologies etc.

However, private actors may not yet be ready to make major investments in some of the most revolutionary innovations and the required infrastructure. The public sector can then serve as a catalyst by funding early demonstrations and Public-Private Partnerships to share and reduce investment risks. Examples of investment funds at national level include the initiatives Danish Green Investment Fund, Circular Business and Circular Business Models in Denmark.[46]

A major barrier to mechanical recycling of plastics is the quality and purity requirements on the ingoing material. Much of the low-quality plastics that is unsuitable for mechanical recycling can be processed chemically to preserve quality and value, but today only 2% of plastics recycling in Europe is chemical. To reduce plastics' environmental impact, the Nordic Council of Ministers has set up a program to increase plastics recycling. Chemical treatment of plastic waste is also high on the Finnish parliament's agenda and a full-scale plant managed is planned. Additional Nordic chemical recycling capacity would reduce emissions further and could be supplied with pooled secondary plastics from the entire region to fill capacity and reach scale advantages. This could be facilitated through investment support and aligned policies allowing cross-border shipment of plastic waste.

In parallel, the public sector should avoid crowding out private investment in circular business models, as illustrated by the example of Danish recycling plants and the ownership of waste. Private recycling firms are reluctant to invest in recycling plants since the waste is owned by the municipality. In several regions, municipalities have invested in recycling plans close to private plants and control the waste that supply the plants.

RECOMMENDATION 5: LEVERAGE DIGITALIZATION

The Nordic region is impacted by two parallel megatrends: the urgency to mitigate and adapt to a changing climate and the transition towards a more digital society. Digitalization supports the transition to a circular economy and helps manage complex data sets and enables upscaled material recirculation, product material efficiency and new business models. Extended reuse and recycling require better information on the availability, content, condition and location of materials and products, as do material-efficient product design and new business models such as sharing, rental platforms and virtual marketplaces. However, digitalization does not necessarily lead to improved circularity and sustainability. For example, increased online sales may fuel consumption of fast-moving consumer goods and lead to excess consumption and returns, and hardware itself generates e-waste. Therefore, digitalization needs to be brought into circular economy plans, and vice versa.

The strong links between circularity and digitalization have not been sufficiently recognized in policy, business and academic research to date. As global leaders in digital innovation and sustainability, the Nordic countries are well-positioned to develop solutions for the digital circular economy.

Each government already promotes digitalization and the Danish national strategy on circular economy focus on facilitating access to public and private data for circular business development. The Nordic countries could also earmark funding for digitalization and circularity in Research & Development and innovations funds.

RECOMMENDATION 6: SERVE AS A STRONG VOICE IN THE EUROPEAN UNION

The Nordic countries can impact emissions well beyond their own borders by serving as a strong voice on circular economy in the European Union. This will help large Nordic companies with global footprints and a strong appetite for circular economy to justify launching circular business models. In addition, since each member state has a certain degree of freedom on how to implement EU policy, the Nordics can collaborate on the implementation of circular policies and showcase to other member states how circularity is done.

• • •

This report has explored the circular economy as a way for the Nordic countries to accelerate their transition to climate neutrality. While further research is required, it finds that circularity is indeed a promising route to examine further. Going forward, a high priority should be to build a deeper knowledge base of what a Nordic circular economy could look like and to further investigate the actions, policies and investments needed to get there. New knowledge is needed to ensure that long-term policy is based on full understanding of the potential, barriers, and economics of circular economy measures. Based on such deepened, quantified understanding of the circular economy's potential in the Nordic region, Nordic focus areas could be refined and further developed. A first set of policy areas at the Nordic level has been identified. None of these are quick fixes, but in the view of the authors, they represent promising areas for the Nordic Council of Ministers to explore.

7. ENDNOTES

[1] Official communication from Danish Government, Finnish Government, Iceland's Ministry for the Environment and Natural Resources, Nordic Energy Research, Government Offices of Sweden and Faroe Islands, Nordic Council of Ministers.

[2] Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation.*

Ellen Macarthur Foundation and Material Economics (2019). *Completing the picture: How the circular economy tackles climate change.*

Material Economics (2019). *Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry.*

The reports can be accessed at www.materialeconomics.com/publications/overview.

[3] This report covers Denmark, Finland, Iceland, Norway, Sweden, Greenland, Åland and the Faroe Islands. Some data is not available separately for Greenland, the Faroe Islands and Åland. In those case, data for these countries are covered by Danish and Finnish statistics.

[4] Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation*.

[5] Enkvist, P., Stuchtey, M. and Zumwinkel, K. (2016). *A good disruption: Redefining growth in the twenty-first century*.

[6] Re-manufacturing is the rebuilding of a product according to specifications of the original product using a combination of reused, repaired and new parts.

[7] The Nordic population is 2.6 times larger than Sweden's and approximately five times larger than that of Denmark, Norway or Finland.

[8] Excluding energy for material production. Data for greenhouse gas emissions are based on official statistics reported to the United Nations in National Inventory reports, see reference 12.

Sources include Nordic Statistics database (2019). "EMIS11: Greenhouse gases, national emissions in 1000 tonnes CO2 equivalents by reporting country, sector and time"; Statistics Finland (2019), "GHG emissions in Finland 1990 to 2017"; The Environment Agency of Iceland (2019), "National Inventory Report - Emissions of Greenhouse Gases in Iceland from 1990 to 2017"; Norwegian Environment Agency (2019), "GHG emissions 1990-2017, National Inventory Report"; Swedish Environmental Protection Agency (2019), "National Inventory Report Sweden 2019", United Nations Framework Convention on Climate Change, "GHG Profiles - Annex I".

[9] This is the 2017 share of renewable energy in gross final energy use across Nordic countries. It ranges from 36% in Denmark to 72% on Iceland. Nordic Statistics database (2019), *ENER08: Share of energy from renewable sources by reporting country, energy indicator and time*.

[10] Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation*.

[11] Material Economic analysis based on Nordic Statistics database (2019). "*EMIS11: Greenhouse gases, national emissions in 1000 tonnes CO_2 equivalents by reporting country, sector and time*"; Statistics Finland (2019), "*GHG emissions in Finland 1990 to 2017*"; The Environment Agency of Iceland (2019), "*National Inventory Report - Emissions of Greenhouse Gases in Iceland from 1990 to 2017*"; Norwegian Environment Agency (2019), "*GHG emissions 1990-2017, National Inventory Report*"; Swedish Environmental Protection Agency (2019), "*National Inventory Report Sweden 2019*".

[12] Emission data is based on official statistics reported by each country's National Inventory Report that is submitted to the United Nations. The data is for 2017. Emissions include all types of greenhouse gases, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N_2O). Emissions are reported in carbon dioxide equivalents (CO2e). Total emissions exclude Land Use, Land-Use Change and Forestry (LULUCF), as well as memo items (CO2 from biomass, Indirect N2O, International aviation, and International water-borne transport).

The categorization of emissions is based on analysis done by Material Economics. Data from National Inventory reports originally split emissions in four categories: (1) Energy, (2) Industrial processes and product use, (3) Agriculture, and (4) Waste. Emissions from energy use in industry and agriculture have been included in their categories since these emissions are hard to abate and will be affected by circular economy levers.

This has been done by moving emissions from the energy sub-category '1.A.2. Manufacturing Industries and Construction' to 'Industry' and '1.A.4.c Agriculture/Forestry/Fishing' to 'Agriculture'. Emissions from energy use has also split into the three sub-categories 'Transport', 'Energy industries' (which include refineries and oil/gas distribution), and 'Other energy use.

Sources include Nordic Statistics database (2019). "EMIS11: Greenhouse gases, national emissions in 1000 tonnes CO2 equivalents by reporting country, sector and time"; Statistics Finland (2019), "GHG emissions in Finland 1990 to 2017"; The Environment Agency of Iceland (2019), "National Inventory Report - Emissions of Greenhouse Gases in Iceland from 1990 to 2017"; Norwegian Environment Agency (2019), "GHG emissions 1990-2017, National Inventory Report"; Swedish Environmental Protection Agency (2019), "National Inventory Report Sweden 2019", United Nations Framework Convention on Climate Change, "GHG Profiles - Annex I".

[13] World Bank (2017 and 2018).

[14] Emissions from 'Materials' are the same as Exhibit 2.

Production emissions for the four materials (cement, aluminium, plastics, and steel) are calculated bottom-up using Nordic production volumes and Nordic emission factors for each material. There is some uncertainty regarding this data since there are no official statistics. Emission factors are for the production of the raw material (e.g. crude steel). It does not include emissions from mining and material extraction (e.g. mining of iron ore), downstream processes (e.g. cold rolling for steel), or consumption/use of materials (e.g. production of cars using steel). Emission factors are based on previous reports by Material Economics and Hillman, K., et al. Production volumes of materials in the Nordics are based on a wide range of sources from companies (e.g. Cementa), Statistical Databases (e.g. Statistics Norway), and Material Associations (e.g. World Steel Association). Some production volumes were confidential, when data can be linked to specific companies, and have therefore been triangulated using e.g. statistics on total emissions of a specific material and emission factors in the EU.

Production emissions from food are based on official statistics for agricultural production. Emissions for food production only include agricultural production and energy use. It excludes emissions from the value-chain (processing, distribution, storage), refrigerants, and end-of-life emissions from food. Data is for all agricultural production in the Nordics, including non-food production such as crops for bioenergy. Data is based on official statistics from National Inventory Reports and have a high degree of reliability.

Sources include Hillman, K., et al., (2015) "Climate Benefits of Material Recycling Inventory of Average Greenhouse Gas Emissions for Denmark, Norway and Sweden"; Material Economics (2018), "The Circular Economy – A Powerful Force for Climate Mitigation"; Material Economics (2019), "Industrial Transformation 2050 – Pathways to Net-Zero emissions from EU Heavy Industry"; Milford, R., et al., (2012) "Supporting Information: The last blast furnace?"; : USGC (2018), "2016 Minerals Yearbook - ALUMINUM [ADVANCE RELEASE]", Svenskt Aluminium, "Om Aluminium"; European Environment Agency, "EU Emissions Trading System (ETS) data viewer"; OECD (2010), "Materials Case Study 2: Aluminium"; Mistra Closing the Loop, "Rest från aluminiumsmältning värdefull för svensk stålindustri"; Cementa, "Nollvision 2030"; Norcem HeidelbergCement Group; IVL och Naturvårdsverket (2019), "SMED Rapport Nr 01 2019 V: Kartläggning av plastflöden i Sverige"; World Steel Association, "Steel statistical yearbook 2018"

[15] Ellen Macarthur Foundation (2917). *A new textiles economy: redesigning fashion's future.*

Watson, D. (2017). *Nordic perspectives on used textiles and circular economy.*

[16] Emission Factors in kg CO2-Equivalent per unit, City of Winnipeg. Available online.http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf

[17] Papineschi, J. et al. (2019). *Nordic regulatory framework and its effect on waste prevention and recycling in the region.*

[18] Material Economics (2018). *Ett Värdebeständigt Svenskt Materialsystem: En rapport om materialanvändning ur ett värdeperspektiv.*

[19] Ibid.

[20] The most common way of calculating emissions is territorial emissions. The calculations are based on detailed statistics and corresponding emissions in a geographical area. Statistics calculated in this way show how physical emissions in a country develop over time. Territorial emissions are part of national

official statistics and are based on internationally agreed methods according to UNFCCC, IPCC and EU guidelines.

IPCC (2007). Climate Change 2007: The Physical Science Basis.

Naturvårdsverket (2019). Tre sätt att beräkna klimatpåverkande utsläpp.

[21] Peters, G. et al. (2016). Nordic Council of Ministers. *Global environmental footprints, A guide to estimating, interpreting and using consumption-based accounts of resource use and environmental impacts*.

[22] Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation*. Material Economics analysis.

[23] Trade between Nordic countries is included in exports and imports.

Production data is the same as Exhibit 4.

Emissions from imports and exports are calculated bottom-up using trade statistics and emission factors for materials in the EU. Trade volumes include both materials and products containing the material. This data is more uncertain since there are no official statistics. Emission factors for the materials (aluminium, cement, plastics, steel) are based on EU averages from previous work done by Material Economics. The emission factor includes the same steps of the value chain as used to calculate emissions from Production, see Exhibit 4 for further details. The emission factor for food imports and exports is assumed to be the same as food production in the Nordics. Trade volumes for steel are based on statistics from the World Steel Association. Trade volumes for aluminium, cement, plastics, and food are from Statistical Databases for each country (e.g. Statistics Norway). Trade volumes exclude imports and exports of scrap. Emissions from trade can be overestimated since not only the material (cement) is included in the statistics, but also products (concrete). Emissions from food consumption is likely to be underestimated in this analysis.

[24] Material Economics (2018). *The Circular Economy: A Powerful Force for Climate Mitigation*.

[25] This reduction potential is based on detailed assessment for Europe and the world - and can be refined for the Nordic context in follow-up studies.

Material Economics (2018). The Circular Economy: *A Powerful Force for Climate Mitigation*.

Ellen Macarthur Foundation and Material Economics (2019). *Completing the picture: How the circular economy tackles climate change.*

[26] 'Current (2017)' is based on the Nordic Sphere of Influence on Global GHG, see Exhibit 7.

'Baseline Scenario 2050' is based on increasing production volumes and improved emission factors. The percentage growth rate for the four materials is based on analysis done by Material Economics in previous reports ("Industrial Transformation 2050" and "The Circular Economy"). The growth rate is assumed to be the same as for the EU. The growth in production and import volumes for food is assumed to be correlated to population growth. The population growth forecast for the Nordic region is based on United Nations projections. Improvements in emission factors assume decarbonized electricity and energy for material and agricultural production in 2050. Improvements in emission factors also include initiatives such as Hybrit in Sweden, but not any plans for carbon capture and storage (see page 18 for further details).

The circular economy potential for materials is based on previous analysis done by Material Economics for the report *The Circular Economy – A Powerful Force for Climate Mitigation* and *Completing the Picture - How the Circular Economy Tackles Climate Change*. This potential has been applied both to emissions from imports and production. The circular economy potential for food is based on analysis by Material Economics using Panorama and expert knowledge. Productivity gains are not included as a circular measure.

[27] Nordic Energy Research and Pöyry, (2019). *Food waste to Biofuels.* https://www.nordicenergy.org/wp-content/uploads/2019/04/Food-Waste-to-Biofuels_FINAL.pdf

[28] Other partners were European Climate Foundation, Climate-KIC, Energy Transitions Commissions, Ellen Macarthur Foundation, MAVA Foundation and Climate Works Foundation.

[29] von der Leyen, U. (2019). *A Union that strives for more, My agenda for Europe – By candidate for President of the European Commission*.

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States to consider approaches and policies for achieving sustainable consumption and production, including but not limited to improving resource efficiency and moving towards a circular economy, when developing relevant national plans and policies."

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[33] Financial Times website, visited December 4 2019. https://www.ft.com/content/b50bbbec-eda9-11e9-ad1e-4367d8281195

[34] Denmark's Energi-, Forsynings- og Klimaministeriet (2018). *Sammen om en grønnere fremtid Klima- og luftudspil.*

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[35] Iva (2014), Rossi, Marique And Reiter (2012), Cuéllar-Franca And Azapagic (2012).

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