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Barents 2050 – Impacts, opportunities, and risks of climate change and climate change mitigation

Tommi Ekholm | Tomi J. Lindroos | Laura Sokka | Kati Koponen | Tiina Koljonen

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Executive summary

The Paris Agreement sends a strong signal on the joint international effort on mitigating climate change. The Agreement's aims to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels".

These objectives require major and rapid actions on reducing greenhouse gas (GHG) emissions all over the world. If successful, the Paris Agreement will largely reshape the energy sector, industry, and many other economic sectors. The required transformation to a sustainable, low-carbon society will create both pressure for businesses to adapt to changing conditions and also offer a number of new opportunities and new markets.

At the same time, some sectors, societies, and local environments will face the impacts of a changing climate, particularly if the Paris Agreement will not success in limiting global greenhouse gas emissions.

Enhanced policy actions are necessary to achieve the ambitious goals of the Paris Agreement and realize the opportunities. Political action is needed on national, regional, and municipal level, but these levels should work together and complement each other. Based on research and literature reviews presented in this study, we have identified a larger frame of policy actions to achieve the Paris Agreement targets. The framework is already well established at national levels, but could be strengthened on regional and municipal levels.

Table ES1. Policy actions that could contribute to the Paris Agreement's goals on mitigating climate change, and help different sectors to realize their opportunities.

	National level	Regional level	Municipal level
1. Build shared vision	1. Build a shared vision of the future under the Paris Agreement; avoid sub-optimal national solutions. 2. Acknowledge the associated uncertainties regarding future development; prioritize main targets over specific solutions.	1. Enhance common understanding of the future of the Barents region under the Paris Agreement. 2. Bring the Barents regions' perspectives to national energy and climate strategies.	1. Review how well national and regional visions apply to local circumstances; suggest improvements when necessary. 2. Participate to municipality climate networks, e.g. Covenant of Mayors.
2. Study available emission reduction measures	1. Create and model low carbon scenarios; identify and assess available mitigation measures; estimate if current targets are on the required emission pathways. 2. Study sensitivity analysis and alternative pathways to increase robustness.	1. Compile regional data; use it to support studies and political discussion; publish the data. 2. Develop tools for joint assessment of the Barents region's climate and energy strategies; ensure proper regional coverage.	1. Reflect local prospects and development trends to national and regional studies; conduct local studies when required. 2. Map the local renewable energy resources and estimate pros and cons of their different uses.

	National level	Regional level	Municipal level
	3. Identify risks related to studied emission pathways and measures.	3. Study potential benefits of cooperation with other countries and regions, such as Arctic region countries.	3. List the potential of cost-effective energy efficiency measures in the public and private sector.
3. Set up the climate and energy policy framework	1. Set 2030, 2040, and 2050 targets based on mitigation studies, monitor, evaluate, and report the progress regularly. 2. Commit to decided long term targets to provide a consistent message to industry and stakeholders; dare to update if new scientific information contradicts existing targets.	1. Ensure consistency between national policies in the Barents countries; avoid partial-optimization at the national level 2. Adopt additional regional targets if certain topics or sectors are not presented in national targets, and new targets would benefit both national and regional levels.	1. Adopt a municipal level low-carbon strategy; coordinate with national and regional frameworks. 2. Commit to 2030 targets and adopt the shared 2050 vision.
4. Implement required measures	1. Identify and remove barriers to low-carbon investments; start from power and heat, then proceed to transport and buildings. 2. Improve energy-efficiency in the public and private sector. 3. Create a balanced set of mitigation measures based on researched impacts and cost-effectiveness. 4. Add flexibility to mitigation measures when possible, e.g. technology neutral capacity auctions. 5. Encourage municipalities, companies, and citizens to participate.	1. Improve the regional cooperation to align actions and to increase the efficiency of measures; many forums such as Barents Euro-Arctic cooperation already exist. 2. Foster measures that require regional cooperation, e.g. improvements on electricity markets. 3. Use Mission Innovation; work together to have larger global impact. 4. Exchange information about best practices among Barents region countries. 5. Encourage municipalities, companies, and citizens to participate.	1. Exchange information about best practices with other municipalities. 2. Update long-term planning to enable and encourage public transportation in growing urban areas 3. Invest to energy-efficient solutions in the public sector and private sectors through ESCO agreements or similar. 4. Invest to local energy sources when economically and environmentally reasonable. 5. Encourage companies, and citizens to participate.
5. Boost innovation	1. Fund the research on new low-carbon technologies and solutions; keep funding predictable on long term. 2. Demonstrate new technologies and solutions with the industry.	1. Shortlist the best emerging solutions, especially the ones that origin from the Barents region. 2. Promote Barents region's strengths; aim for clean-tech exports.	1. Educate and train enough skilled work force to match the needs of local industries 2. Work with local industries to promote local strengths.

	National level	Regional level	Municipal level
6. Adapt	1. Identify the most likely affected and the most vulnerable regions and sectors. 2. Decide clear distribution of responsibilities of different actors and sufficient long term funding.	1. Highlight and suggest priority areas to adaption from Barents region perspective. 2. Inform municipalities of adaptation needs; collect and distribute best practices.	1. Consider adaptation needs in zoning and spatial planning. 2. Utilize the traditional and local knowledge. 3. Provide support to local communities for adaptation.

The Barents region can contribute to the Paris Agreement's aims in climate change mitigation in numerous ways. This study identifies ways how various sectors in the Barents Region can contribute to climate change mitigation. This study identifies also possible benefits, risk, and threats to these sectors that arise from mitigation measures and from climate change itself. The most important identified opportunities, benefits, risks, and threats are summarized in Table ES2.

Table ES2. Overview of how different economic sectors could contribute to the Paris Agreement's goals on mitigating climate change, and what benefits and risks the implied transition might pose.

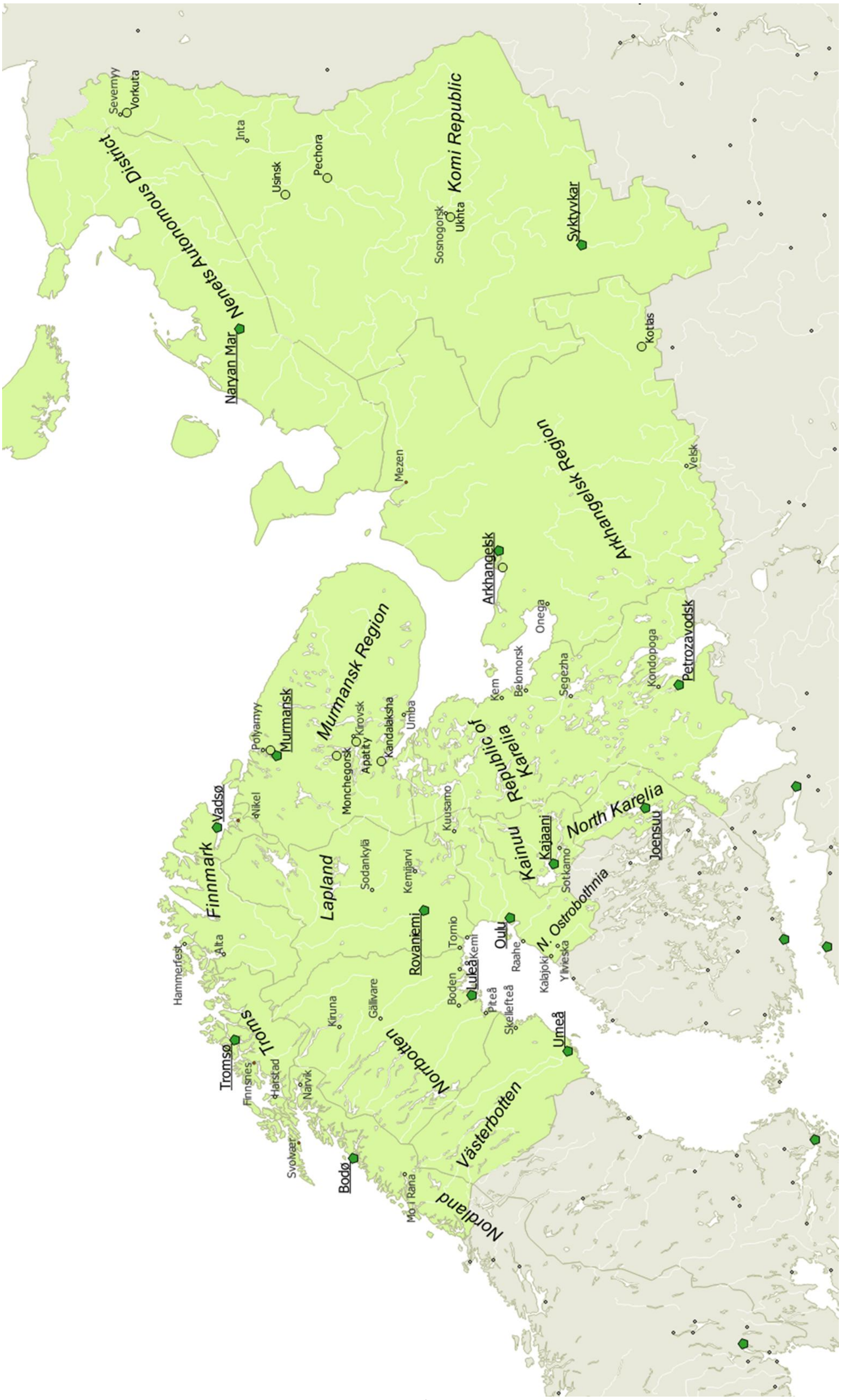
	Opportunities to contribute	Potential benefits	Risks and threats
Power and heat	· Rapid investments to zero-CO_2, and even negative CO_2 generation. · Improve grids for variable supply and demand. · Provide other sectors an opportunity to mitigate emissions through electrification.	· Increasing precipitation adds hydropower production. · Increasing demand due to electrification on other sectors · Export potential of clean electricity to Central Europe.	· Phase-out of fossils may cause early retirement of power plants. · More volatile electricity prices due to a larger share of variable electricity. · Feasibility and environmental issues of hydropower expansion in Russia.
Oil and gas	· Reduce GHG and black carbon emissions from production, and pipelines. Use flared methane if possible. · Use depleted fields for Carbon Capture and Storage (CCS).	· Easier winter conditions in the Barents offshore fields can reduce costs.	· Declining market volumes and competition from lower cost fields might result in stranded assets. · Faster decline of market volume if CCS will not be successful.

	Opportunities to contribute	Potential benefits	Risks and threats
Transportation	· Phase-out of fossil fuels and switch to electricity, advanced biofuels, and other alternative fuels. · Develop new low carbon solutions for heavy transport, ships, and aviation. · Produce forest-based biofuels for transportation, if forest carbon stock impacts are sufficiently minor.	· New industries and services on alternative fuels production and distribution. · Better winter conditions on roads can decrease costs. · Sea transportation easier due to shorter winters and easier ice conditions.	· Increasing transport costs can decrease competitiveness. · Delayed action locks in fossil fuel based system. · 'Betting the wrong horse' when competitive technologies are developed. · Technological performance of EVs over long distances and in a cold climate.
Manufacturing	· Decarbonize energy use and improve efficiency. · Develop low-emission and energy efficient equipment. · Research new technologies to reduce emissions from industry processes.	· Added cleantech demand due to investments for GHG reductions. · Early adopters of new technology might gain new markets.	· Increased costs of mitigation measures might reduce the industry's competitiveness. · Limited existing technologies to mitigate process emissions. · Delayed mitigation action exposes to additional costs when carbon price rises
Mining	· Reduce methane emissions from coal mining. · Adopt best available technology to increase energy efficiency in mining. · Mitigate emissions from work machinery with similar measures as in transport.	· Increased demand of metals and materials in the manufacturing of low-carbon technologies. · Warming climate might decrease mining costs.	· Coal mines end up as stranded assets. · Volatile market and uncertain value of production. · Increased recycling, material efficiency, and innovative technologies might decrease the demand.
Agriculture	· Produce biogas for heating and transport fuels. · Improve feeding to reduce emissions from animals. · Respond to demand change if vegetarian diet gains popularity.	· Warming climate improve yield and allow new crops. · Export potential if crop production on lower latitudes suffer from changes.	· Increasing precipitation can make ground too wet for ploughing. · Demand risks due to a possible changes in diets.
Forestry	· Enhance forest carbon sinks through forest management. · Provide more wood for industrial uses and renewable energy to replace fossil fuels · Find a sustainable balance between enhancing sinks and additional production.	· Improved tree growth rate and expansion of forest line towards the north. · Increased possibilities for intensified forestry also in the north.	· Growing risk of diseases and pests in a warmer climate. · Potential increases in storm damages in all Barents region and forest fires mainly in Russian Barents Region. · Trees might adapt to changing conditions too slow.

	Opportunities to contribute	Potential benefits	Risks and threats
Fish-eries / Aqua-cul-ture	· Sustainable fishing as a source of low-emission animal protein. · Demonstrate the most promising alternative fuels in fishing vessels.	· Warming waters potentially benefit fisheries, and particularly aquaculture. · Potentially higher fish catches, but north-wards migration of fish species will likely change the distribution of commercial species.	· Changed conditions and increased competition threaten Arctic species, especially in high Arctic. · Some economically important species at risk of disappearing. · Increasing carbon price and fuel costs may negatively affect profitability of fisheries.
Rein-deer herd-ing	· Reindeer herding can prevent or slow the tree and bush expansion towards north. Low grow tundra area remains covered in snow longer and reflects solar radiation cooling the planet.	· Later snowfall and earlier snowmelt enable longer usage of pastures and benefits reindeers as they have easier access to forage.	· Variability in winter temperatures may build ice on snow, threatening reindeer access to forage. · Increased bush and tree-growth, and new pests risk degrading the quality of the pastures.
Tour-ism	· Promote ecotourism to mitigate emissions and decrease the impact on nature.	· Increased temperatures improve conditions both in the summer and in winter through reduction of extreme cold periods.	· Shorter season for winter tourism. · Increased rainfall and cloudiness may decline conditions for tourism.

Climate change mitigation and adaptation are continuous processes. It is crucial to observe the actual development, learn from it, and update the targets and measures when necessary. It will be essential to find a healthy balance between solid long term targets, new prospects of developing technology, and new scientific information.

Contents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Komi Republic
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Lapland
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Troms
Norrbotten
Västerbotten
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Sotkamo
Tornio
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Boden
Piteå
Skellefteå
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Kiruna
Alta
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Finnsnes
Harstad
Narvik
Svolvær
Mo i Rana

1. Introduction

The Paris Agreement on climate change was made in December 2015. Signed by 195 countries, it is the first agreement on mitigating climate change with a global coverage. Under the agreement, countries provide their Nationally Determined Contributions (NDCs) towards mitigating climate change, increasing the ability to adapt to the adverse impacts of climate change, and providing climate finance. Currently, 148 countries have ratified the Agreement and 142 countries provided their NDC.

The Paris Agreement sends a strong signal on the joint international effort on mitigating climate change. The Agreement's objective is to keep global temperature increase well below 2°C from pre-industrial levels, and pursue efforts on limiting the temperature increase to 1.5°C.

These objectives require major and rapid actions on reducing greenhouse gas (GHG) emissions all over the world. The transformational change in the economy required by the emission reductions will largely be policy-driven, but policies will also have market implications, reflected, e.g., in prices for energy and emissions. The Paris Agreement will therefore shape energy and climate policies, as well as energy markets, structure of the economy, transportation modes and industrial sectors globally.

In order to have foresight on how the Paris Agreement can shape regional economies, we need to consider what actions are necessary to meet the Agreement's aims, how countries and regions can contribute towards these aims, and how the collective action might shape the markets. As the future transition towards a sustainable and low-carbon society involves inevitably large uncertainties, the consideration of multiple alternative futures allows finding robust solutions and identifying open questions.

1.1 Barents region

The Barents Sea is part of the Arctic Ocean, north of the shores of northern Norway to the northwest Russia. The Barents region – depicted in the map on the previous page – is the land-area in proximity of the Barents Sea, comprising 14 provinces from Nordland in Norway to Nenets and Komi in Russia.

The Barents region can provide its own contribution to the aims of the Paris Agreement. Of the Barents Region countries, Finland and Sweden submitted their targets to Paris Agreement as a part of the EU, while Norway and Russia have submitted their own targets. It is important to notice, that Norway participates in the EU Emission Trading Scheme (ETS) for electricity, heat and energy-intensive industries', and in the Effort Sharing Regulation (ESR) covering emissions from other energy use, agriculture, and waste. All of the countries also have their own policies and strategies for mitigating and adapting to climate change in practice. The relationships between the Barents region, its parent countries and the climate policy frameworks are illustrated in Figure 1.

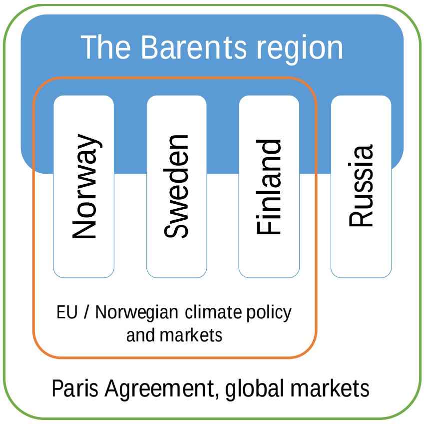

Figure 1. The relationships between the Barents region, Barents region countries, climate policy regimes and markets.

When planning mitigation strategies, regional cooperation can provide better results than if the respective countries acted alone. Direct benefits can be achieved, e.g., through trade in renewable energy from a region with plentiful resources, but also more subtle benefits can be attained through exchange of know-how on innovations and best practices, joint financing, co-operation in education and mobility of workforce within the Barents region. Understanding the region's activities as a whole is essential in the integration and coordination of national and sub-national strategies.

1.2 Climate impacts

Even if the Paris Agreement will be successful in its aims, the global mean temperature is likely to increase more than 1.5°C in the long-term. Warming has been more pronounced in the Arctic region (Walsh 2014; AACA 2017) and this trend is expected to continue in the future (Benestad et al. 2016). Thus, the economic activities in the Barents region will be affected both by mitigation and the residual climate change.

Climate impacts that the Barents region might face are yet uncertain, but active mitigation measures will make them smaller. Especially the impact after 2050 is highly dependent on the level of mitigation. The more effective the Paris Agreement and national policies will be in reducing GHG emissions, the lesser the impacts will be. Considerable additional warming up to 2050 will nevertheless take place even under the most ambitious mitigation strategies, requiring adaptation in the Barents region.

Second, the model projections of climate change for some chosen emission developments are themselves uncertain, particularly on the regional level. Climate models' projected global temperature increase following a doubling of CO_2 concentration – a parameter known as *climate sensitivity* – is likely to be between 1.5°C and 4.5°C (IPCC, 2013). As even the global level of temperature change is difficult to project, more relevant regional quantities, such as the rainfall, windiness or length of the growing season, are even harder to predict.

Thirdly, single climate model uncertainties are much larger than model-mean approaches. In this study, the analysis of climate change is based on the RCP scenario modelling by NOAA supplemented by a review of existing literature providing a broader perspective.

While acknowledging these uncertainties, it is important to consider what impacts climate change might inflict on the Barents region. This information can help communities, businesses and individuals consider what climate risks they or their descendants might face in the future, and what might be the best ways to adapt to possible changes.

1.3 Finding ways to contribute to Paris Agreement

The objective of the study is to portray how the Barents region can contribute to the aims of the Paris Agreement, how these contributions could affect the economic activities in the region, and how large climate impacts could be expected in the region depending on the effectiveness of the Agreement. The temporal scope of the analysis extends to the year 2050.

Given that the ultimate effectiveness of the Paris Agreement is not fully known, we portray two levels of global mitigation ambition: either ambitious emission reductions are implemented globally, keeping the temperature increase well below 2°C; or that developing countries' actions are more moderate, leading to a long-term temperature increase of 2.4°C. These two alternatives are tied to the Representative Concentration Pathways (RCPs) used, e.g., in the IPCC process (van Vuuren et al., 2011). This framing is illustrated in Figure 2.

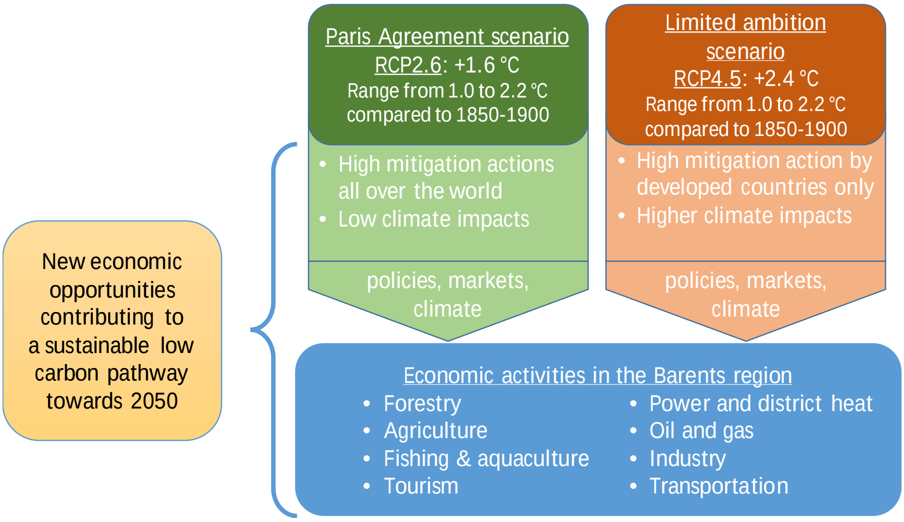

Figure 2. Framing of the analysis used in this study. Temperature ranges of each RCP scenario are from IPCC fifth assessment report (IPCC 2013)

The mitigation contributions by the Barents region countries up to 2050 are modelled with TIMES-VTT, a global integrated assessment model with high detail on energy production, transformation and end-use. The analysis of climate is based on the RCP scenario modelling by NOAA and a review of existing literature.

The structure of the report is the following: Section 2 describes the current structure and past trends of the Barents region economy. Section 3 presents mitigation action in the Barents region countries under the Paris Agreement targets, modelled with the TIMES-model, while Section 4 discusses the climate impacts under the RCP 4.5 scenario. Section 5 summarizes the main opportunities and impacts for the most important sectors in the Barents region, and finally overall conclusions are presented in Section 6.

2. The Barents economy

2.1 GVA, a metric to measure local economies

In this section, we study the economy in Barents region based on statistical data. National statistic centres publish vast amounts of regional data, which can be better utilized in further Barents region and Arctic region studies. We have collected statistics on population, regional Gross Value Added (GVA), employment, compensation to employees, disposable income of households, and specific sectoral data. All data is collected for NUTS2 regions[1] when possible. However, Finnish and Norwegian statistic centres release more detailed data than what is available from Sweden and Russia.

Table 1. Regional Gross Value Added (GVA) of the Barents region measured in local currencies in current values and EUR(2015) in constant prices.

		2005	2010		2014	
		regional GVA (billions)	regional GVA (billions)	Growth '05–'10 (%/a)	regional GVA (billions)	Growth '10–'14 (%/a)
NO Barents	Local Currency, real	-	143	-	180	+5.9%
	EUR(2015)	-	20	-	22	+2.6%
SE Barents	Local Currency, real	149	187	+4.7%	190	+0.4%
	EUR(2015)	20	22	+2.4%	21	-0.9%
FI Barents	Local Currency, real	19	19	+0.6%	22	+3.4%
	EUR(2015)	23	23	-0.2%	23	-0.3%
RU Barents	Local Currency, real	548	1081	+15%	1527	+9%
	EUR(2015)	27	30	+1.8%	27	-2.3%

GVA is a similar macroeconomic measure to GDP (Gross Domestic Product). GVA is GDP excluding taxes and subsidies on products. In addition, regional GVA often excludes some sectoral data due to the amount of limited information or problems in regional allocation. For an example, Norway's regional GVA excludes off-shore activities (e.g. off-shore oil and gas, sea transport, and likely part of the fishing industry) which is why Norway's regional GVA covers only 70% of the total GDP. In Russia, the regional GVA covers 80% of the total GDP. In Finland and Sweden, the coverage of regional GVA is better, reaching 88% of the GDP.

[1] Norway has 3 counties in the Barents region (19 counties in total), Sweden has 2 counties in the Barents region (21 in total), Finland has 4 regions in Barents region (20 regions in total), and Russia has 5 oblasts in the Barents region (46 in total). See map at the beginning of this report.

We have converted all currencies to constant 2015 Euros to account for inflation and currency rate fluctuations from the data. Table 1 shows that inflation and decreasing value of currency might lead to a situation where real GVA in local currency might increase, but the constant price GVA still decreases. To simplify, this means that people might have a larger sum of money to use, but it is worth less.

2.2 Population – Ageing, urbanizing, and gaining wealth

5.1 million people lived in the Barents region in 2016, of which the majority resided in the Russian Barents. The population in the other three countries' Barents regions were about the same size: 0.8 million in the Finnish Barents region, 0.5 million in Norwegian Barents region, and 0.5 million in Swedish Barents region. The total population of the Barents region is decreasing. Russian Barents had 4.8 million inhabitants in 1990, 3.3 million in 2015, and the projected population is 2.9 million in 2030. The population in the Nordic Barents might increase from 1.8 million in 1990 to 1.9 million by 2030.

The share of national population living in the Barents region is decreasing in each Barents country and the relative weight of the Barents region compared to other regions in Barents countries is decreasing. Figure 3 shows that the decrease of the share is fastest in Norway, where the population of the Southern parts is increasing considerably faster than the population in the Barents region.

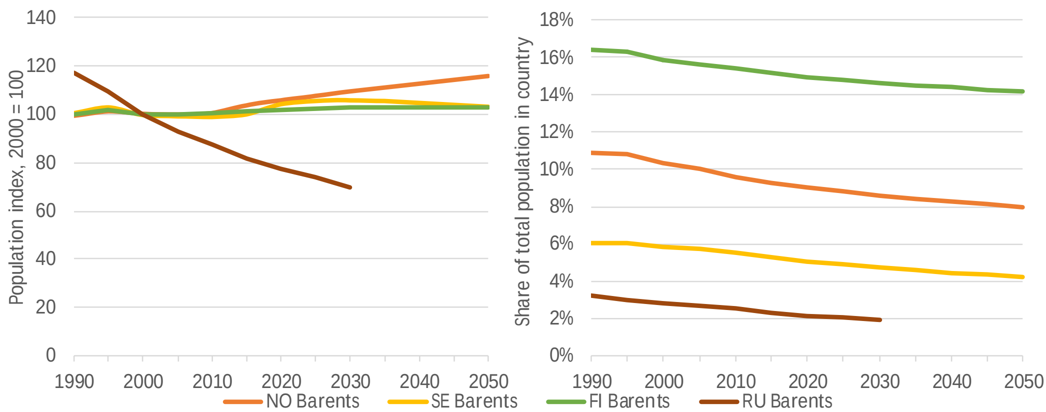

Figure 3. Left panel: Population in Russian Barents has been decreasing 1% per year. The population is slightly increasing in Norwegian, Swedish, and Finnish Barents. In total, the Barents population decreases. Right panel: Barents region's share of national population decreases in all Barents countries.

The population in the Barents region is getting older, yet it is still 1 year younger than national average. The mean age of the Barents region population has increased from 34 years in 1990 to 40 years in 2015. There has been more old people (65 years and older) than young (below 15 years) since 2006. In 2015, the share of old people was 22% in the Barents region and 23% in the national population. The share of young people in the Barents region has decreased from 25% in 1990 to 18% in 2015, but this is 1 per cent point above national averages. The population structure is very similar in all countries. The Russian Barents population was slightly younger than the Nordic in 1990, but it has reached others by 2015.

The Barents population is moving to cities. National statistic centres published the share of urban population, but unfortunately the definition on 'urban' varies in each country. For this reason, it is more meaningful to look at the trend than the actual value. According to national statistic agencies, the share of urban population grows fastest in the Finnish Barents and slowest in the Swedish and Russian Barents regions. According to previous studies, the large cities gain most of the population increase, while smaller cities roughly maintain their population, and rural areas lose population (Norden 2016).

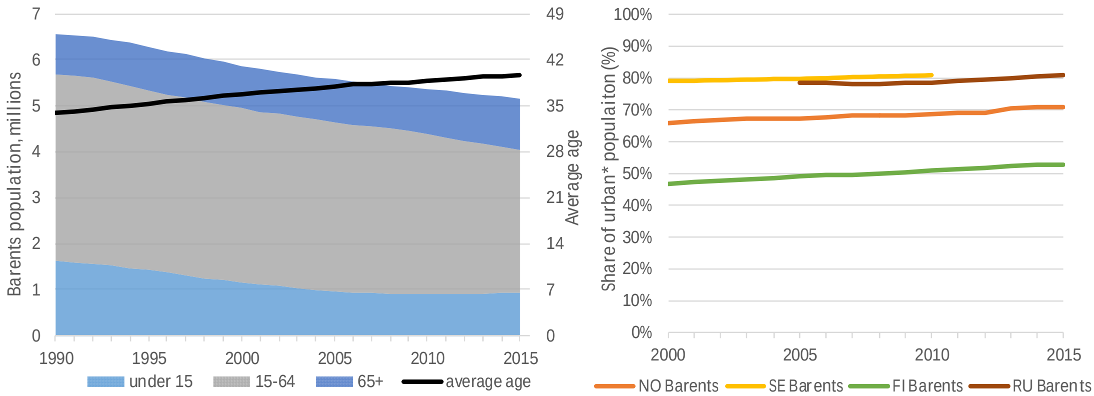

Figure 4. Left panel: The Barents region population is getting older. Population structure is similar in each country. Right panel: Barents population is moving to urban areas. National statistic agencies publish urban shares, but have varying definitions of 'urban'.

The urbanizing trend increases the populations of cities by 7000 per year in the Nordic Barents and reduces the population of rural areas by 5000 persons per year. In the Russian Barents, both the urban and rural population are decreasing, but the share of urban population slightly increases.

A recent OECD report concludes that the combined trends of urbanization and ageing will be a challenge for rural and remote areas (OECD 2017). There is a risk that the rural population will have limited access to all basic goods and services, will face increasing time in transportation while taking care of daily chores, and local companies might have difficulties finding a work force.

Previous studies also show that rural areas will be more difficult to decarbonize (Norden 2016) as there is a lower concentration of energy consumption that offers fewer possibilities and incentives to invest in new technologies.

Table 2. National statistics centres' estimates of urban and rural population change in the Barents region.

	Urban population change each year	**Rural Population** change each year
NO Barents	+3000	-1200
SE Barents	+1200	-900
FI Barents	+3800	-3100
RU Barents	-28 000	-17 000

Share of employed 15–64 years old has been steadily increasing in the Barents region. Persons not working include students, unemployed, disabled, retired under 65, and people participating in the informal subsistence economy. The rate of economic dependency[2] has been improving steadily as it was 2.3 in 2000 and 2.0 in 2014. The Barents region's demographic dependency[3] improved from 0.55 in 1990 to 0.51 in 2007, but the ratio has been increasing since and was 0.65 in 2014. This clearly indicates that despite the ageing population, the region has managed to remain economically competitive and to create new jobs.

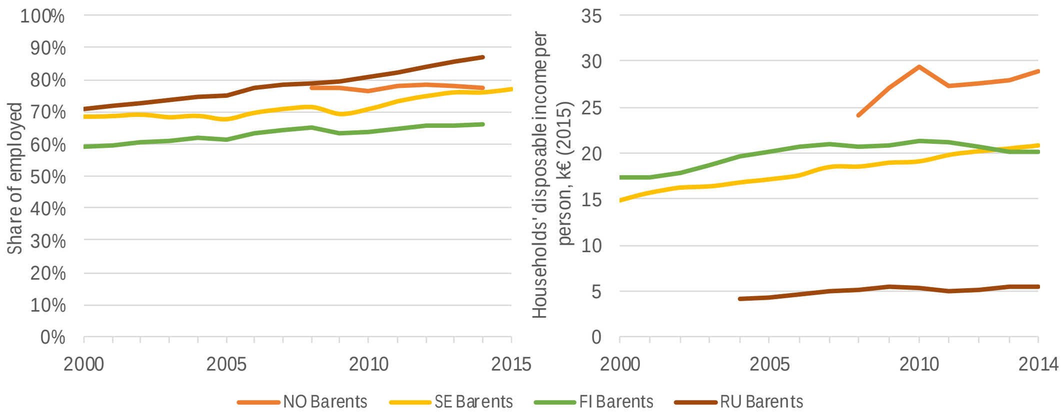

Figure 5. Left panel: The share of employed 15–64 year olds has been increasing in the Barents region. Only in Norway has the share remained at the same level. Right panel: Household disposable income (k€ per person) has increased in the long term and suffered slightly after the 2008 recession in Norway, Finland, and Russia.

[2] population / employed
[3] (number of less than 15 years + number of over 64 year) / (number of 15–64 years old)

The wealth of the Barents region population has increased when measured in terms of disposable income. The first year of available statistics varies from one country to another, but they all seem to share economic growth in the long term and a decrease in household income after the 2008 recession. Only the Swedish Barents region households did not seem to be largely affected. Norwegian and Russian Barents region households' income had increased back to the 2010 income level by 2014, but the disposable income of the households in the Finnish Barents region had not recovered and had dropped to 2005 levels.

2.3 Diversified economies can adapt and respond to challenges

In 2014, the public sector generated 28% of the Barents region's GVA, industry 24%, commercial sector 15%, financial sector 14%, construction 7%, and agriculture (including agriculture, forestry, hunting, fishing, and aquaculture) 5% (see Figure 6). The Russian Barents region had a 40% share of GVA from industry, while the Norwegian Barents had only 14%. The Statistics Norway excludes off-shore activities from regional GVA. Industry would likely be the largest source of GVA in the Norwegian Barents as well, if the Statistics Norway would allocate off-shore activities to the regional GVA. A table at the end of Annex A presents how national classifications are summed into the categories in this report.

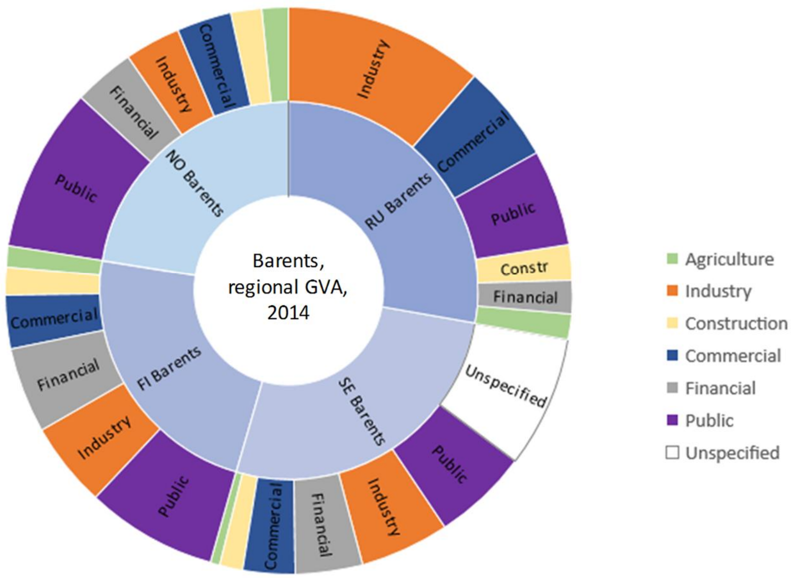

Figure 6. GVA in the Barents regional GVA in 2014. Countries and sectors within a country are organized from the largest to the smallest. Statistics Sweden has a considerable share of unspecified data in regional accounts. Statistics Norway excludes off-shore activities from regional statistics. Agriculture includes also forestry, fishing, and aquaculture.

The public sector's share of GVA varies from 20% in Russia and Sweden to 42% in Norway, but these are slightly smaller than the national averages. Only Norwegian Barents has larger public sector than the national share of 31%, but this could change if Statistics Norway would allocate off-shore activities to regional accounts.

Detailed analysis of the Swedish Barents region's economy is somewhat limited, as the Swedish statistics contain a large share of unspecified data. Unspecified data in Swedish national accounts is an unallocated portion of the GVA consisting of net product taxes, differences between several estimation methods, and consumption of indirect financial services (SCB 2017).

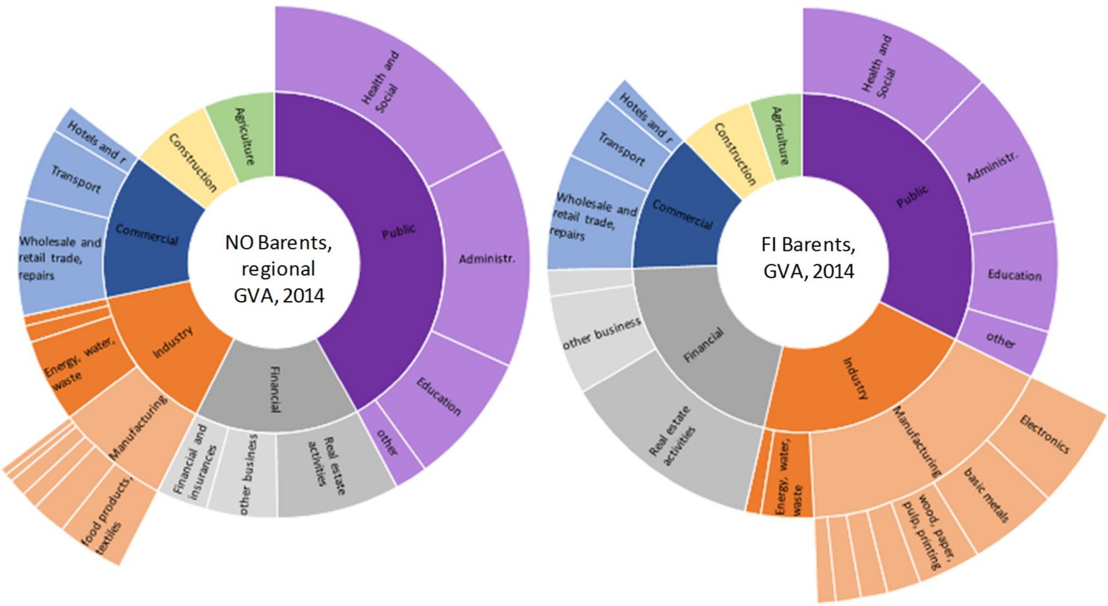

Figure 7. Regional GVA of Norway's and Finland's Barents regions in 2014.

The economy in the Norwegian Barents region has grown 2% per year from 2008 to 2014, which is slightly faster than in other regions in Norway (1.7% per year). The Economy growth in the Norwegian Barents has been driven by a public sector whose regional GVA increased from 7.2 billion EUR(2015) in 2008 to 9.3 billion EUR(2015) in 2014. Aquaculture, commercial, financial, and construction sectors grew, but less than the public sector. The total GVA from industry remained at the same level from 2008 to 2014, because some industry sectors grew (mainly food processing with strong link to fisheries and aquaculture) while others decreased (especially basic metals and chemicals). Slightly over 50% were employed in the public sector.

In Norwegian Barents, fishing and aquaculture produced 7 times more value added to the region and employed 30% more than agriculture, forestry, and hunting at 2015. If summed together with food processing industry, the size of the sector was 10% of the Norwegian Barents regional GVA making the aquaculture and fishing economically the most important industry branch in Norwegian Barents. And the future prospects are very promising as the annual growth has been over 10% for the last 6 years.

The economy structure of the Finnish Barents region changed after the 2008 recession, as the industry's GVA has decreased from 8.1 billion EUR(2015) in 2007 to 4.8 billion EUR(2015) in 2014. The public sector GVA increased from 5.3 billion EUR(2015) in 2000 to 7.6 billion EUR(2015) in 2012, after which public spending slightly decreased. The public sector increased its volume after the 2008 recession to stimulate the economy, but industry did not recover during these years and the GVA per person is now 20% lower in the Finnish Barents region than the national average. Figure 7 shows a snapshot of 2014 situations in Norway and Finland Barents regions. Annex I presents more data from these countries.

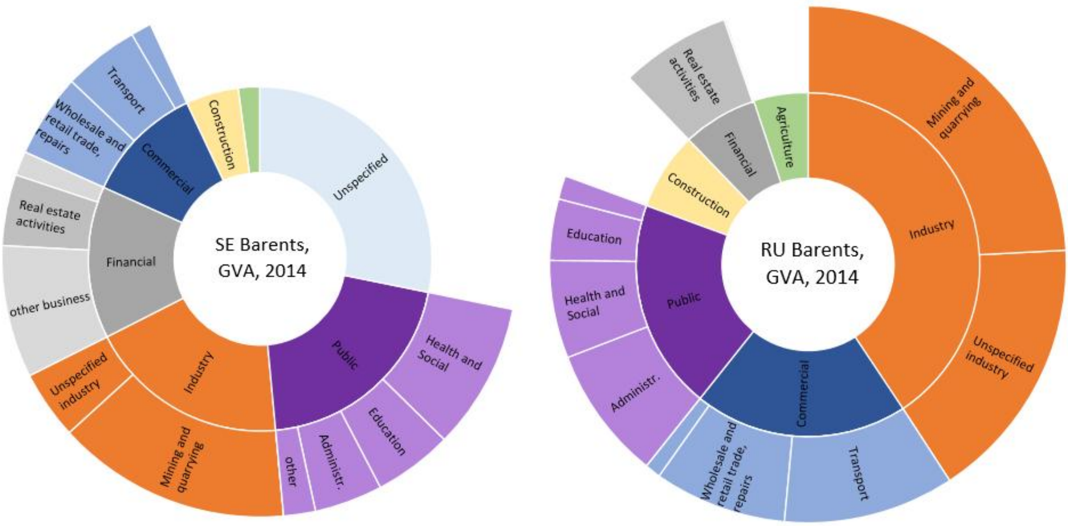

Figure 8. Regional GVA of Sweden's and Russia's Barents regions.

Swedish Barents has 10% higher regional GVA per person than the national average. Sweden's Barents region has a higher amount of industry and public sector GVA per person, but less financial and commercial GVA than the national average. The economy of the Swedish Barents grew 3.5% per year from 2000 to 2008, but has stagnated since and remained at the 2008 level. The Industry GVA region fell sharply in Sweden's Barents in 2008, but the sector has recovered better than in Finland. The most recent years have been less fortunate and the industry GVA has started to decrease again.

Russia's Barents regional GVA peaked between 2006 and 2010, but the amount of industrial and commercial GVA has decreased since. The share of the public sector's GVA has increased from 12% in 2004 to 20% in 2010. Compared to national average, Russia's Barents region has a larger share of industry and public sector GVA, but less commercial and financial GVA. Russia's Barents regions have 10% higher GVA per person than the national average. Figure 8 shows a snapshot of 2014 situations in Sweden's and Russia's Barents regions. Annex A presents figures from 2000 to 2014.

The Barents region had a total of 2.6 million employees in 2014, of which 1.9 million were in Russia's Barents. Finland's Barents employed 0.3 million while both Sweden and Norway Barents regions employed 0.25 million people. The public sector employs 51% of employees in the Norwegian Barents region, 44% in the Swedish Barents, 41% in the Finnish Barents and 30% in Russia's Barents. The commercial sector was the second largest employer in 2014 employing 25% of employees. Figure 9 shows the sectoral split for each country.

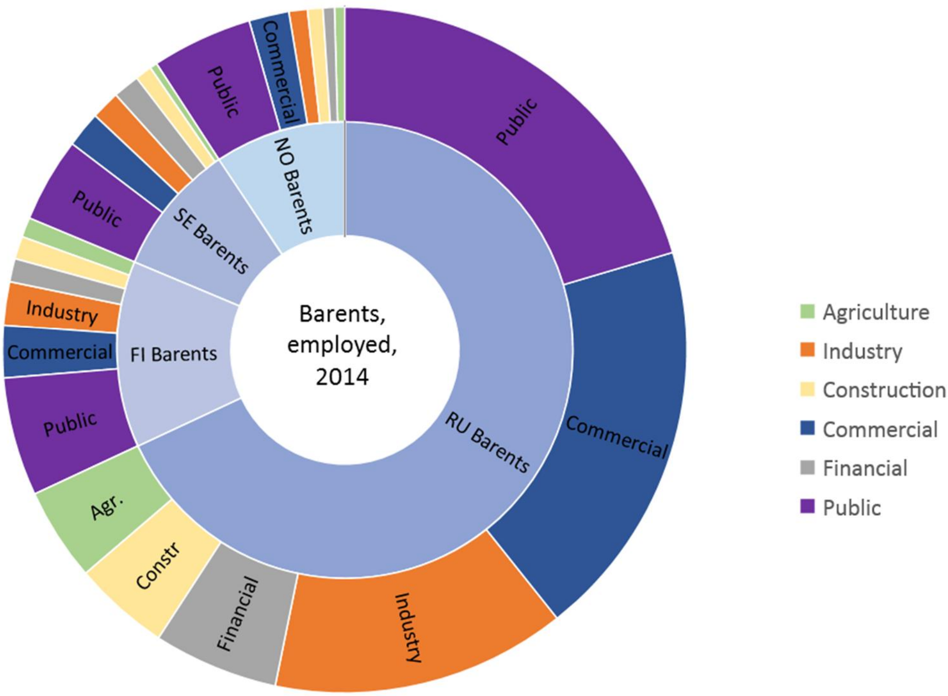

Figure 9. Russia's Barents region employed 1.9 million of the total of 2.6 million employees in the Barents region in 2014. The public sector was the largest employer (35% of employees) in the Barents region, followed by commercial (25%) and industry (18%).

The industry sector and financial sectors are high added value sectors, where the share of work places is considerably smaller than the share of GVA. Industry employed 18% of employees in 2014, but generated 25% of the Barents regional

GVA. The financial sector employed 9% of employees, but generated 14% of the GVA. All subsectors of these groups are listed in a table at the end of Annex A.

Table 3. Average value added per employee in the Barents region in 2014. * Agriculture includes also forestry, hunting, fishing, and aquaculture. Statistics Norway excludes offshore activities.

	Value added per employed, k€(2015) / employee / year				
	Financial	Industry	Commercial	Public	Agriculture *
NO Barents	250	140	60	75	120
SE Barents	120	120	70	50	60
FI Barents	160	90	45	50	45
RU Barents	13	95	11	10	12

Financial and industry sectors provide the best compensation per employee, and Norway provides much higher compensation per employee than other Nordic Barents regions (see Table 4). There is no sectoral data available from the Russian Barents.

Table 4. Average value added per employee in the Barents region at 2014. * Agriculture includes also forestry, hunting, fishing, and aquaculture. Statistics Norway excludes offshore activities.

	Compensation per employed, k€(2015) / employee / year				
	Financial	Industry	Commercial	Public	Agriculture*
NO Barents	77	70	49	61	25
SE Barents	39	43	34	34	16
FI Barents	43	50	30	40	13
RU Barents	-	-	-	-	-

2.4 Sectoral perspectives

Oil and gas industries are very important for both Norwegian and Russian Barents, though that is not visible from regional accounts. Norwegian Barents produces 15 Mtoe of oil and gas annually, which is 6% of the national total. Russian Barents production increased quickly after 2001 when available data starts and reached a peak of 35 Mtoe in 2009. The total production has been approximately 3% of the national total. Both regions have untapped oil and gas reserves.

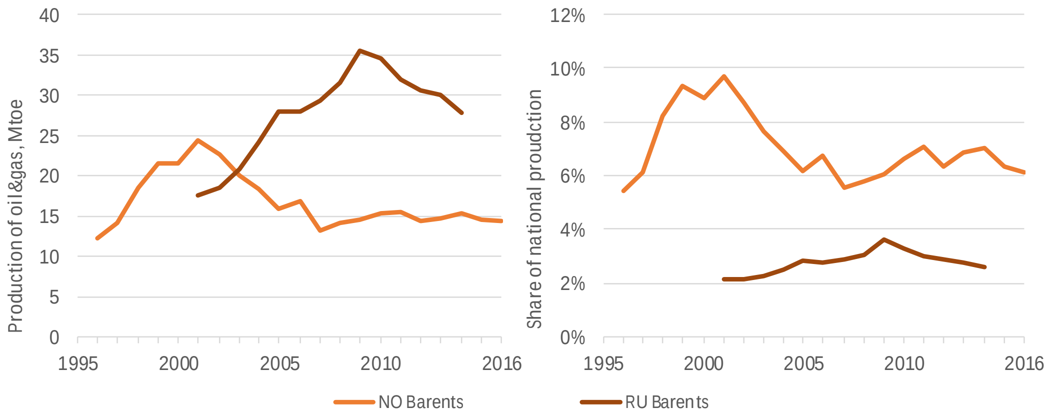

Figure 10. Left panel: Oil and natural gas produced in Norwegian and Russian Barents. Right panel: share of national production.

The Barents region has two large Harbours, one in Murmansk and other in Narvik. Murmansk's volume of goods has been approximately 30 million tonnes per year varying from 20 to 50 million tonnes depending on the year. Most of the exported products from the Murmansk harbour are oil and gas products. Narvik's harbour transfers approximately 20 million tonnes of goods annually, but the share of oil shipments is relatively low, as the main commodity is iron ore from the Kiruna mine in Northern Sweden. The most important harbours in the Swedish and Finnish Barents regions are in Luleå and Raahe serving local industries.

The Nordic Barents region has a large amount of hydro power which is used in local industries and exported from the region. The Nordic Barents region has 8% of the population in these countries, but it produces 20% of the electricity generated on Barents regions on an average year. The Nordic Barents regions have energy-intensive industry and average electricity consumption of is 60% above national averages, but there is still enough electricity to export.

Electricity export from Swedish and Norwegian Barents regions is a major income source. Between 2009 and 2014, the Swedish Barents region exported electricity worth 550 to 900 million euros annually. In 2015 and 2016 the Norwegian Barents region exported electricity worth 60 and 160 million euros, respectively. Finnish Barents region is a net electricity exporter when annual precipitation is above average and a net importer when it rains less. The monetary worth of electricity net export has been from -110 to +70 million euros depending on the water year.

Mining is a particularly important but volatile sector. In Swedish and Russian Barents regions mining contributes 20% and 25% of the total regional GVA, but mining is less important in Finnish and Norwegian Barents regions, where mining sector contributed only 1% of the total regional GVA. The mining sector's economic performance is very hard to predict as the Swedish Barents mining sector's GVA fell

37% between 2008 and 2009, but increased 80% between 2009 and 2010. Changes in the Swedish Barents mining GVA has been up to 2 billion EUR per year. Annual variability has been even greater in Finland, but the total volume is smaller, at the level of 0.2 billion EUR in 2014.

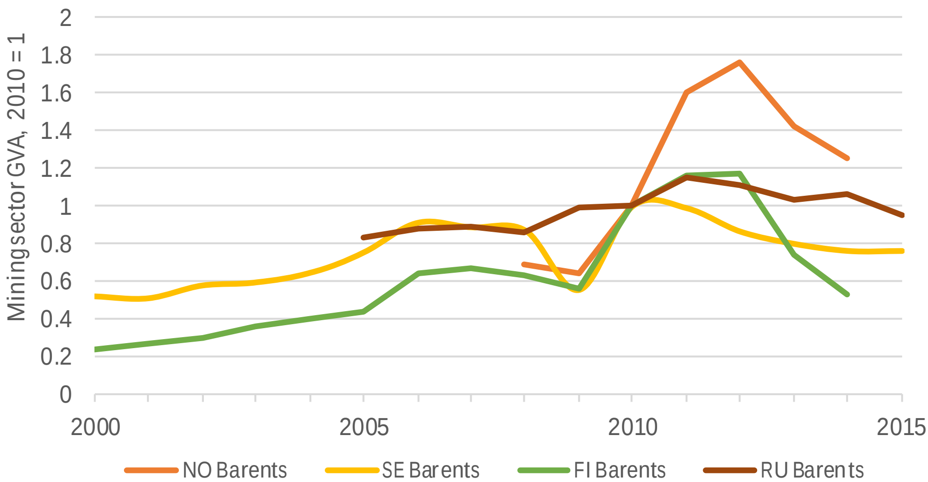

Figure 11. The mining sector is very important for Swedish and Russian Barents as the GVA is 20% and 25% of the total, respectively. The mining sector's GVA has also very high annual variability.

Norway and Finland publish detailed sectoral data of manufacturing industries while Russia and Sweden publish only two categories: mining, and other industry. Norwegian Barents' manufacturing industries are mostly food products, beverages, textiles, and unclassified smaller manufacturing industries. Finnish Barents has a large amount of electronics, basic metals, and wood, pulp, and paper industries. Norwegian Barents food processing industries are growing, while the Finnish Barents industries faced harder times in 2014. The situation has improved since, but the data ends in 2014.

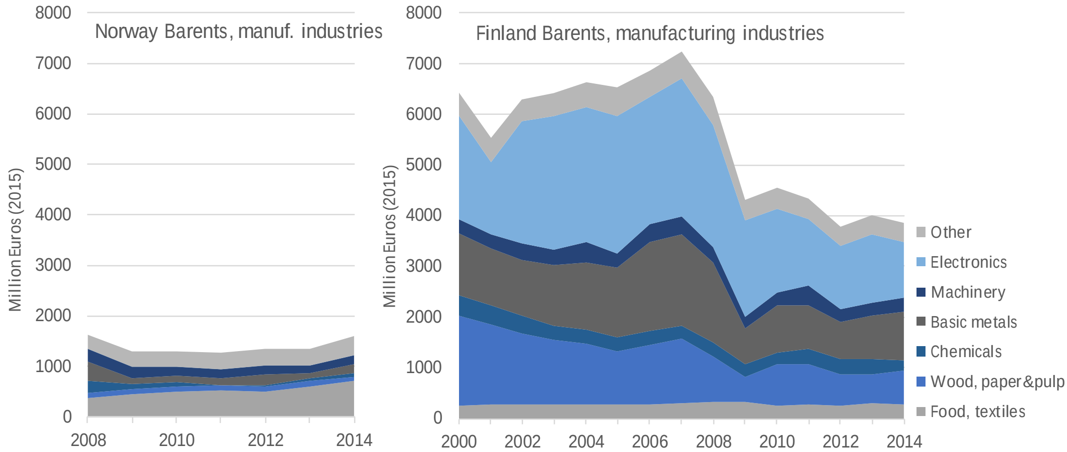

Figure 12. Norwegian and Finnish Barents regions industry GVAs up to 2014. Sweden and Russia do not publish this detailed sectoral data from industry.

The agriculture sector (agriculture, fishing, aquaculture, forestry, and hunting) forms 5% of the Barents region GVA and employs 6% of the employees. Based on the regional accounts, these sectors are growing in Finnish and Norwegian Barents, stable in Swedish Barents, and decreasing in Russian Barents. Aquaculture is an especially important sector in the Norwegian Barents, and it has been growing quickly creating the growth also in closely linked sectors such as food processing.

It is difficult to compare the Barents regions in these sectors, because national statistics centres group them differently. Statistics Norway and Russia group agriculture, forestry, and hunting under one category in statistics, and fishing and fisheries under another category. Statistics Finland group agriculture and hunting under one category, and forestry, fishing, and aquaculture under another. Statistics Sweden group all five under one category. Reindeer herding is not explicitly mentioned in the statistics and it is likely grouped under the agriculture. Table 5 compares the significance of these sectors at each countries' Barents regions and Table 6 compares the share of e.g. fishing and aquaculture in the Barents region to the national totals.

Tourism does not have a clear classification in statistics, but it is divided under transportation, commercial, hotels, and restaurants, among others. Hotels and restaurants are a good indicator of tourism activities, but they form a smaller share of the total GVA directly, ranging from 1% (Sweden) to 2% (Finland). The annual growth has been fast in Norway and Sweden Barents regions, on average 5%/year and slightly slower in Finland Barents (2%/year). Other sources estimate that tourism would contribute from 2% to 5% of regional GVA in the Barents region (Glomsrød et al. 2017).

The amount of Asian tourists increased much during the winter 2016–2017. It remains to be seen if the increasing numbers of tourists is a long-term trend, but the Barents region has been able to offer safety, cool weather during summer, and snow in winter. Chapter 4 discusses the impacts of climate change on tourism and other sectors.

Table 5. Regional Gross Value Added (GVA) and employment of agriculture, aquaculture, fishing, forestry, and hunting as shares of the regional total GVA and employment, at the level which national statistic centres publish the data. Reindeer herding is not explicitly mentioned in the statistics and it is likely under agriculture.

	Share of local GVA				**Share of local employed**			
	NO Barents	SE Barents	FI Barents	RU Barents	NO Barents	SE Barents	FI Barents	RU Barents
Agriculture, forestry, and hunting	1%			2%	2%			5%
Agriculture and hunting			1%				5%	
Fishing and aquaculture	6%			3%	3%			1%
Fishing, aquaculture, and forestry			4%				2%	
Sum of all 5 sectors	**7%**	**3%**	**5%**	**5%**	**5%**	**4%**	**7%**	**6%**

Table 6. Barents regions' agriculture, aquaculture, fishing, forestry, and hunting compared to the national totals. The share is calculated from employment and GVA, which give good estimates. Reindeer herding is not explicitly mentioned in the statistics and it is likely under agriculture.

	Share of national total, calculated from GVA and employment			
	NO Barents	SE Barents	FI Barents	RU Barents
Agriculture, forestry, and hunting	10%			2%
Agriculture and hunting			20%	
Fishing and aquaculture	40%			20%
Fishing, aquaculture, and forestry			30%	
Sum of all 5 sectors	**20%**	**10%**	**20%**	**4%**

3. Mitigation contributions under the Paris Agreement

The mitigation contributions required to fulfil the Paris Agreement goals are modelled with the TIMES-VTT integrated assessment model. The model describes global energy supply and use, as well as non-energy-related greenhouse gas emissions and GHG mitigation efforts, in long-term scenarios. Given projections on future energy, industrial, and transportation demand; development of energy technologies, available resources and policies governing energy use and emissions, the model finds a least-cost way of satisfying both the future energy demand and stated policy targets, e.g. emission limits. Using the economic theory, the solution can be interpreted to portray the actions of individuals, companies, and governments under efficient energy and emission markets.

The following section presents how the Paris Agreement's implications have been interpreted in the TIMES-VTT model, while Section 3.2 presents energy and emission scenarios of Barents region countries under the Paris Agreement. These results are further discussed in the sectoral analyses of Section 5. A slightly more detailed description of the model is provided in the Appendix B and a full model documentation of TIMES models has been updated at 2016 (Loulou et al. 2016). TIMES-VTT and its input data has been documented also in several studies (Matthews et al. 2015 and Kallio et al. 2015). Specific assumptions used in this study are described in the chapter below.

3.1 Scenario specifications

The main objective of the presented mitigation scenarios is to portray how the Barents region could contribute to the mitigation efforts of the Paris Agreement. The level of geographic detail in modelling does not allow present energy or emission scenarios for the Barents region itself. However, the Barents region will be guided by the national-level policies and market developments. Thus, the national-level energy and emission pathways presented here do provide an outlook for development also in the Barents region. These results will be combined with the insights from the Barents region economic structure, presented in Chapter 2, in the sectoral analysis for the Barents region in Chapter 5. Also, as the mitigation effort differs considerably between the two mitigation scenarios, the residual climate impacts from these scenarios are presented in Chapter 4.

Emission targets

The long-term objective of the Paris Agreement is to limit global mean temperature increase well below 2°C, and to pursue efforts stabilizing temperature increase at 1.5°C.The Paris Agreement is built bottom-up, on countries' voluntary and self-declared contributions for reducing emissions: the Nationally Determined Contributions (NDCs). In line with the United Nations' framework climate agreement, the countries' mitigation contributions should be based on countries' capabilities, meaning that a higher mitigation contribution is expected from more wealthy countries.

At the time of writing, 168 countries have submitted their first NDC, which involve emission targets up to the year 2030. Of the Barents region countries, Norway has its own NDC, Sweden and Finland are included in the NDC of the European Union, and Russia has submitted its preliminary Intended Nationally Determined Contributions (INDC).

Past analyses have estimated that the aggregate contribution of currently expressed NDCs and INDCs do not suffice to keep the temperature increase below 2°C (see e.g. Ekholm and Lindroos, 2015). However, NDCs will be updated sequentially over time and the emission targets will be extended beyond 2030, with the intention of raising the mitigation effort. How effective the Paris Agreement will ultimately be in mitigating climate change is therefore yet uncertain, and depends on how willing the individual countries will be in pursuing ambitious climate policies.

To reflect the uncertainty in the Agreement's outcomes, we calculate the main Paris Agreement scenario (RCP 2.6) that assumes a strong international action on mitigating climate change and a sensitivity scenario (RCP 4.5) that assumes strong mitigation only from the most developed countries and moderate action from the rest of the world. In these scenarios, we limit the radiative forcing at 2.6 W/m^2 in the first case (RCP 2.6) and at 4.5 W/m^2 in the latter (RCP 4.5), which respectively correspond to a temperature increase of approximately 1.6°C and 2.4 °C.

We set specific medium- and long-term emission targets for the Barents region countries based on EU and national targets. Norway, Finland and Sweden act under the EU climate policy (pricing of emissions under the EU Emission Trading System (ETS) and national emission targets under the Effort-Sharing Regulation (ESR)). Swedish climate policy framework (Sveriges Riksdag, 2017) sets a target for achieving carbon neutrality by 2045, but this target includes emission offsets and domestic reductions will be around -85%. For other Barents region countries we assume -80% GHG target for 2050 as presented in Table 7. However, the model has the freedom to overachieve the national emission targets if that would be cost effective in order to meet the global-level targets.

Table 7. Climate policy assumptions for the RCP 2.6 and RCP 4.5 scenarios. The Barents region carries out ambitious mitigation in both cases, but in RCP4.5 the Paris Agreement does not create ambitious action in developing countries.

	RCP2.6	RCP4.5
Global	Cost-efficient mitigation to keep radiative forcing below 2.6 W/m^2 (~1.6°C warming)	Cost-efficient mitigation to keep radiative forcing below 4.5 W/m^2 (~ 2.4°C warming)
Norway	2030: Norway NDC target, EU ETS and ESR 2050: GHG at least -80% from 1990	as RCP 2.6 scenario
Sweden	2030: EU NDC target, EU ETS and ESR, domestic transport GHG -70%	as RCP 2.6 scenario

	RCP2.6	RCP4.5
	2050: at least 85% reduction of GHG[4]	
Finland	2030: EU NDC target, EU ETS and ESR 2050: GHG at least -80% from 1990	as RCP 2.6 scenario
Russia	2030: INDC target 2050: GHG at least -80% from 1990	as RCP 2.6 scenario

Technology development

The modelling approach used in the TIMES-VTT model intends to satisfy the projected energy demand and emission targets with least costs (see Appendix B for further information). The scenarios resulting from this optimization procedure are highly dependent on what assumptions are made for future energy technologies; that is, how current technologies develop, and when new technologies will be available on the market, how efficient and costly they will be and how efficiencies and costs might evolve over time.

The default assumptions of TIMES-VTT model involve gradually declining costs for existing technologies, such as solar power, wind power, and electric vehicles. Based on recent development, the solar power costs have been updated and the investment cost is assumed to be 600 €/kWp at 2020, 450 €/kWp at 2030, and 600 €/kWp at 2050. Solar power production cost is and will be higher in the Barents region than in Central and Southern Europe due to lower number of sun light hours. Amount of solar power often remains quite low in Nordic countries especially because the hydro power and wind power resources are excellent. Solar power produces most of the electricity in summer when the demand is lower. But solar power gains a certain market share with updated price assumptions.

Nuclear power assumptions are updated to reflect the development over the recent years. Sweden has several times either decided to phase out or not to phase out the nuclear power. In this study, we assume that some nuclear plants will be phased out in Sweden, but some will remain and new plants could be built. The assumed maximum nuclear power production in Sweden is 53 TWh at 2020, 47 TWh at 2030, 35 TWh at 2040 and onwards. The model can choose to produce less nuclear power, but it cannot increase the production over the assumed maximum.

TIMES-VTT can reduce emissions in transportation by increasing energy efficiency in fossil fuel cars, and changing to alternative fuels such as electricity, biogas, natural gas, or hydrogen. All these are commercially already available for private cars, but only biofuels have been demonstrated for all transport modes. Maritime and heavy road transport can already use natural gas, but fossil fuels currently dominate the markets. Electricity is under demonstration phase in heavy road transport, maritime, and aviation. In default assumptions, we have electric vehicles in road transportation, but not in aviation and maritime. To study the importance of

[4] Sweden has a target to reach net-zero emissions by 2045, which includes 85% domestic reduction below 1990 levels and 15% carbon offset from low-carbon projects.

EV assumptions, we calculate a sensitivity scenario where all electric road vehicle prices will decline faster than assumed and be 20% lower than in default assumptions.

Industry sector can reduce emissions with energy efficiency, fuel changes, and new processes. Fuel changes are allowed for electricity, heat, and steam production. Process emissions are considerably harder to mitigate, but can be reduced with fuel efficiency, recycling of steel and aluminium, and new non-commercial technologies, such as CCS and biomass feedstock for oil refineries. Available measures for each sector are the same in all Barents region countries, but available measures in each country depend on which industry sectors each country has. TIMES-VTT follows the classification of the IEA energy statistics where part of the industries, such as blast furnaces, are classified under upstream.

As a reflection on very recent trends, the development of CCS has been underperforming and the availability of CCS has been restricted. We assume that Nordic Barents countries can use 9 $MtCO_2e$ of CCS at 2040 and 30 $MtCO_2e$ of CCS at 2050. For Russia, we assume that there could be 10 $MtCO_2e$ of CCS at 2040 and 50 $MtCO_2e$ of CCS at 2050. Limiting the amount of available CCS will increase both mitigation costs and required measures in other sectors.

Due to recent setbacks of CCS technology, we model a case where CCS technologies will not be commercialized at all. The overall level of mitigation targets are assumed to remain unchanged in this sensitivity scenario as well as in the low cost electric vehicle scenario. Thus, the differing assumptions will change only the composition of cost-efficient mitigation actions in different sectors, not the overall target.

3.2 Scenario results

Greenhouse gas (GHG) emissions

The modelling results indicate that greenhouse gas emissions decline rapidly in all Barents region countries under the Paris Agreement, as depicted in Figure 13. The decline is fastest in the power, district heat, and domestic transport. Industry, buildings, and upstream emissions are reduced slower, and agriculture emissions mostly remain at current level. At 2050 we have assumed some CCS potential that can produce negative emissions if applied to biomass processes, such as power and heat, pulp and paper or biofuel refining.

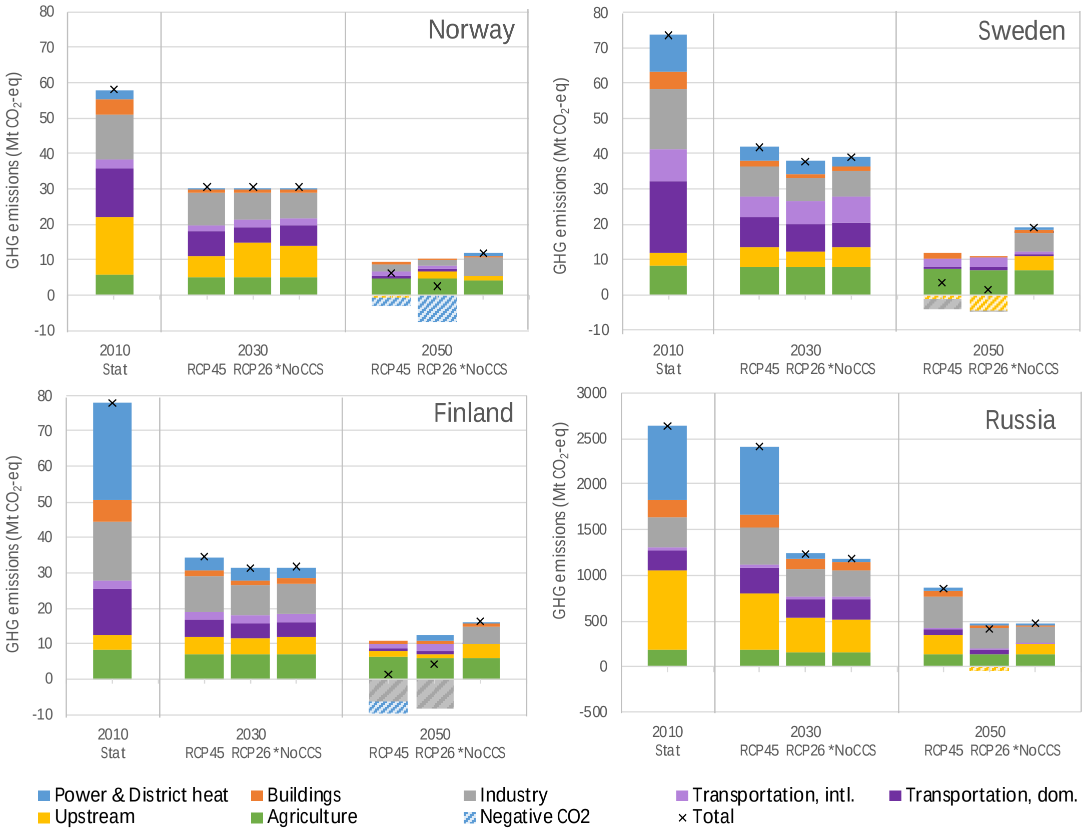

Figure 13. Greenhouse gas emissions by sector (excluding LULUCF) in the Barents region countries up to 2050 in the RCP 2.6 scenario. Shaded areas on the negative side result from CCS used with biomass. Colours on negative side refer to same sector than on the positive side.

Power and district heat was the first sector to decarbonize fully in the scenarios. This means that the model finds the decarbonization of the power and heat sector to be the most cost-efficient solution to reduce emissions. In general, the most cost efficient measures to reduce emissions from power and district heat are wind power, solar power, switching coal and peat to biomass in existing power plants, and expanding hydro power if environmentally viable. If the CCS is assumed to be available at 2050, the model chose to invest in to the bio-CCS to achieve negative emissions in the power and district heat sector.

Building stock does not cause large direct emissions, but is indirectly responsible for a share of power and district heat emissions. The energy efficiency in buildings increased in both RCP2.6 and RCP4.5 scenarios reducing the total energy demand of building sector. In addition, fossil fuels in direct heating are replaced with renewable alternatives. Oil heating in residential sector end by 2030 in Paris agreement scenarios, but this might be a challenge as actual decisions are made by many individuals.

Industry emissions are often closely linked to the industry processes. Industrial processes can increase efficiency and switch fuel to some extent, but it might have to be linked to wider modifications in the industrial installations. The fuel switching within industry should be easies in industrial power and heat production where fossil fuels could be replaced with lower emissions fossil fuels (natural gas), biomass, or electricity. All these happen in Paris agreement scenarios, but in much lower extent than in public power and district heat production. Industry process emissions are considerably harder to mitigate, but can be reduced with fuel efficiency, recycling of steel and aluminium, and new non-commercial technologies, such as CCS and biomass feedstock for oil refineries.

Domestic transportation will also reduce emissions in significant amounts, but emissions from international transportation (maritime and aviation) will remain at a higher level. In the RCP2.5 scenario, domestic transport shifts to electricity, biofuels, and other alternative fuels mostly by 2030 and almost completely by 2050. International transportation can shift to liquid biofuels or natural gas, but the costs are estimated to be higher especially in the aviation.

Upstream emissions from fuel extraction, pipelines, refining, and blast furnaces are reduced, but less than in other energy use sectors. Emissions of flaring, venting, and pipeline leakages are estimated to be easier to reduce than emissions from refineries and blast furnaces. In addition, oil and gas production declines, but industry production grows. These are the main reasons why upstream emissions would be reduced in Norway and Russia, but not that much in Sweden and in Finland.

Agriculture emissions remain notable up to 2050. Many studies have suggested emission reduction measures to agriculture, such as biogas, improved farming measures, improved manure handling, and increasing grass coverage in set-aside fields. TIMES-VTT model has the production of biogas, but otherwise the potential of measures in the agriculture sector are assumed to be limited. Emission reductions from agriculture requires further studies and might be underestimated here.

CCS is an important mitigation measure in deep decarbonisation scenarios from 2050 onwards. It could be used in electricity generation, particularly in conjunction with biomass to achieve net-negative emissions within the sector; and in certain industrial processes, particularly in the production of clinker for cement, blast furnaces for iron making, and refineries with fossil or biofuels.

The most notable effect of excluding CCS from the mitigation mix is the persistence of emissions from certain industrial and upstream processes. These include clinker production for cement, where CO_2 is released through calcination of limestone, production of iron in blast furnaces, where carbon acts as the reductive agent, and industry feedstocks of oil and natural gas. Cement production can use clinker substitutes in limited amounts, and steel can be produced also from recycled steel in electric arc ovens and direct reduction of iron oxide with, e.g. natural gas. Still, virgin steel produced via the blast furnace route is required for higher-grade steel. This situation is assumed to prevail until 2050. Thus, these approaches cannot fully eliminate the CO_2 emissions from these processes.

The total mitigation contribution from the Barents region countries is significant. In the Barents region countries, emissions are reduced 50% below 2010 by 2030 and 90% below 2010 level by 2050 under the Paris agreement scenarios if CCS is available. The 2050 reductions are more ambitious than national targets, but Barents region countries would not reach 80% reduction targets if we assume that CCS technology will not be commercial by 2050. The current model version does not have enough emission reduction measures to reach very deep emission reduction targets in agriculture, industry, and upstream without CCS. This does not mean that CCS is required, but it does mean that some new technology or technologies are required for industry processes, upstream, and agriculture.

Electricity generation

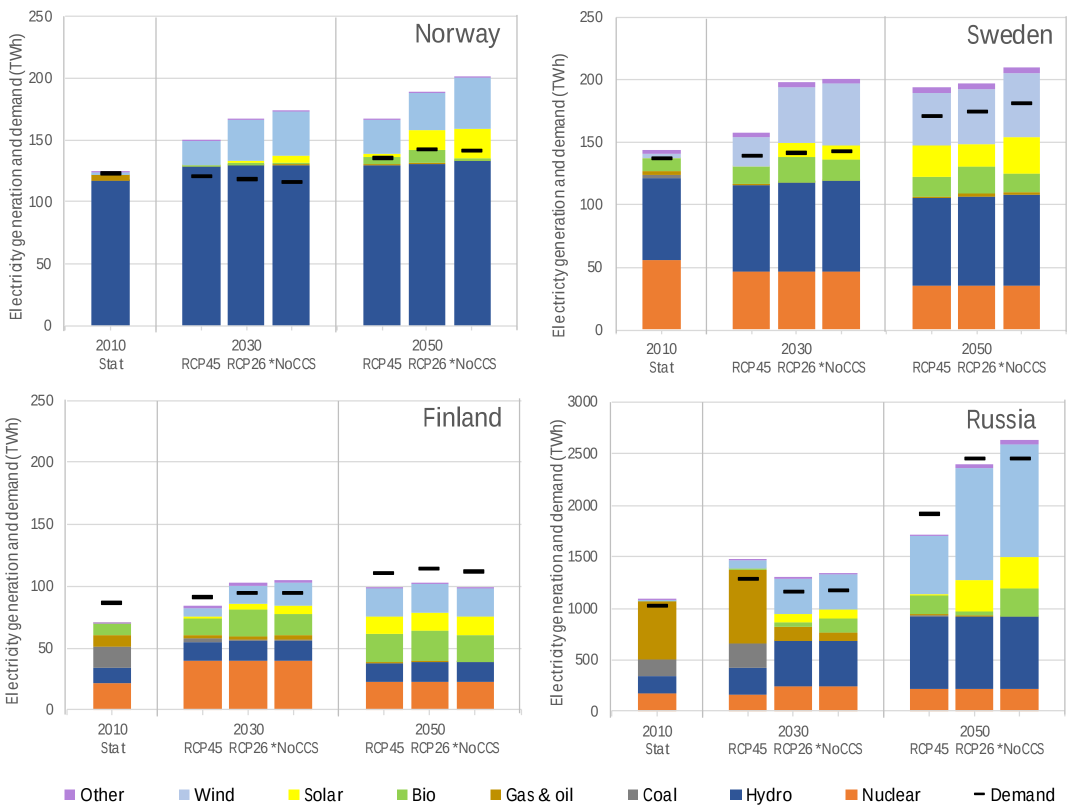

Figure 14. Electricity generation in the Barents region countries up to 2050 in the RCP 2.6 scenario. Other fuels are mostly municipal waste.

The existing electricity generation mix varies considerably between Barents region countries, and the required changes in the generation mix differ accordingly by country. Electricity generation and demand increases in the RCP 2.6 scenario in all the Barents countries, as presented in Figure 14. Increasing demand of electricity due to electrification and phase-out of fossil fuels needs to be balanced with new zero-emitting capacity. At the same time, Nordic countries electricity surplus increases and they export more electricity to Central Europe.

With the assumptions used in the scenarios, wind and solar power increase in significant amounts in all Barents region countries supplemented with production from biomass. In all Barents region countries, wind and solar could cover most of the required capacity expansion. Notable expansion of hydropower is feasible only in Russia, which has significant untapped hydropower potential (WEC, 2016), but this would require considerable investments. The hydropower capacity expanded 1.5 GW in Norway from 2010 to 2014 and 10 TWh of further capacity additions are under construction or planned (NVE 2017).

Paris Agreement scenarios have more demand than supply of sustainable biomass in the Paris Agreement scenarios. The use of biomass grows in CHP plants mainly due to district heat production from biomass, but smaller heat only units will be needed in smaller DH grids. Biomass could replace much higher share of fossil fuels, but available sustainable biomass resources are estimated to give higher total value in mitigating emission in other sectors where alternative options are more expensive.

Electricity demand is projected to increase despite the advantages in the energy efficiency. The main reasons is the electrification in other sectors to reduce direct emissions. The demand is increased especially through electrification in the heating, transportation and in industry. The scenario without CCS required more electricity, because end use sectors need to electrify more than when CCS is assumed to be available. It is important to remember that, if power generation is not decarbonized first, electric vehicles and other electrification might lead to an increase in the emissions.

Transport

Future transportation energy demand is characterized by an increase in transportation demand, improving efficiency and energy carrier switching. The Paris Agreement scenarios, depicted in Figure 15, involve a sharp decrease in gasoline and diesel use in land transportation, as vehicles gradually switch to a mix of advanced biofuels, electricity, and biogas. The decrease is sharper in gasoline, which is primarily used by passenger vehicles; while the switch in heavy road transportation using diesel is more gradual.

The electric car scenario is calculated without specific subsidies of electric cars. We assume in that sensitivity analysis that fully electric vehicles will be 5% cheaper and hybrid EVs will be as expensive as combustion engine vehicles by 2030. We also assume that road electric vehicle (EV) costs would be 20% below combustion engine vehicles by 2050. The fuel costs of EVs are considerably cheaper already in 2020 and declining price will make them considerably more cost-efficient mode for transportation. But due to long lifetime of existing car stock, the scenarios have at very similar differences at 2030. If higher share is desired, electric car likely need support and subsidies to be competitive before the year 2030. Support can be direct subsidies or indirect subsidy, such as a permit to drive on bus lanes. Norway has very successful managed to increase the EV sale numbers with a selection of measures including both direct and indirect support.

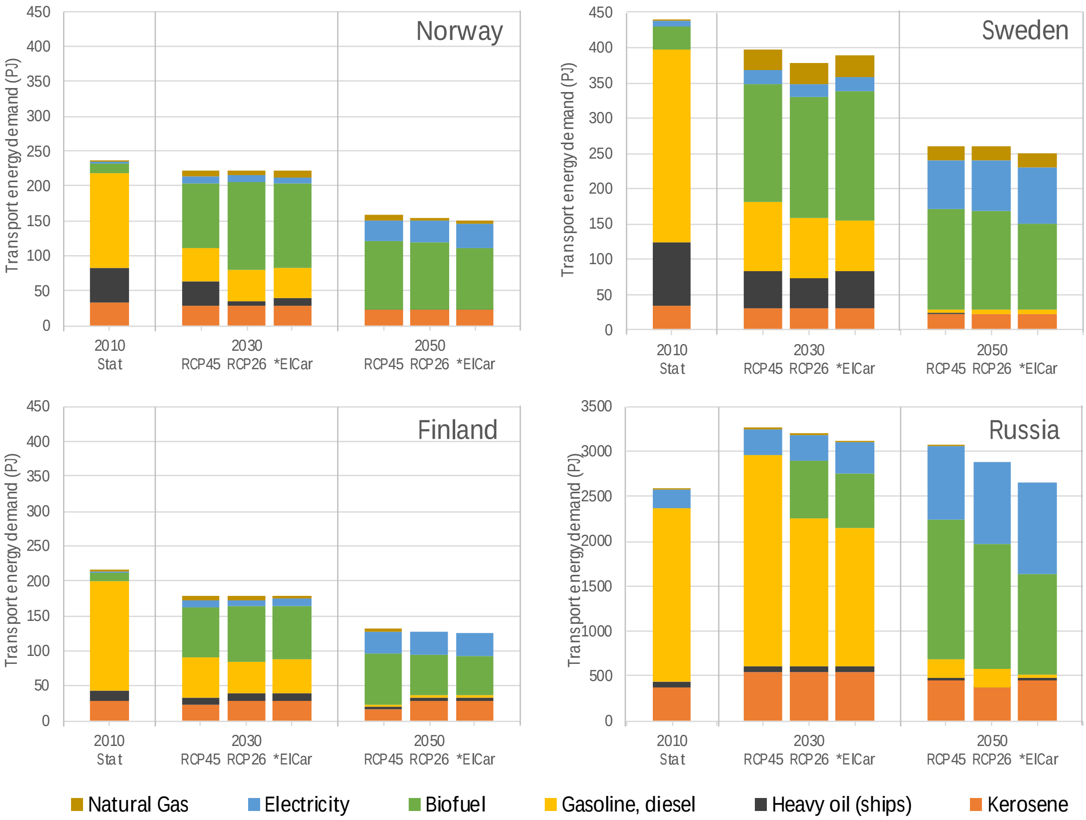

Figure 15. Energy use for transportation in the Barents region countries up to 2050. Kerosene is for aviation only, and heavy oil in transport is for ships only. 2010 is calibrated to national energy statistics.

Given that electricity generation faces fast transition to fossil-free sources, rapid and low-cost electrification of road transportation provides an attractive option for mitigation. All Paris Agreement scenarios require such deep GHG reductions that electric electricity and biofuels replace basically all fossil fuels except most of the kerosene. The model invests also to biokerosene, but that is considered to be the most expensive fuel to replace in transport sector.

The road transportation mileage per capita is expected to rise in Russia, converging towards the mileage per capita levels of other developed countries, leading to an increasing transportation energy demand despite the increases in efficiency. In the Nordic countries, efficiency improvements in road transportation outweigh the increase in mileage growth, leading to a decreasing trend of road transportation energy consumption. This trend has, in fact, already existed in the Nordic countries since 2007.

International maritime and aviation are not directly covered by the Paris Agreement, but international maritime and aviation organizations are considering mitigation contributions from these sectors. Our scenario show that these sectors have to contribute if we want to limit the global warming well below two degrees. As a result, international transportation emissions start decreasing already before 2030 in Paris Agreement scenarios. International maritime transport and aviation have less mitigation options that in road transportation and the situation can develop more positively if emerging technological solutions, such as electric airplanes and ships, will be successful.

Industry energy use

Industrial energy use varies considerably between Barents region countries, as can be seen from Figure 16, reflecting both the differences in energy supply and structure of the industry in each country. In Sweden and Finland, bioenergy forms a large part of the industrial energy mix, particularly due to the forest industry. In Norway, more than half of industrial use is electricity. In Russia, electricity and district heat supplied to industry comprise roughly one third of industrial energy, while two thirds come from fossil sources, predominantly gas.

Efficiency improvements in industry limit the future increase in energy use. TIMES models take industry production, e.g. tonnes of steel, and current energy use from statistics as input data. Then model is given an assumption of future production, but used energy and applied processes are optimization results. Although industrial production volumes increase in all the countries in the scenarios, the growth in industrial energy use is very modest in the Nordic countries. In Russia, however, a higher growth in industrial production, following an assumption of faster economic growth than in the Nordic countries, leads to an increasing industrial energy use, despite the notable improvements in energy efficiency.

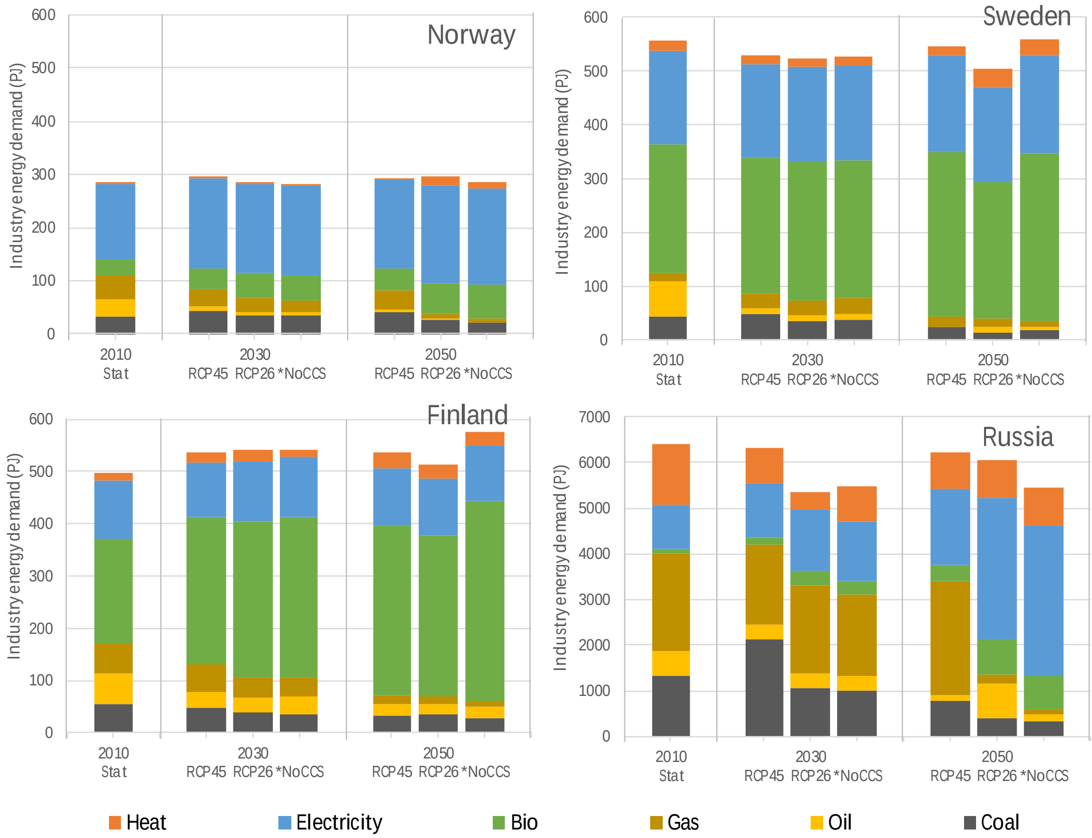

Figure 16. Industry energy use in the Barents region countries up to 2050 in the RCP 2.6 scenario.

Despite the high mitigation efforts, increasing energy efficiency, and new industrial processes, the use of fossil fuels does not cease completely in industry. A number of industrial processes – such as blast furnaces, cement kilns or petrochemical processes – have less viable substitutes for fossil fuels and feedstocks. Blast furnace steel can be replaced with recycled steel, but not completely. Oil refineries are assumed to be able to use biomass as a feedstock. Some industrial processes can be combined with CCS to avoid atmospheric release of the fossil emissions. In addition, Paris Agreement scenarios (RCP2.6 and RCP4.5) do not require 100% GHG reductions. With 90% total GHG reductions, the model can still emit some CO_2 from fossil fuels in sources where it is the most expensive to switch to other fuels.

Oil and gas production

The climate targets have notable implications for fossil fuel markets. The modelled RCP2.6 scenario exhibits a decrease in demand, but a stable price for crude oil on the global oil market. The European natural gas market, which is the main market for the Barents region gas producers, shows in turn a declining demand and a slightly increasing price due to increased extraction and transport costs. Both these still lead to significant decreases in monetary volumes of markets during the next decades in the RCP 2.6 scenario, as presented in Figure 17.

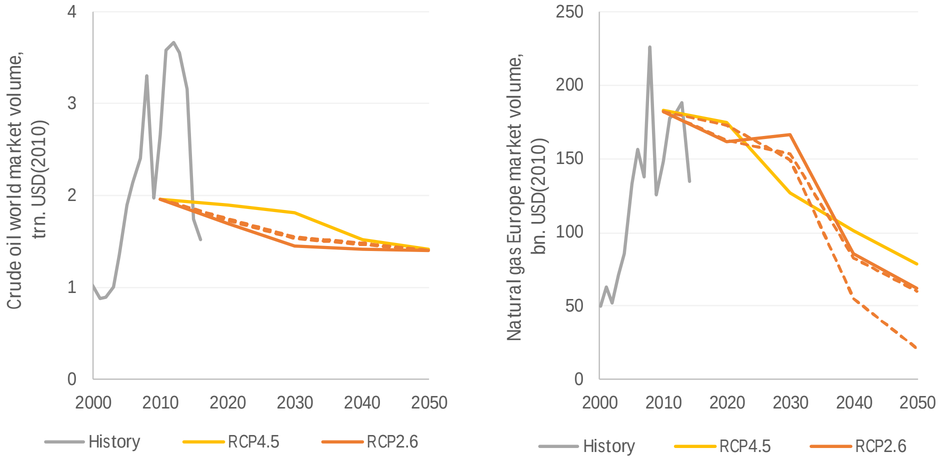

Figure 17. Crude oil world market and natural gas European market volumes up to 2050. Dashed lines indicate the sensitivity scenarios for the RCP2.6.

The sensitivity scenarios to the RCP2.6 case, which are shown with dotted lines in Figure 17, show mostly similar market outlooks compared to the default RCP2.6 scenario. The only exception is the European gas market if no CCS is available, in which case the gas market volume declines very rapidly post-2030 due to a more exacerbated need for reducing GHG emissions. If CCS technology would mature successfully, natural gas could be used with CCS. Without CCS, models have to reduce the use of fossil fuels faster in low carbon scenarios and natural gas could be easier fuel to switch than oil.

These effects are similar, but somewhat more pronounced, than in the 450 ppm scenario of the IEA World Energy Outlook 2016 (IEA, 2016). The IEA's 450 ppm scenario exhibits also a declining demand for gas in Europe. For oil, however, the IEA expects a stronger upward trend in price, exceeding 80 $/barrel by 2030, and a slower decline in demand. As a combination of these two trends, the rebounding price drives the global oil market volume in the IEA 450 ppm scenario. Even despite the declining demand, IEA projects that significant investments are needed for developing new oil and gas resources due to the declining production from existing fields (IEA, 2016).

However, the caveats involved in the perfect-foresight ideal-market simulation approach used in the TIMES-VTT model and similar challenges associated with the IEA scenarios should be noted. The risk of stranded assets arises from investments based on inaccurate future forecasts. The ambition level of global climate policy and emerging technologies pose large uncertainties for oil and gas demand. Estimating the price evolution of crude oil and natural gas is wrought with high uncertainties. Uncertainty over how producers compete for the market share on a declining and uncertain market adds to this risk. That is, although new investments in upstream oil and gas are needed to satisfy future demand, these investments will be more risky than earlier with hard-to-predict returns.

3.3 Other potential mitigation contributions

While the TIMES-VTT covers all emission sources covered by, e.g. the Kyoto-protocol and current EU emission targets, some emission sources and potential mitigation actions were outside the model scope. The model does not consider carbon stocks in land-use and forestry, which excludes the consideration of forest carbon sinks – a potent source of negative emissions in the Barents region. Another source of potential mitigation contributions excluded in the scenarios are changes in cultures and behaviour, including consumption patterns, acceptance or values. On the other hand, lock-ins or other bottle-necks in investments are not considered either. Consumption focusing less on tangible goods, more efficient use of materials and a dietary shift towards vegetarian options could result in a notable mitigation contribution that is additional to the presented scenarios.

The Barents region has notable forest reserves. While forest can provide a renewable source of energy and material, they also bind carbon from the atmosphere through tree growth. In statistics, these emission sink belong to category called land-use, land-use change and forestry (LULUCF). The emissions and sinks from LULUCF sector will be included in the EU climate policies (European Commission, 2016). As the presented scenarios involve notable amounts of biomass, partly of forest origin, this might have a negative impact on forest carbon storages and sink, which was excluded in the numerical results. Further scenario analyses that cover the energy system, forest carbon stocks and greenhouse gas emissions (Siljander & Ekholm 2017) would be needed to analyse the ideal balance of wood use and forest carbon stock enhancement.

Dietary choices, on the other hand, could affect the composition of agricultural production. Agricultural emissions arise primarily from cattle methane, soil nitrous oxide, and manure management methane and nitrous oxide emissions. Very limited mitigation options exist, particularly for the cattle and soil sources, and the scenarios exhibited a very stable level of agricultural emission up to 2050. However, the TIMES model considers a fixed projection for agricultural activities, and the scenarios did not consider alternative pathways of agricultural demand and activity. A dietary shift towards vegetarian options would reduce the cattle and manure management emissions perhaps significantly. However, the trade in food products and the coupling between bovine meat production and dairy products make the dynamics of such change non-linear and somewhat hard to predict. The impact dietary changes should nevertheless be explored further.

4. Climatic impacts on the Barents region

4.1 Introduction

Climate change is taking place faster in the Arctic than in the rest of the world. In addition to warming, climate change will impact several other processes, such as precipitation, snow cover, storms and other severe weather events, ice and thawing of the permafrost. The Arctic is particularly sensitive to temperature increase because warming affects key features of the Arctic environment, such as the extent of sea ice, seasonal variation in snow and ice, glaciers and permafrost and snow cover. The Arctic has already experienced significant warming over the past century, and the annual mean temperatures increased by 1–2 degrees in the Barents region between 1954–2012 (Walsh 2014; AMAP 2017). Further warming is expected over the next thirty years (Figure 20) and thereafter. Under the scenario RCP4.5, the typical winter temperature in Northern Fennoscandia would be 7 degrees higher than today in 2100 (Benestad et al. 2016; AMAP 2017).

The impacts of climate change interact with other factors (e.g. acidification and impact on fisheries). Moreover, there are interacting social and economic drivers that affect the Barents area, such as population development, economic growth, demands for natural resources (particularly by extractive industries) and land use issues (AACA 2017). All these factors work in parallel with climate and other environmental change and it is therefore difficult to predict the exact ecosystem impacts of climate change. There is also strong spatial variation in the impacts of climate change in the Arctic because the communities, biophysical regions and drivers of change are different in the different regions (Larsen et al. 2014). Moreover, climate change is compounded with the existing vulnerabilities, such as demographic factors and economic development, of the population in the area (Larsen et al. 2014).

4.2 Changes in temperature and sea ice extent in the Barents region by 2050

The analysis of climate change impacts up to 2050 presented in this Section, is based on climate model data regarding the RCP4.5 scenario from the ESM2G model by the U.S. National Oceanic and Atmospheric Administration (NOAA), and on relevant literature on the impacts of climate change on the environment and economy in the Barents region. It should be highlighted that analyses based on single models are inherently uncertain, and therefore multi-model approaches are usually recommended. Thus, Figure 18 to Figure 20 should be considered as illustrations of potential impacts in the Barents region. More emphasis is put on the literature review, the results of which are presented in Section 4.3.

In RCP4.5, reductions in emissions lead to a stabilization of emissions by the end of this century, and to an increase in the global average temperature of 1.7 to 3.2 degrees Celsius compared to 1850-1900 (IPCC 2013).

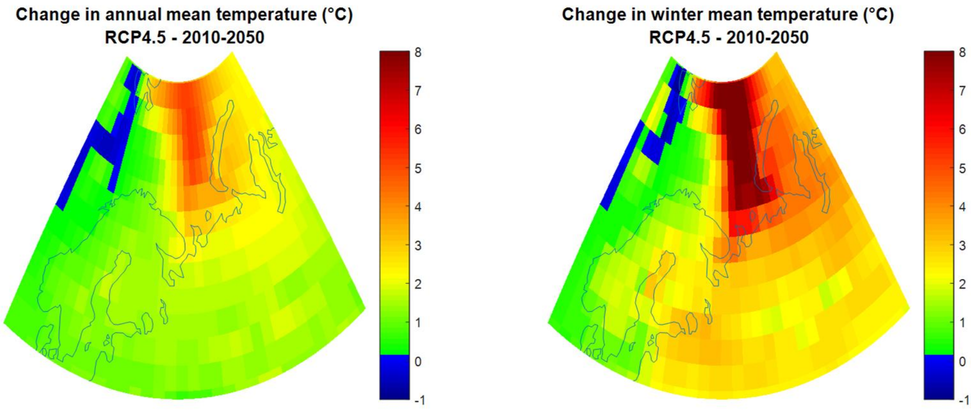

Figure 18. Change in annual mean temperature (left) and winter mean temperature (right) from 2010 to 2050 in the RCP 4.5 scenario.

As can be seen in Figure 20, the annual temperature is estimated to change by 1–3 degrees in Barents from 2010 to 2050. Expected change is somewhat higher for the winter average temperatures, ranging from 1 degree in Northern Scandinavia to over 3 degrees in the Russian Barents. The average temperature in April is estimated to increase by 1–2 degrees by 2050.

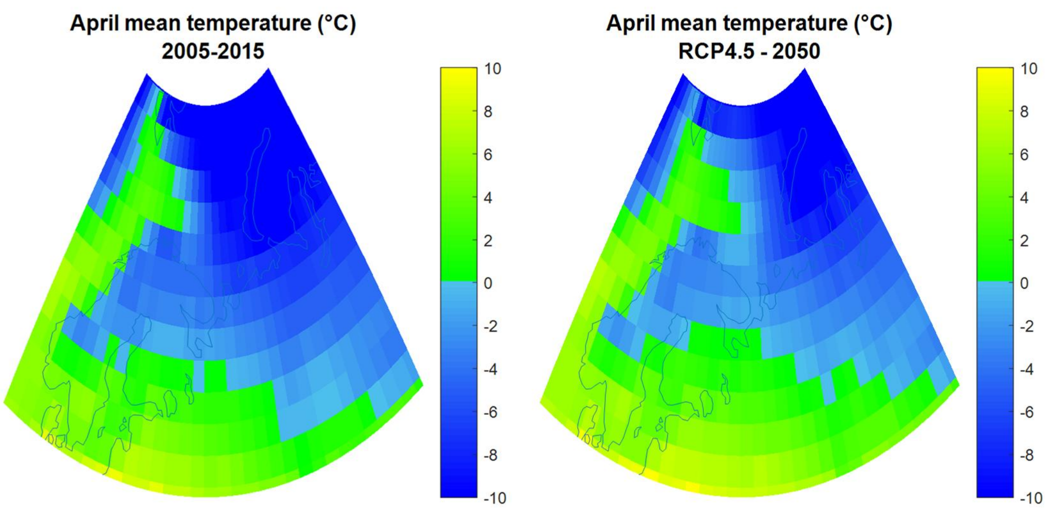

Figure 19. April mean temperature in 2010 (left) and 2050 (right) in the RCP 4.5 scenario.

According to the NOAA model results used in this study, the current trend of declining sea ice extent is predicted to continue in the Barents region. The differences between 2005-2015 average and at 2050 in the RCP4.5 scenario are the most obvious in the Barents Sea along the Russian coast.

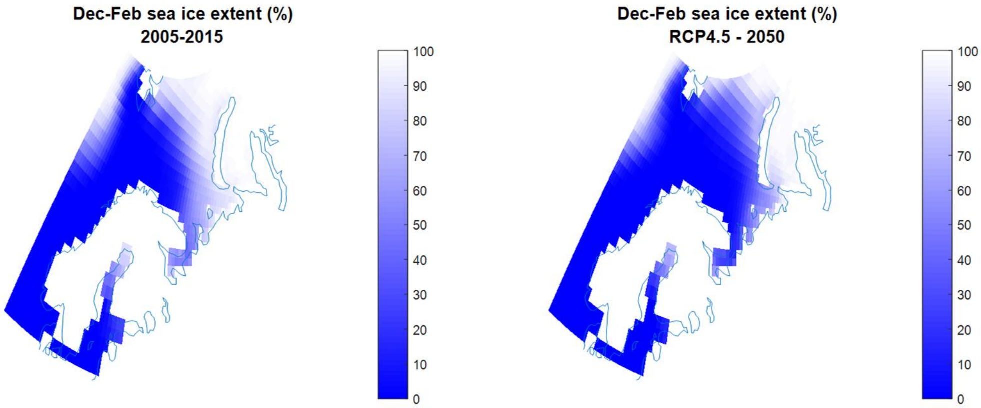

Figure 20. Winter sea ice extent in 2010 (left) and 2050 (right) in the RCP 4.5 scenario.

4.3 Impacts of climate change on the different sectors

The impacts of climate change on economic activities are intertwined with other factors, and it is thus difficult to separate the exact impact of climate change. Moreover, many of these factors act in opposite directions (Jansson et al. 2015). In addition to risks, warming climate may also bring about new opportunities, for instance by making resources more accessible and increasing the productivity of land and forest resources (Jansson et al. 2015). Dannevig et al. (2015) point out that the impacts of climate change often mix with other factors. For example, if reindeer pastures become fragmented due to infrastructure development, there is less land available to substitute areas that have become unusable as a result of changes caused by climate change, such as ice formation. In such situations, increased costs are imposed on reindeer herders' cooperatives, for example due to transportation of animals to other areas, or helicopter surveillance of animals.

Infrastructure and energy production

Major economic costs and risks are imposed on installations, such as bridges, pipelines, drilling platforms and hydropower, through damage from ice action and flooding. These risks are more linked to the design structure of the buildings than to thawing permafrost (Larsen et al. 2014). Climate change can have an impact on the integrity and reliability of electricity grids and pipelines. These impacts can be particularly strong in Barents and other Arctic regions because temperature increases are likely to be higher than average at the higher latitudes. In the most North-Eastern parts of the Barents region the melting of permafrost may cause destabilization of pillars or prevent access for maintenance and repair (Arent et al. 2014).

Impacts of climate change are likely to be different from one energy carrier to another. Some of them are more sensitive to climate impacts than others. Generally, renewable energy can be more vulnerable to climate change than fossil energy resources because it is more dependent on weather and climate (Schaeffer et al. 2012). On the other hand, renewable energy promotes energy security because it is typically available on site. Moreover, it is not dependent upon exports from elsewhere.

Increased precipitation will increase the availability of hydropower. However, according to Seljom et al. (2011), flooding is also likely to increase because it is not possible to utilize all the additional precipitation in existing or potential new hydro-reservoirs. According to Vormoor et al. (2015), autumn/winter floods are likely to intensify, and may also lead to a systematic shift in the current flood regimes from spring/summer to autumn/winter regime.

Agriculture

Presently agriculture in the Barents region is based on animal breeding (cows and other ruminants) and grass farming (Hannukkala & Kietäväinen 2017). It can be expected that with warming temperatures, farming in the Barents region will become more important. According to an assessment conducted in Northern Norway, the growing season will increase by 6–30 days over the period 2021–2050 (Ulenberg et al. 2014). The systematic review on the impacts of climate change on crop yields in Northern Europe by Knox et al. (2016) concludes that over 10% yield increase is expected in the region by the 2050s. This increase in agricultural production in Northern Europe also implies an increased potential for exports of agriculture production to low-latitude regions where the impacts of climate change on agricultural production are expected to be severe (Knox et al. 2016).

Potentially positive impacts of climate change on agricultural production in Northern Europe also mean that crops that are presently marginal, or not grown at all in certain areas, could become feasible. Thus, there could be potential for crop diversification (Knox et al. 2016). Dannevig et al. (2015) point out that with higher temperature, the availability of light may increasingly become the most crucial variable for plant growth. Due to limited light availability, there is limited potential to lengthen the growing season in the autumn. Thus, earlier onset of spring becomes the critical factor for agricultural production. In order to begin farming earlier, the ground also needs to be dry enough. If it is too wet, ploughing is not possible.

On the other hand, warming also makes conditions more favourable for plant diseases and weeds (Ulenberg et al. 2014). A crucial process for plant survival over winter is cold-hardening during autumn. Cold hardening is a complex process controlled by the interaction of light and temperature (Ulenberg et al. 2014). Warmer autumn days may shorten the winter hardening period by even a few weeks, making the plants less hardened. Moreover, less stable snow cover makes plants more vulnerable to frost damage (Ulenberg et al. 2014).

Höglind et al. (2013) assessed the potential impact of climate change on grass production (timothy and ryegrass) in Northern Europe. Two of the study locations they covered were situated in the Barents region (Tromso and Rovaniemi). The study concludes that the yields of timothy increased in all the regions studied. The yield increase is primarily caused by an increase in temperature. However, as the authors point out, the analysis does not give information on whether the additional or increased harvests projected could also be manageable. In order to successfully harvest the grass, it needs to be dry enough to carry the weight of tractors (i.e. 2–3 days without rain), otherwise compaction of the soil and damage to the plants will occur. Overall, many uncertainties remain regarding the exact impacts of climate change on agriculture in the Barents region. Plant breeding can have an important role in adaptation to the changing winters, longer autumns and varying conditions during the growing season (Hannukkala & Kietäväinen 2017).

Climate change can also have impacts on animal husbandry. Increased afforestation or bush formation on pastures decreases pasture quality, which reduces sheep body mass (Dannevig et al. 2015). Precipitation and temperature increase may result in foot rot and appearance of new diseases. On the other hand, an increased growing season can contribute to higher lamb weight and increased animal numbers (Dannevig et al. 2015). For animals that are kept indoors in the winter, shorter and warmer winters reduce the need for shelter and feed concentrates (Ulenberg et al. 2014).

Fisheries and aquaculture

According to Filin et al. (2015), temperatures will increase in the Barents Sea between 2–10 degrees, sea ice will be significantly reduced and may even disappear completely, and salinities are likely to decline due to increased precipitation and higher fresh water run-off from rivers by 2100. Warmer temperatures and reductions in sea ice can lead to higher phytoplankton production, which in turn is likely to result in higher fish production (Haug et al. 2017; Filin et al. 2015). Cod is arguably the most studied species in the Barents Sea, but studies on other species indicate that they will be markedly impacted as well. Herring, blue whiting and eventually Atlantic mackerel are expected to expand eastwards. This could potentially reduce cod populations but many studies also indicate that cod populations will grow as a result of warming (Haug et al. 2017). In addition, climate change is likely to result in overall higher production, and thereby larger catches of haddock, herring and other boreal species (Filin et al. 2015).

However, there are large uncertainties concerning the impact of climate change on the Barents Sea, and also other factors than temperature affect the ocean, such as changes in fishing intensity, time and place, and acidification due to increased carbon dioxide concentration in the air. For these reasons, improved management has been implemented since 2003 and robust management strategies will continue to be needed in the future as well (Filin et al. 2015). Already, it has been observed that the recent warming in the Barents Sea has led to changes in the spatial distribution of the fish communities (Fossheim et al. 2015; Wiedmann et al. 2014)). Boreal fish communities, particularly large, migratory fish predators, have expanded northwards, especially in the summer period (Haug et al. 2017). At the same time the Arctic shelf fish communities have retreated northwards to deeper areas (Fossheim et al. 2015).

Aquaculture is an important sector particularly in Northern Norway. In a global assessment conducted by Handisyde et al. (2017), Norwegian aquaculture (together with Chile) was found to be the most vulnerable to impacts of climate change. The impacts of climate change on sea water at a local level are difficult to predict, but some assumptions can nevertheless be made (Hermansen & Heen 2016). The main impacts of climate change on marine aquaculture result from increases in temperature, reduced salinity, increases in storms and other extreme events, and ocean acidification due to higher atmospheric carbon dioxide levels (Handisyde et al. 2017).

However, climate change can also have positive impacts on aquaculture. Hermansen and Heen (2012) assessed the impact of temperature increase on salmonid farming in different Norwegian regions. They found that the impact of warming on salmonids is generally very positive in Northern Norway if relocation of production is allowed freely. Production units are likely to move away from Northernmost and Southernmost regions. In Northern Norway Nordland county would considerably benefit while Finnmark and Troms would lose some production units. However, the analysis by Hermansen and Heen (2012) uses annual average temperature and does not take into account seasonal variation in temperature. Nevertheless, the authors conducted sensitivity analysis, which showed that the results for Northern Norway are fairly robust.

Forestry

Along with warming temperature, forest growth may increase and forests may spread further North to areas which are presently treeless. According to climate modelling cited in Eriksson et al. (2016), if the global average temperature increases by two degrees, the growing season is likely to increase by 1–2 months in Sweden. They also estimate that rainfall will increase by 15–20% over this century.

Together these changes increase the possibilities for intensified forestry also in the North, but the changes can be both positive and negative (Eriksson et al. 2016). For example, according to Rautio (2017), it might be possible to increase harvest level in Northern Finland to the present level of Southern Finland. Presently, the productivity of the forests in the boreal areas is limited by short growing season, low summer temperatures and shortage of nitrogen. The predicted increase in temperature would prolong the growing season and enhance decomposition of soil organic matter and availability of nitrogen (Lindner et al. 2010). However, the forest growth models usually do not take into account possible increases in diseases or insect damage. In addition, variations in temperature during winter may aggravate conditions for seedlings and endanger their survival over the winter (Rautio 2017). This has considerable impacts on costs as well because re-establishing the forest is the most important phase in forestry. Less frost on the ground and a higher level of groundwater can make forests more prone to storm damage. Moreover, increasingly wet winters make logging conditions more challenging (Lindner et al. 2010). Damage through pressure from vehicles may decrease local forest productivity. However, it should also be noted that these climate changes are fast in relation to the capacity for natural adaptation of trees and other species.

Boreal forest fires presently mainly take place in Siberia, Alaska and Canada (Flannigan et al. 2009). Climate change is likely to increase the severity and frequency of forest fires. In the Barents region, this primarily concerns the Russian Barents where both the severity and frequency of forest fires are estimated to increase (Stock et al 2017, JRC 2017). Forest fires have become slightly more common in some parts of the Norwegian Barents, but on the other hand, many regions in the Norwegian Barents have experienced decreasing trend in forest fires from 1980 to 2010 (EEA 2017). The future estimates show only a small increase in projected change in forest fire damages in Norwegian Barents (EEA 2017). Swedish Forest Agency and Finnish Ministry of Agriculture and Forestry have estimated that forest fire risks increase in Southern parts of the countries and Barents region would be mostly unaffected (Andersson 2017, Torniainen 2017). These estimates are supported by earlier work compiled by IPCC (2014).

Tourism

Tourism in the Arctic is often based on nature and natural resources, for example fishing. Tourism is therefore also particularly vulnerable to the impacts of climate change. Moreover, impacts of climate change are more intensively felt in communities whose economies rely mainly on tourism (Kajan 2014; Nicholls & Amelung 2015). Adaptation to the impacts can also be more difficult for a community that has few other economic opportunities. The impacts of climate change on tourism can be both negative and positive. Negative impacts include increases in temperature variation, and unpredictability, which makes planning more difficult, earlier snow melt can shorten the season and therefore mean less income. Moreover, increased temperature variation and the resulting unpredictability in snow and ice conditions could bring about safety issues (Kajan 2014). On the other hand, in the coastal areas of Northern Norway, for which tourism is one of the primary sources of income, temperature has always been variable. This makes prediction of the resulting temperature changes challenging (Foerland et al. 2013). According to the assessment by Foerland et al. (2013), who compared preferences of international visitors in Norway during summer to predicted changes in temperature, precipitation and cloudiness found that tourists still have a preference for an increased number of warmer days. They are fine with some increase in rainfall but recurrent precipitation is disliked by most of the visitors.

There are no reliable methods to estimate changes in cloudiness on local levels but from the present climate we know that increased rainfall is usually accompanied with increased cloudiness (Foerland et al. 2013). Increased cloudiness usually decreases visibility of the original Arctic landscape, which for many visitors is one of the most important attractions in Northern Norway. Furthermore, such consequences of climate change as migration of the tree line, taller bushes and changes in the species composition have an impact on tourism as well. On the other hand, positive impacts include reduction in temperature extremes (less extreme colds), which is beneficial for outdoor activities in the winter. Earlier snow melt implies a longer summer season, which in some regions may bring in more tourists but in others that are more concentrated on winter tourism, may shorten the term. For alpine sports, a shorter winter season can also mean that more artificial snow has to be produced, which increases costs and energy consumption of the activity. Thus, the impacts of climate change on tourism are variable, and both negative and positive impacts can be expected. Foerland et al. (2013) point out that in the longer-term managers of the tourism sector should pay attention to marketing the "improved" weather conditions as many tourists have an overly negative picture of the climate.

Reindeer herding

Reindeer herding communities will be impacted by greater variability in temperatures, weather, snow melt and freeze, ice, winds and precipitation. All these factors affect snow quality and quantity, which are critical for reindeer herding sustainability (Larsen et al. 2014). Increased bush and tree-growth have already been observed by reindeer herders and the trend is expected to become stronger. However, research indicates that reindeer herding could potentially also contribute to a cooling effect, as grazing decreases the growth of the shrubs and thereby increases albedo (Beest et al. 2016). Yet, results by Beest et al. (2016) suggest that this effect is likely to be limited to areas with high reindeer densities, as it requires a dramatic vegetation change. In addition, Vowles et al. (2017) conclude that the impact on reindeer and other herbivores is determined by how they influence the competitive balance of plant species, and may thus be very site-specific.

Increasing variation in temperature in the wintertime with temperatures increasing over freezing combined with rain and then followed by re-freezing are becoming more usual and lead to ice forming on snow (Larsen et al. 2014). If such ice layers are formed over the snow, reindeer access to forage is blocked and starvation could occur if the animals are not given supplemental food. On the other hand, later snowfall or earlier snowmelt benefit reindeer as they have easier access to forage (Kajan 2014). Shorter winters can thus also mean reduced starvation and mortality of animals (Dannevig et al. 2015). Changes can also affect migration patterns of reindeer and increase summer heat stress experienced by them. As reindeer herding has and continues to be affected by other societal processes as well, such as habitat fragmentation and land use changes, these together with climate change impacts can lead to cumulative effects. As mentioned in the beginning of Section 4, if reindeer pastures become fragmented due to for example infrastructure development, there is less land available to substitute areas that have become unusable due to climate change, and reindeer herders' cooperatives face increased costs as a result of adaptation actions (e.g. transportation of animals to new areas, or helicopter surveillance of the animals).

4.4 Summary of the impacts of climate change in the different sectors

The rate of change in climate is rapid in the Arctic, and it is affecting the natural and social systems. In some cases it can exceed the rate at which different components can successfully adapt (Larsen et al. 2014). This particularly applies to situations where the local economies are narrow and there is therefore a smaller amount of adaptive solutions available, such as in communities relying on the informal, subsistence-based economy (Larsen et al. 2014). In many cases the impacts of climate change will be mixed with other factors that are taking place, such as the changing structure of the economy and population.

A summary of positive and negative impacts are presented in Table 8. The impacts listed here are not directly linked to the modelling conducted in Section 3. Instead they are based on the literature review, the results of which are presented in Sections 4.1–4.3.

Robust management strategies that are beneficial from multiple aspects, and aim to provide for the impacts of climate change as broadly as possible, can be recommended. For example, in order to prepare for increased rainfall in the summer, tourism managers should develop activities that are weather independent (Foerland et al. 2013). Furthermore, infrastructure and financial capital are crucial in adaptation to the impacts of climate change. The availability of electricity, sewage systems, health and education services and regional communication centres, among other factors, provide the basis for successful adaptation (Dannevig et al. 2015). Moreover, potential impacts of climate change should always be taken into account in spatial planning and when building new infrastructure.

Table 8. Summary of negative and positive impacts that climate change pose to different sectors in the Barents region.

Sector	Positive impacts	Negative impacts
Infrastructure and energy production	- Impacts vary from one energy carrier to another, some being more sensitive to climate change impacts than others. - Increased use of renewable energy for climate change mitigation increases energy security in that it is typically	- Major economic costs and risks due to potential damage from ice action and flooding to installations such as bridges, pipelines, drilling platforms and hydropower.

	available on site and not dependent upon exports from elsewhere.	- Melting permafrost may destabilize pillars or prevent access for maintenance and repair. - In general, renewable energy may be even more vulnerable to climate change than fossil energy resources due to its greater dependence on weather and climate.
Agriculture	- With warming temperatures, farming in the north becomes more important. - According to some studies, 10% yield increase is expected in the region by the 2050s. - Crops that are presently marginal or not grown at all in certain areas could become feasible. - Plant breeding can have an important role in adaptation to the changing winters, longer autumns and varying conditions during the growing season. Potential for crop diversification. - Overall, increased potential for exports of agriculture production to low-latitude regions where adverse impacts on agricultural production are expected.	- Potential negative effects in harvesting conditions, e.g. ground dry enough to carry tractors (2–3 days without rain) due to risk of compaction of the soil and damage to the plants.
Fisheries and aquaculture	- Warmer temperatures and decreased sea ice can lead to higher phytoplankton production, likely resulting in higher fish production and thereby larger catches. - Boreal species such as haddock and herring likely to benefit. - Blue whiting and eventually Atlantic mackerel are expected to expand eastwards. - Warming sea water likely to have positive effects on aquaculture.	- Potential reduction in cod populations. - Reduced salinity of the waters and acidification of waters due to higher CO_2 concentration in the air might have negative impacts on fish populations and other sea fauna. - The above factors can have negative impacts on marine aquaculture, which is locally very important in Northern Norway, as well. However, lot of uncertainties on the impacts. - Warming can also lead to increased diseases and parasites, which threaten the survival of the fish.
Forestry	- Due to increased summer temperatures, forests may spread further north to presently treeless areas.	- Potential increases in diseases and insects. - Increase of forest fires especially in Russian Barents. Nordic Barents

	- Warmer temperature may also increase growth rate of forests, prolong growing season, enhance the decomposition of soil organic matter and availability of nitrogen. - Together these effects increase the possibility for intensified forestry also in the North.	likely to see only minor increase in forest fires. - Variations in temperature during winter may aggravate conditions for seedlings and endanger their survival over winter. - Increasingly wet winters make logging conditions more difficult. - Results in costs as tree planting and related stages usually most expensive. - There is a limit to the natural adaptation of trees and other species.
Tourism	- Increased temperature improves conditions for both summer and winter tourism. Less extremely cold days during winter and more warm days during summer.	- Later snowfall and earlier snowmelt shorten the winter season. - Increased precipitation and cloudiness worsen conditions for summer tourism.
Reindeer herding	- Later snowfall or earlier snowmelt benefit reindeer as they have easier access to forage. - Possibly longer usage of pastures.	- Greater variability in temperatures, weather, snow melt and freeze, ice, winds, and precipitation. - Changes in snow quality and quantity, which are critical for reindeer herding sustainability. - Increasing variations in winter temperature may lead to ice forming on the snow. If such ice layers form over the snow, reindeer access to forage may be blocked, resulting in starvation if the animals are not given extra food. - Warming can potentially result in increases in parasites and animal diseases.

5. Sectoral summaries

This section summarizes the opportunities and impacts that have been presented on the preceding sections for the main economic sectors in the Barents region.

For each sector, the big picture and background will be summarized under the heading ‘General’, and more-detailed and region-specific issues will be discussed under the heading ‘Role in Barents Region’. For each sector, a summary is provided of the main opportunities to contribute, primary benefits arising in the future, and also potential risks and threats resulting from either the Paris Agreement or climate change itself.

Opportunities to contribute present the main opportunities for each sector to contribute to the climate change mitigation. That box lists practical measures that can be adopted on each sector to reduce emissions, increase energy efficiency, or increase renewable energy. Some opportunities can provide added value to the sector and increase the competitiveness, but some proposed measures will increase the costs and sectors likely will not be able to realize these measures without active policies.

Potential benefits, risks and threats include potential positive and negative effects both from mitigation measures and from climate change itself.

5.1 Power and district heat

General

The role of electricity generation in sustainable growth is broader than its direct influence on emissions. Decarbonization in other sectors can lead to substitution of fossil fuels with electricity. This electrification leads to a notable increase in the demand of electricity in all studied countries.

The power and district heat (DH) sector is the first sector to decarbonize in all modelled scenarios. It is also a prerequisite that other sectors can reduce emissions through electrification. The power and DH sector is a large emitter of CO_2, and can provide significant and cost-efficient emission reductions with wind, solar, hydro power, and biomass.

Substitute technologies for electricity generation are already commercial, and the costs of particularly wind power and solar power are declining rapidly. District heating and heating of buildings can be decarbonized with biomass and electrification. Through the combined use of biomass and CCS, the sector could even become a net sink of carbon by 2050.

Role in the Barents region

The electricity production mix differs notably between Barents region countries. Norwegian and Swedish Barents regions have high amounts of hydro power, Finnish and Russian Barents have relatively more thermal capacity. Many cities are already replacing old units with new ones using biomass, waste and excess heat. Russian Barents uses notable amounts of natural gas, along with hydro and nuclear power.

Transmission linkages and demand management will become more important, when the system will have higher share of variable generation (solar, wind) and demand (e.g. electric vehicles and heat pumps). The Barents region can contribute to the future energy systems with flexible production (hydro and biomass) to match demand-supply imbalances and by exporting additional electricity to Central Europe, but the economies depend on the costs of transmission capacity.

Opportunities to contribute to climate change mitigation

- Invest in renewable and CO_2-free generation. Decarbonization of electricity sector is required also because, then other sectors can reduce emissions through electrification. Power and district heat sector should be the first sector to decarbonize.
- Improve electricity and heat grids to balance variable demand and supply;
- Prepare to increase exports of clean electricity to Central Europe.

Potential benefits:

- Increased hydropower production due to increased rainfall.
- Increased demand due to electrification.
- Export potential to Central Europe.

Risks and threats:

- Phase-out of fossils may cause early retirement of power plants.
- More volatile electricity prices due to higher share of variable generation.
- Feasibility and environmental issues of hydropower expansion in Russia.

5.2 Oil and gas

General

Oil and gas face severe challenges under the Paris Agreement scenarios. While gas has lower specific emissions per unit of energy than oil products, its market volume falls faster in the mitigation scenarios. The reason is that substitution of most of the current energy uses for natural gas by electricity is relatively easier than substituting oil, e.g. in aviation and industry feedstocks. Biomass could partly replace kerosene and oil in feedstocks.

Oil and gas markets will face an interesting dilemma, as producers will compete in a markets with declining demand and value. If producers start battling for their share of the declining market, those with low production costs – e.g. the Gulf countries – might drive prices down. Forecasting actual price movements is nevertheless nearly impossible. Consumer prices would still increase due to higher CO_2 prices.

Role in the Barents region

Currently, the volume of oil and gas production in the Barents region is modest compared to total volumes in Norway and Russia (6% and 3%, respectively), but the volume could increase significantly in the future if market conditions are favourable. The Barents Sea has vast oil and gas resources. Existing infrastructure is limited, however, and significant investments are required for the exploitation of these resources. (NPD, 2016; OIES, 2014)

The costs in oil and gas exploration and recovery vary between the fields, but many new fields in the Barents region can have relatively high extraction costs due to the infrastructure needs and Arctic conditions. This makes the projects in the Region more susceptible to price risks, if oil price remains low due to declining demand under the Paris Agreement. On the other hand, future production and transport costs might decrease due to lower sea ice extent and the decreasing amount of days when the sea is frozen.

Opportunities to contribute to climate change mitigation:

- Optimize processes to avoid GHG emissions in production, pipeline leakages, and use currently flared methane.
- Avoid the development of high cost oil and gas fields.

Potential benefits

- Improved ice and snow conditions in the Barents Sea offshore fields in a warmer climate can reduce costs.

Risks and threats:

- Declining market volumes and price competition from low-cost producers might lead to stranded assets.
- Faster decline of market volume if CCS will not be successful

5.3 Transportation

General

Transportation is one of the largest sources of CO_2. Road traffic uses gasoline and diesel, while naval transportation relies on heavy fuel oil and aviation on kerosene. Vehicle fuel efficiency has increased significantly during the past years, and this trend will continue both through further improvements and the renewal of the existing vehicle fleet.

Road transportation faces two competing paths for contributing towards the Paris Agreement targets: electrification or biofuels. The attractiveness of both options depends on future technological progress, the pace of which is difficult to anticipate. Biofuels are also susceptible to the ongoing debate over sustainability and effects on forest carbon stocks.

International transportation is outside the Paris Agreement's scope and more challenging to decarbonize, but there are companies developing new solutions. The more options we will have in the future, the less costly it will be to decarbonize also the international transportation.

Role in the Barents region

The Barents region is sparsely populated and transportation distances are long. Despite the urbanizing trend, transportation is a necessity, with very limited substitutes. Given the long distances in the region, biofuels are likely a more viable way for contributing towards mitigation and the Paris Agreement, as electric vehicles are likely to have a more limited range than internal combustion engines. This can change if the current significant improvements in batteries' energy density and costs will continue.

The Barents region has significant forest resources, which could be used as a feedstock for biofuel production and export to other regions. The risk in this is, however, whether forest-based biofuels lower the carbon-sinking capacity of the region's forests.

Opportunities to contribute to climate change mitigation:

- Decarbonize transportation through biofuels, electrification, and other alternative fuels.
- Develop new low carbon solutions for heavy transport, ships, and aviation.
- Produce forest-based biofuels, if forest carbon stock impacts are sufficiently minor.

Potential benefits:

- Better winter conditions on roads can decrease costs.
- Sea transportation easier due to shorter winters and easier ice conditions.
- New industries and services on alternative fuels production and distribution.

Risks and threats:

- Competitiveness impacts of increasing transport costs.
- Locking in to fossil fuel based system if action is delayed.
- 'Betting the wrong horse' when many competitive technologies are developed.
- Technological performance of EVs over long distances and cold climate.
- Less existing measures in heavy transport.

5.4 Manufacturing industries

General

Manufacturing industries are a broad and diverse economic sector. While industry is a major consumer of energy and source of GHG emissions, only a number of industrial sub-sectors are very energy intensive, namely the production of metals, minerals, pulp and paper, and chemicals. Most of the sub-sectors are neither energy- nor emission- intensive.

Industry has also a critical role in the decarbonization of the whole economy, as new, low-emission technologies need to be manufactured by the industry. The low-carbon transition will alter the composition of the economy and business areas, as some old industries will fade and new ones are founded. Early adopters of low carbon technologies and the manufacturers of these technologies have a chance to gain an advantage in the future markets.

Role in the Barents region

The Barents region has relatively more manufacturing industry than other parts of the Barents countries. Notable sub-sectors include mining, pulp and paper, metals, machinery and electronics. The impacts on industry are especially important for the Barents region.

In non-energy-intensive industries, such as food processing and electronics, decarbonization and fossil fuel phase-out can be usually implemented through electrification. The situation is more difficult with certain processes in energy-intensive industries. Blast furnace iron is required for higher-grade steel, the production of cement emits CO_2 during limestone calcination, the chemical industry uses hydrocarbons as feedstock, and aluminium smelting emits F-gases. Some of these emissions could be avoided with some non-commercial technologies such as carbon capture and storage or utilization, or adding biomass to chemical industry feedstock, but the technological solutions are mostly not demonstrated. Industry process emission mitigation requires both basic research and demonstration of new solutions.

Opportunities to contribute to climate change mitigation:

- Adopt the Best Available Technologies to increase energy efficiency and decarbonize the industry energy use
- Research new technologies to reduce industrial process emissions.
- Develop clean-tech machinery and appliances needed in other sectors

Potential benefits:

- Transition to a sustainable, low-carbon society requires large investments into new cleantech machinery and appliances.
- Early adopters of low carbon technologies in energy intensive industries might gain an advantage in the future markets.

Risks and threats:

- Increased costs of energy and mitigation measures could decrease the competitiveness.
- Limited existing technologies to mitigate process CO_2.

5.5 Mining

General

Impacts on mining sector highly depend on extracted mineral or material. The mining of metals in general is less affected, because it consumes relatively small amounts of fossil fuels. Mining of coal will be highly affected both due to declining demand of coal and the need to reduce methane emissions from mines. All mines use diesel for work machinery and transportation of products. Work machinery emissions can be mitigated with similar measures than in the transport sector. Metal smelting and processing is discussed under manufacturing industry.

New technologies will likely increase the demand for copper, silver, and rare earth metals for batteries, engines, solar panels, etc. The mining sector will be a critical player enabling new industries as it can be more cost efficient to build the factory close to the mine.

Role in the Barents region

The mining sector is already very important to the Barents region, especially in Sweden and Russia, where the mining sector corresponds to 20% and 25% of regional Gross Value Added (GVA), respectively. Mined minerals include iron, gold, copper, silver, zinc, and many other basic metals and metals for industry use. Also coal is mined in the Komi region.

Mining industry production depends highly on international markets prices, and annual productivity levels have been changing quickly. For an example, the Swedish Barents mining sector's Gross Value Added (GVA) decreased 1.8 billion euros from 2008 to 2009 and increased 2.6 billion euros from 2009 to 2010 affecting the regional economy significantly.

The importance of the mining sector in the Barents region might increase in the future, because the Barents region has considerable potential for new mines and minerals. A warming climate might decrease the operation costs, but might reduce road network quality.

Opportunities to contribute to climate change mitigation:

- Reduce methane emissions from coal mining.
- Mining sector has relatively small direct CO_2 emissions and energy consumption, but it can Adopt Best Available Technologies to increase energy efficiency
- Mitigate emissions from work machinery with similar measures than in transport sector.

Potential benefits:

- Increasing demand of material, metals, and rare earth metals.
- Warming climate might decrease costs and make new sites available.

Risks and threats:

- Increased recycling and material efficiency might decrease raw materials demand.
- New, innovative technologies might reduce the need of rare metals.
- Coal mines ending up as stranded assets.

5.6 Agriculture

General

Agriculture plays an important role in climate regulation and mitigation of greenhouse gases through land use and land use change. The agriculture, forestry and other land use sector (often referred to as AFOLU) has a wide potential for emission mitigation through enhancement of the removal of greenhouse gas emissions, and reduction of emissions from land and livestock.

Since 1970, the world grain harvests have doubled from 1.2 to 2.5 million tonnes per year as a result of changing land-use practices, technological advancement and varietal improvement (Smith et al. 2014) Over the same period, there has also been a 1.4 fold increase in the numbers of cattle, buffalo, sheep and goats and a 1.6 and 3.7 fold increase in pigs and poultry, respectively (Smith et al. 2014),

Role in the Barents region

Agriculture is important for the social and economic viability of the Barents region's rural areas (AACA 2017). Agriculture in the Barents region is mainly based on animal breeding (cows and other ruminants) and grass farming. In addition, reindeer herding is an important occupation in the region. In the Barents region agriculture produces more greenhouse gas emissions than is sequestrated in the soil.

Approximately 6% of the Barents region's workforce is employed in fishing, agriculture and reindeer husbandry (Table 5). However, these activities have an even more important cultural and social importance in the Barents region. Plant breeding can have an important role in the adaptation of agricultural production to the changing winters, longer autumns and varying conditions during the growing season.

Opportunities to contribute to climate change mitigation:

- Produce biogas for heating and transport fuels.
- Respond to change in the demand of agriculture products if vegetarian diet gains popularity.
- Explore options to improve feeding and feed additives to reduce enteric fermentation emissions from animals.

Potential benefits:

- Agricultural production conditions can potentially improve with warming temperature.
- Crops that are presently marginal or not grown at all could become feasible.
- Yield increases create potential for exports to low-latitude regions where adverse impacts on agricultural production are expected.

Risks and threats:

- Increased precipitation can make the ground too wet for ploughing. Tillage of too-wet ground can lead to soil compaction.
- Increased afforestation or bush-forming decreases pasture quality, which has adverse impacts on animal husbandry.

5.7 Forestry

General

Forests and forestry play an important role in climate regulation and mitigation of greenhouse gases through provision of renewable raw-materials and energy, as well as by creating a notable sink for atmospheric carbon. Climate change also impacts forests in many ways. Along with increasing temperature, treeline is expected to move northward. This would make practising forestry possible in more northern areas than presently. However, this gradual shift is slow and likely to take place mainly in the second half of this century.

Role in the Barents region

Forestry is presently practiced in the southern part of the Barents region, and it has an important role in northern Sweden, Finland and northwest Russia (AACA 2017). Forests have an important role in the climate and energy policies of Sweden and Finland, in particular. Along with warming temperature, forest growth may increase and forests may spread further north to areas which are presently treeless. As presented in Section 3, it has been estimated for Sweden that if the global average temperature increases by two degrees, the growing season is likely to increase by 1–2 months.

The changes caused by climate change may increase the possibilities for intensified forestry also in the Barents region but there are uncertainties over the exact impact of climate change, which can be negative as well, e.g. through increased rainfall which aggravate the conditions for wood harvesting, and increased storm damages. Forest fire intensity and frequency is expected to grow mainly in Russian Barents.

Opportunities to contribute to climate change mitigation:

- Enhance forest carbon sinks through improved forest management.
- Provide more wood for industrial uses and renewable energy.
- Try to find a sustainable balance between the sink enhancement and additional production.

Potential benefits:

- Improved tree growth rate and expansion of forest line towards the north.
- Increased possibilities for intensified forestry also in the north.

Risks and threats:

- Growing risk of damages from diseases and insects.
- Potential increases in storm damages in all Barents region and forest fires mainly in the Russian Barents region.
- Trees may not be able to adapt fast enough to changing conditions.

5.8 Fishing and aquaculture

General

Global supply of fish for human consumption has grown faster than human population over the past 50 years, increasing per capita consumption from 9.9 kg in the 1960s to the present level of approximately 20 kg per capita (FAO 2016). For millennia, fishing was almost completely based on capturing of wild fish but over the past decades, the share of aquaculture has been constantly growing, being over 40% of the total fish catch now. The greenhouse gas emissions of fisheries mainly stem from N_2O emissions from fish farming (Smith et al. 2014). According to Smith et al. (2014) they were about 93 kt N_2O-N in 2009, which represents less than 2% of the global total agricultural N_2O-N emissions (Reay 2012).

Role in the Barents region

Fisheries, including fishery-related activities and supporting industries are all economically significant, particularly in the Norwegian and Russian Barents where their share of the gross value added is ca. 6% and 3%, respectively (Table 5). Climate change has major impacts, both positive and negative, on the future of the fisheries' industries, for example through changes caused by acidification and migration of fish species due to warmer waters. Warming in the Barents Sea has already led to changes in the spatial distribution of the fish communities, i.e. boreal fish communities, particularly large, migratory fish predators, have expanded Northwards, mainly in the summer period. Robust management strategies are needed.

Changes in the distribution of fish species can lead to variation in the operation time and distance for the fishing vessels and increasing price of carbon might increase operation costs. Norwegian marine aquaculture has been estimated to be very vulnerable to climate change impacts. However, studies on Northern Norwegian salmonids have found that warmer seawater can also have positive impacts leading to more beneficial conditions for the salmonids.

Opportunities to contribute to climate change mitigation:

- Sustainable fishing can provide a source of low-emission animal protein.
- Demonstrate the most promising alternative fuels in fishing vessels.

Potential benefits:

- Potentially higher fish catches, but northwards migration of fish species will likely change the catched species.
- Warming sea water will make Nordland, Troms and Finnmark more conducive and important areas for aquaculture.

Risks and threats:

- Changed conditions and increased competition threaten Arctic species, especially in high Arctic.
- Some economically important species at risk of disappearing.
- Increasing price of carbon might increase operation costs.

5.9 Reindeer herding

General

Reindeer herding is practiced across the Arctic countries, and also in Mongolia and China. It has been applied in these regions for thousands of years. Generally it has been estimated that the impact of reindeer herding to climate change is minimal. However, climate change may impact reindeer herding particularly through changes in the availability of fodder. However, the impacts are likely to vary from region to region.

Role in the Barents region

Also in the Barents region, reindeer herding has less importance as emission sources. Reindeer herding is a fairly small-scale activity in the Barents region. However, it is important locally, and in some areas it is an important employer, such as in northern Finland where about 7% of inhabitants work in reindeer herding and tourism. In Northern Finland, Sweden and Norway, reindeer herders have good access to markets and there is a lot of consumer demand for reindeer products. Also in parts of the Yamal Peninsula and the Nenets Autonomous Okrug, the oil and gas booms of the recent years have had a positive impact on the income level of reindeer herders (http://reindeerherding.org/challenges/economy/). However, in many Russian reindeer herding areas, herders are having problems because of the poor state of the local economy, and herders' lack of access to the markets. In those areas, it is difficult to recruit new herders, which threatens the long-term future of reindeer husbandry (http://reindeerherding.org/challenges/economy/).

Opportunities to contribute to climate change mitigation:

- Reindeer herding can prevent or slow the tree and bush expansion towards north. Low growth tundra areas remain covered in the snow longer and reflects solar radiation cooling the planet thereby contributing to the albedo effect.

Potential benefits:

- Later snowfall or earlier snowmelt benefits reindeers as they have easier access to forage, and enable longer usage of pastures.

Risks and threats:

- Temperature variations can lead to ice formation over snow and block reindeer access to forage.
- Increased bush and tree-growth degrades the quality of the pastures for reindeer grazing.

5.10 Tourism

General

Globally, it has been estimated that tourism is responsible for about 5% of the global CO_2 emissions (World Tourism Organization, 2017). Emissions related to tourism mainly stem from the transportation sector and accommodation. According to the WTO, transport produces 75% of the emissions, and accommodation about 20%. The rest stems from such activities such as visits to museums, theme parks, events and shopping.

Role in the Barents region

Tourism plays an important role in the economy of the Barents region. According to the AACA (2017), tourism is one of the main drivers of economic growth in the Barents region, and it will continue to grow with increasing emphasis on large cruise ships and land-based winter and summer tourism. Tourism in the Barents region is largely based on nature and natural resources. It is therefore also particularly vulnerable to the impacts of climate change. Moreover, impacts of climate change are more intensively felt in communities whose economies rely mainly on tourism. Adaptation to the impacts can also be more difficult for a community that has few other economic opportunities.

The impacts of climate change on tourism are variable, and both negative and positive impacts can be expected. On the other hand, in the coastal areas of Northern Norway, where tourism is one of the primary sources of income, temperature has always been variable. In the longer-term managers of the tourism sector should pay attention to marketing the “improved” weather conditions because many tourists have an overly negative picture of the climate (Foerland et al. 2014).

Opportunities to contribute to climate change mitigation:

- Promote ecotourism, i.e. responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education (TIES 2017).
- Reduction of transport-related emissions – Develop alternative fuels (biofuels, electrification, etc.), emphasis on other means of transportation than flying and cruise ships, or at least buying carbon credits.

Potential benefits:

- Increased temperature improves summer and winter conditions.
- Less extremely cold days during winter and more warm days during summer.
- Earlier snowmelt results in longer summer season.

Risks and threats:

- Later snowfall and earlier snowmelt shorten winter season.
- Increased precipitation and cloudiness worsen conditions for tourism.
- Increasing carbon price and fuel costs may negatively affect the tourism.

6. Policy actions contributing to climate change mitigation in the Barents Region

The proposed mitigation actions do not take place by themselves, but will result from changes in the operating environments of governments, communities, businesses and individual citizens. Many policies are already in place, which has led to improvements in energy efficiency, changes in the energy mix and reductions in emissions, but enhanced action is necessary for achieving the ambitious goals and realizing the opportunities on different sectors.

All Barents region countries have their national plans and targets in energy and climate policy for 2030 and 2050. As the mitigation efforts become more difficult the lower the emission levels are pushed, the role of regional co-operation will become more important for effective mitigation. Regional-level benefits can be achieved, e.g. through trade in renewable energy from a region with plentiful resources; but also more subtle benefits can be attained through exchange of know-how on innovations and best practices, joint financing, co-operation in education and mobility of workforce within the Barents region. Understanding the region's activities as a whole is essential in the integration and coordination of national and sub-national strategies.

Local authorities have also a very important role in building the framework to mitigate greenhouse gas emissions. Municipalities are responsible for most of the planning that permits areas for wind power plants, steers how long distances people have to drive, and how good public transportation will be reasonable to organize. Local decision-making is extremely important also in heat production, public sector energy efficiency investments, infrastructure investments, and providing a localized application of national and regional strategies.

Actions are need in all these three levels to achieve the ambitious targets of the Paris Agreement. Based on the analysis presented in this report, we propose the following general policy recommendations:

1. Build a shared vision how future will look under the Paris Agreement, but acknowledge the uncertainties regarding the future development.
2. Study available emission reduction pathways and measures.
3. Set up and strengthen the climate and energy policy framework that describes the overall targets and gives a long term direction. Increase the targets, if required, to be on a Paris Agreement pathway.
4. Implement measures required to achieve the targets. Find a balance between removing barriers from low-carbon investments, improving energy efficiency, increasing renewable energy, and to reducing emissions.
5. Boost innovation to clean-tech, because new technologies are needed and required emission reduction measures will change existing markets and create completely new markets.
6. Adaptation is required despite the climate change mitigation. Even the ambitious RCP 2.6 scenario has significant impacts already by 2050, but especially by 2100.

These recommendations are expanded below.

1. Build a shared vision of the future under the Paris Agreement

Through discussions and negotiations, the Barents countries could nationally and regionally reach a common vision of how the Region's future under the Paris agreement should look like. This is a top level political discussion that has already been conducted on both national and regional level in the Barents countries. It can be enhanced when new information comes available, and it can be spread to municipal level to engage larger pool of actors to share the vision.

Most importantly, this covers a mutual understanding of deep greenhouse gas (GHG) emission reductions as in the Paris Agreement, but the shared vision can include also reducing other emissions such as black carbon, estimated development trends of different sectors, anticipated impacts of climate change, and acknowledging the associated uncertainties.

Building on the shared vision, the national policies should be coordinated to ensure consistency between them and to allow a better utilization of regional resources (see also Ollila, 2017). Detached national strategies result in partial-optimization: solutions that consider the benefit of one country instead of the whole region. Co-operation, trade and sharing of knowledge would be at sub-optimal levels. For an example, improvements on electricity markets will require common vision and will. Regionally integrated policies could expand the use of renewable resources efficiently, as additional demand could be found in neighbouring countries.

A very important aspect in the regional level vision should be bringing the Barents region perspectives to national energy and climate strategies and avoid national sub-optimization. Similarly, municipalities should review how well national and regional visions apply to local circumstances and suggest improvements when necessary.

Reaching the common vision does not necessitate an agreement on a certain future scenarios for the Barents region or its parent countries. Rather, the vision should acknowledge which questions remain open and which issues already have robust solutions.

Barents Euro-Arctic Council provides an excellent forums for regional discussions, Barents region countries have their own approaches for the national discussions, and municipalities should participate to climate networks, for an example to Covenant of Mayors.

2. Study available emission reduction pathways and measures

The Paris Agreement has very broad target of limiting the global warming well below 2 °C and pursue efforts to limit the temperature increase to 1.5 °C above preindustrial levels. The Paris Agreement works in a bottom-up method where individual countries or regions give their Nationally Determined Contributions (NDC). UNFCCC secretariat registers NDCs and the level of ambition is assessed in the global stocktake process and NDCs should be evaluated every 5 years. The first evaluation should be in 2023.

The UNFCCC process is relatively slow and Barents region countries should carry similar studies themselves both to evaluate the development and to decide if their own targets are on Paris Agreement pathways.

The aim to limit emissions well below 2 °C is a very strict target and requires more efforts from basically all nations than the current NDCs. According to our modelling, the GHG reduction targets for 2050 should be 90% or more to be in line of emissions in our Paris Agreement scenarios. In these levels, it becomes very difficult to reduce emissions from agriculture and industry processes.

National level energy system models do exist and they are regularly used to estimate available emission reduction measures. We encourage countries to study more sensitivity analysis, alternative pathways, and identify risks related to studied measures.

A Barents region energy system model does not currently exist, but it could be developed. This would begin from compiling a regional data that could be used also to support policy makers, and in research projects. Some regional data set are already partly collected by national statistic centres, Barents Regional Council, and the Arctic Council but more effort should be steered at it in order to make the data more detailed and consistent.

Research organizations could develop tools with good regional coverage for joint assessment of Barents regions' climate and energy strategies and available mitigation measures. The TIMES-VTT model used here is an example of a tool that could consider the regional energy system and emissions if further developed. The final selection of tools and their qualities depends on the most important open questions identified in action point 1.

Municipal level studies should reflect local prospects and development trends to national and regional studies and conduct local studies when required. In addition, municipalities should map local renewable energy resources and estimate pros and cons of their different uses. In addition, municipalities should list the potential and cost-effectiveness of local energy efficiency measures in public and private sectors.

3. Set up and strengthen long term climate and energy policy framework

Barents region countries already have decided their 2030 and 2050 targets. These targets should provide a consistent message to industry and stakeholders and countries should monitor the development to ensure that targets are met. However, countries should also dare to update targets if very relevant new scientific information is found.

Regional level cooperation seems the most valuable to ensure consistency between national targets, to identify gaps in between of national targets, and to adopt additional regional targets if certain topics of sectors are not presented in national targets, and new targets would benefit both national and regional levels.

Municipalities should adopt municipal level low-carbon strategies that should be coordinated with both national and regional level targets. When municipality has a low-carbon strategy, it should decide appropriate 2030 targets and commit to them.

Current policy discussion is focused on implementing 2030 targets, which is very urgent and important, but some additional focus should soon be shifted to comparing the adopted 2030 and 2050 targets to Paris Agreement pathways. This will be a part of global stocktaking process, but Barents regions countries could start this work earlier.

4. Implement required measures

In many studies, the most cost-efficient measures are on power and heat, followed by reducing methane emissions, emissions from transport, and from buildings. Measures at the industrial processes, upstream CO_2, and agriculture are generally more expensive, but every sector has some relatively cheap emission reduction potential. Planned measures should be designed flexible enough, for an example, subsidies to renewable power generation can be mostly technology neutral auctions, supplemented by selected technology specific measures.

The cost-efficiency of various measures often comes in the following rough order: removing barriers and improving energy efficiency followed by other mitigation measures. Our main contribution to this discussion was to identify possible opportunities and measures by which different sector in Barents region can contribute to the climate change mitigation. In addition we studied for possible benefits, risk, and threats to these sectors that arise from mitigation measures and from climate change itself. The most important identified opportunities, benefits, risks, and threats are summarized in Table 9.

Table 9. Overview of how different economic sectors could contribute to the Paris Agreement's goals on mitigating climate change, and what benefits, risks and threats the implied transition and climate change might pose.

	Opportunities to contribute	Potential benefits	Risks and threats
Power and heat	· Rapid investments to zero-CO_2, and even negative CO_2 generation. · Improve grids for variable supply and demand. · Provide other sectors an opportunity to mitigate emissions through electrification.	· Increasing precipitation adds hydropower production. · Increasing demand due to electrification on other sectors · Export potential of clean electricity to Central Europe.	· Phase-out of fossils may cause early retirement of power plants. · More volatile electricity prices due to a larger share of variable electricity. · Feasibility and environmental issues of hydropower expansion in Russia.
Oil and gas	· Reduce GHG and black carbon emissions from production. · Use depleted fields for Carbon Capture and Storage (CCS).	· Easier winter conditions in the Barents offshore fields can reduce costs.	· Declining market volumes and competition from lower cost fields might result stranded assets. · Faster decline of market volume if CCS will not be successful.

	Opportunities to contribute	Potential benefits	Risks and threats
Transportation	· Phase-out of fossil fuels and switch to electricity, advanced biofuels, and other alternative fuels. · Develop new low carbon solutions for heavy transport, ships, and aviation. · Produce forest-based biofuels for transportation, if forest carbon stock impacts are sufficiently minor.	· New industries and services on alternative fuels production and distribution. · Better winter conditions on roads can decrease costs. · Sea transportation easier due to shorter winters and easier ice conditions.	· Increasing transport costs can decrease competitiveness. · Delayed action locks in to fossil fuel based system. · 'Betting the wrong horse' when competitive technologies are developed. · Technological performance of EVs over long distances and in a cold climate.
Manufacturing	· Decarbonize industry energy use and improve efficiency. · Develop low-emission, energy efficient and cleantech equipment. · Research new technologies to reduce emissions from industry processes.	· Added cleantech demand due to investments for GHG reductions. · Early adopters of new technology might gain new markets.	· Increased costs of mitigation measures might reduce the industry's competitiveness. · Limited existing technologies to mitigate process emissions.
Mining	· Reduce methane emissions from coal mining · Adopt best available technology to increase energy efficiency in mining · Mitigate emissions from work machinery with similar measures than in transport.	· Increased demand of metals and materials in the manufacturing of low-carbon technologies. · Warming climate might decrease mining costs.	· Coal mines end up as stranded assets. · Volatile market and uncertain value of production. · Increased recycling, material efficiency, and innovative technologies might decrease the demand.
Agriculture	· Improve feeding to reduce emissions from animals · Produce biogas for heating and transport fuels · Respond to demand change if vegetarian diet gains popularity.	· Warming weather improve yield and allow new crops. · Export potential if crop production on lower latitudes suffer from changes.	· Increasing precipitation can make ground too wet for ploughing. · Demand risks due to a possible changes in diets

	Opportunities to contribute	Potential benefits	Risks and threats
Forestry	· Enhance forest carbon sinks through forest management. · Provide more wood for industrial uses and renewable energy · Try to find a sustainable balance between the sink enhancement and additional production.	· Improved tree growth rate and expansion of forest line towards the north. · Increased possibilities for intensified forestry also in the north.	· Growing risk of disease and pests in a warmer climate. · Potential increases in storm damages in all Barents region and forest fires mainly in the Russian Barents region. · Trees might not be able to adapt to changing conditions fast enough.
Fisheries / Aquaculture	· Sustainable fishing as a source of low-emission animal protein, · Demonstrating alternative fuels in fishing vessels	· Warming waters potentially benefit fisheries, and particularly aquaculture. · Potentially higher fish catches, but north-wards migration of fish species will likely change the species	· Changed conditions and increased competition threaten Arctic species, especially in high Arctic. · Some economically important species at risk of disappearing. · Increasing carbon price and fuel costs may negatively affect profitability of fisheries.
Reindeer herding	· Reindeer herding can prevent or slow the tree and bush expansion towards north. Low grow tundra area remains covered in snow longer and reflects solar radiation cooling the planet.	· Later snowfall and earlier snowmelt enable longer usage of pastures and benefits reindeers as they have easier access to forage.	· Variability in winter temperatures may build ice on snow, threatening reindeer access to forage. · Increased bush and tree-growth, and new pests risk degrading the quality of the pastures.
Tourism	· Promote ecotourism to mitigate emissions and decrease the impact on nature.	· Increased temperatures improve conditions both in the summer and in winter through reduction of extreme cold periods.	· Shorter season for winter tourism. · Increased rainfall and cloudiness may decline conditions for tourism. · Increasing carbon price and fuel costs may negatively affect the tourism.

The regional measures could focus on improving regional cooperation to align actions and to increase the efficiency of measures, promoting measures that require regional cooperation such as improvements on electricity markets, working together in Mission Innovation forums to increase global impacts of Barents region countries, and to exchange information on best practices in each country.

Municipal level could focus on reasonable long term zoning and planning to enable and encourage public transportation in growing urban areas, investing to energy efficient solutions in public sector, encaging private sector to energy efficiency measures through ESCO or similar mechanisms, investing to local energy sources when economically, and environmentally feasible, and implementing the best practices learned from climate networks.

All three levels (national, regional, municipal) actors should encourage each other, companies, and citizens to participate to agreed measures.

5. Boost innovation to clean-tech

All technologies required in Paris Agreement scenarios are not yet commercial. These technologies have to be developed and some will require government research funding. We recommend to identify these critical sectors such as CCS, industry processes, heavy transport, and agriculture, and to fund research on low carbon solutions on these sectors. New technologies should also be demonstrated to provide a consistent pathway to commercialization. To mitigate risks concerning which technologies will ultimately penetrate the market, the focus of R&D effort should be sufficiently diversified.

The investments into a sustainable, low-carbon society will involve new machinery and appliances, which need to be manufactured by the industry. To tap the new market potential in clean technology, the region needs to have a competitive advantage against competitors. This could be pursued by support for the R&D of new technologies and a roadmap for starting competitive production in the region. This would start the drafting a list of the most promising technologies. Examples with specific importance for the Barents region could be wind power for arctic conditions, carbon storage in depleted oil and gas reservoirs, or long-term wood products for storing forest carbon.

The transition to a sustainable, low-carbon society will require considerable investments. As a concrete example, renewable energy forms are more capital-intensive than their fossil-based counterparts. The transition phase will carry significant uncertainty regarding which technologies will outperform the others and penetrate the market, making investments more risky. The presented scenarios exhibited such risk particularly regarding the use of CCS technology in electricity and industrial processes, and competition between biofuels and electricity in transportation.

It is important to educate enough skilled workforce and researchers to build all these skills and demonstrate all the solutions. Close cooperation with local industries is required in promoting their work.

6. Adapt

Adaptation is required despite the climate change mitigation. Even the ambitious RCP 2.6 scenario has significant impacts already by 2050, but especially by 2100. There have already been many national, Barents region, and Arctic studies that have identified the most likely affected and vulnerable sectors and areas. AACA report suggested national governments to decide a clear distribution of the responsibilities of different actors and guarantee a sufficient long term funding for the adaptation.

At Barents region, it is important to highlight and suggest priority areas to national adaptation plans from the Barents region's perspective. Local knowledge should be collected and utilized in the adaptation. There should be necessary support for local communities, and also in agriculture, aquaculture, and reindeer herding to adapt to the impacts of the climate change. Municipal authorities should reflect estimated impacts and adaptation needs in the zoning, planning, and other future strategies.

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Appendix A: Barents Regional Accounts

This Annex shows country level data from Norwegian, Swedish, Finnish, and Russian Barents regions. It should be read alongside chapter two which shows the main findings and provides information needed to read these figures.

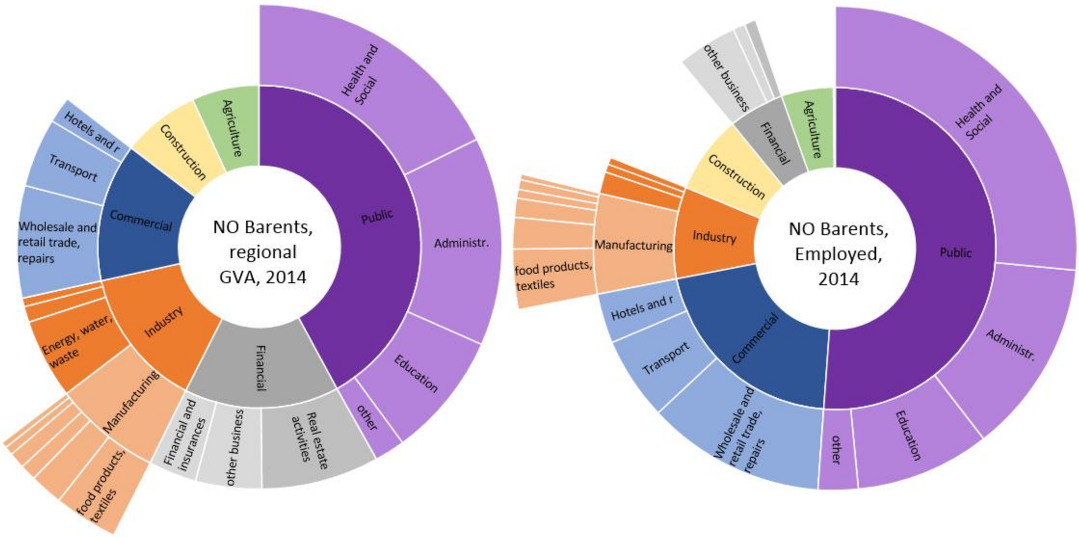

Figure A1. Norway's Barents regional GVA and number of employed presented in a detailed sectoral split at 2014. Agriculture includes agriculture, forestry, hunting, fishing, and aquaculture. Statistics Norway excludes offshore activities from regional accounts.

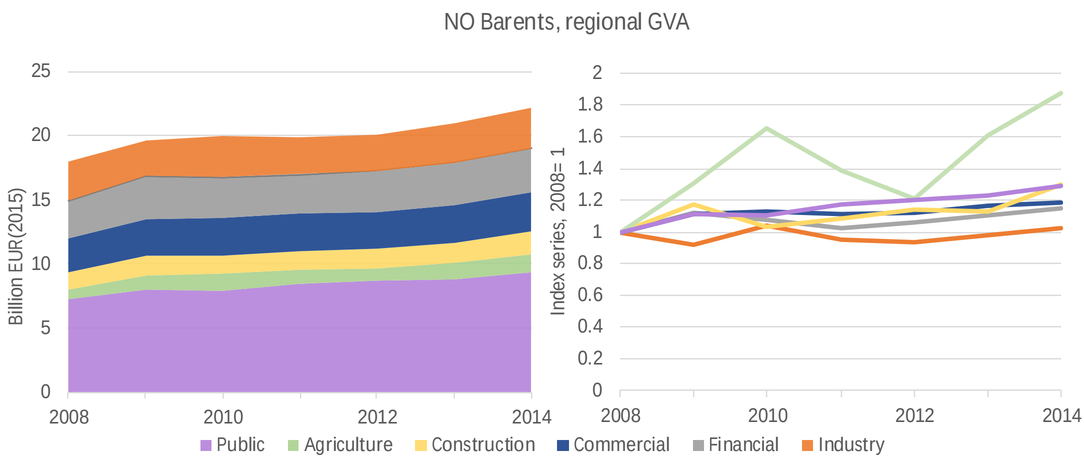

Figure A2. Norway's Barents regional GVA from 2008 to 2014.

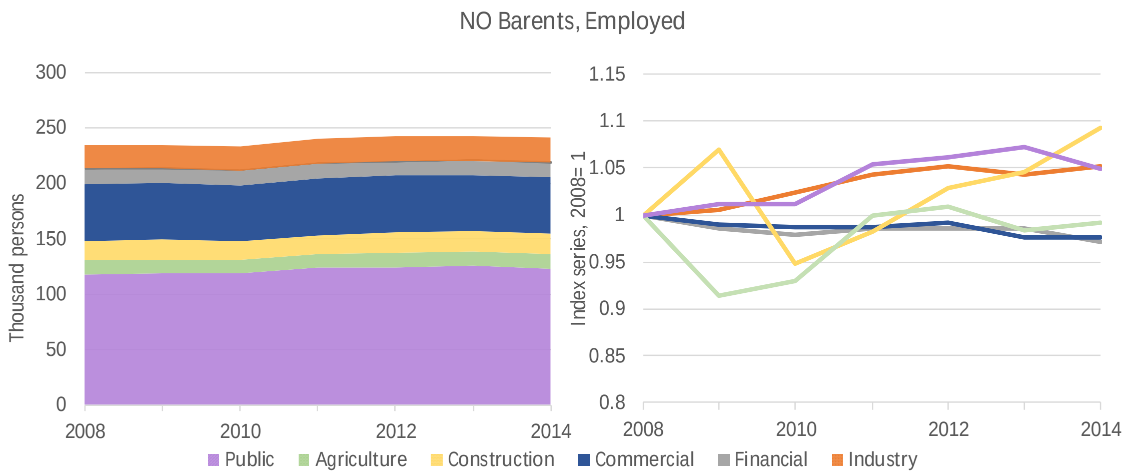

Figure A3. Number of employed from 2008 to 2014 in Norway's Barents. Agriculture includes agriculture, forestry, hunting, fishing, and aquaculture, but Statistics Norway excludes offshore activities from regional accounts.

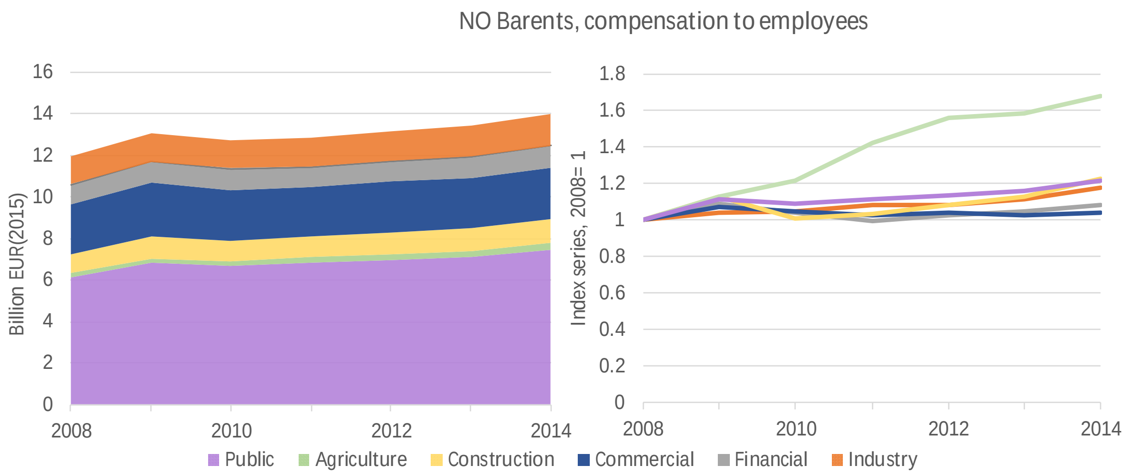

Figure A4. Compensation to employees from 2008 to 2014 in Norway's Barents.

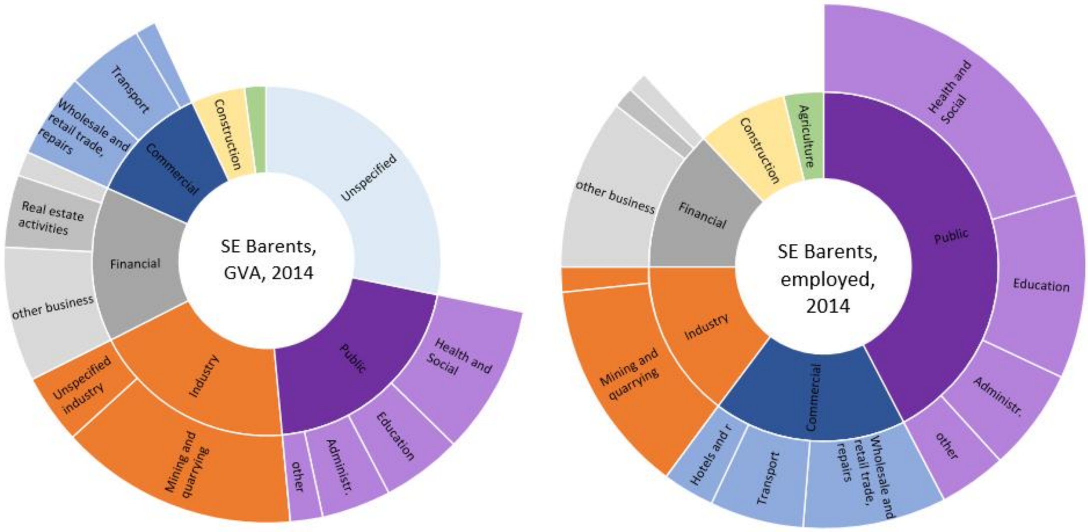

Figure A5. Sweden's Barents regional GVA and number of employed presented in a detailed sectoral split in 2014. Unspecified data in Swedish national accounts is an unallocated portion of the GVA consisting of net product taxes, differences between several estimation methods, and consumption of indirect financial services (SCB 2017). Many industries are grouped under 'unspecified industry' to avoid publishing data from only one or two companies.

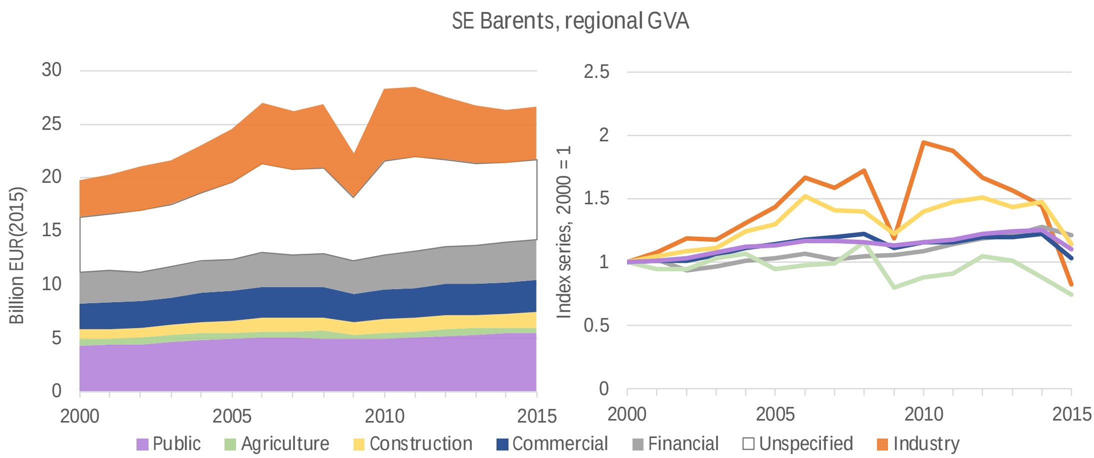

Figure A6. Sweden's Barents regional GVA from 2000 to 2015.

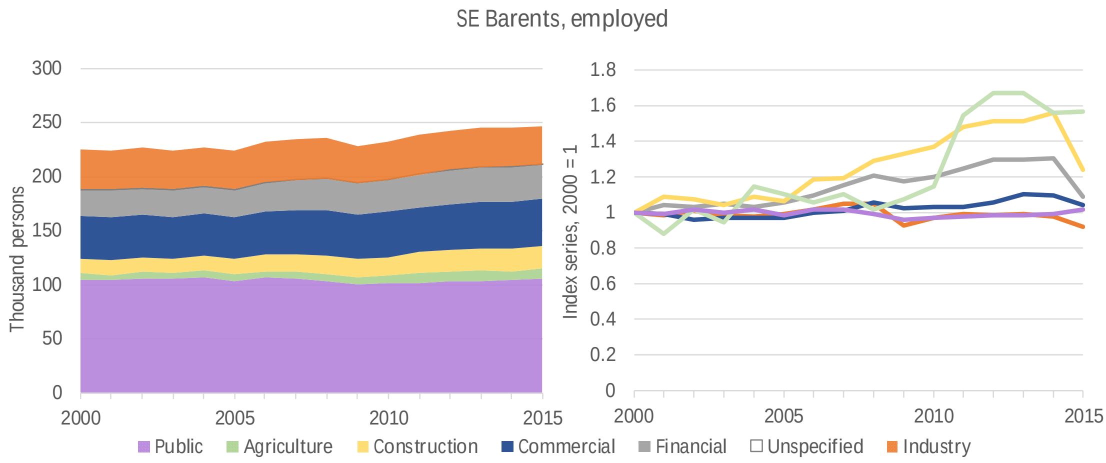

Figure A7. Number of employed in Sweden's Barents from 2000 to 2015.

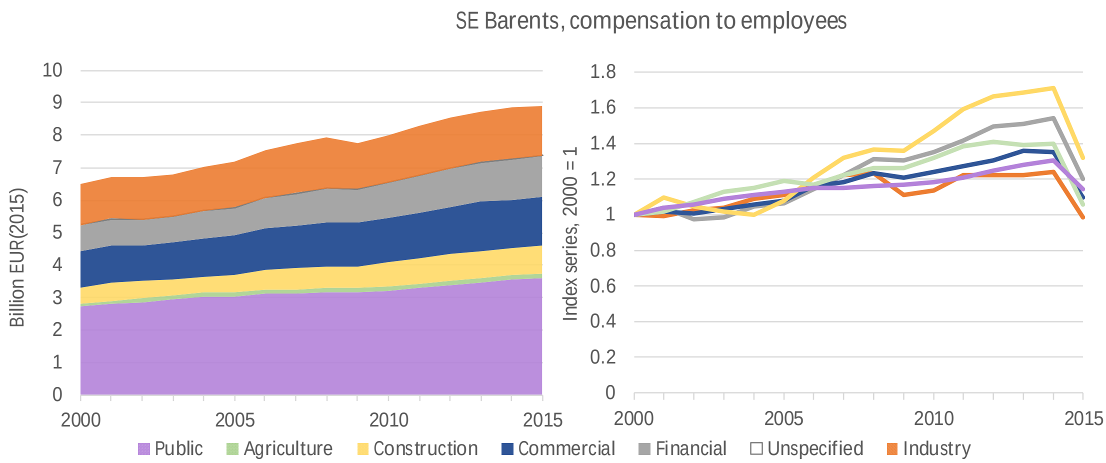

Figure A8. Compensation to employees from 2000 to 2015 in Sweden's Barents.

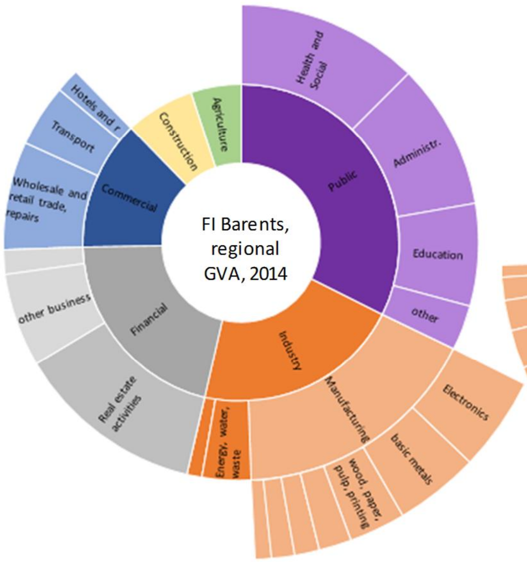

Figure A9. Finland's Barents regional GVA and number of employed presented in a detailed sectoral split in 2014.

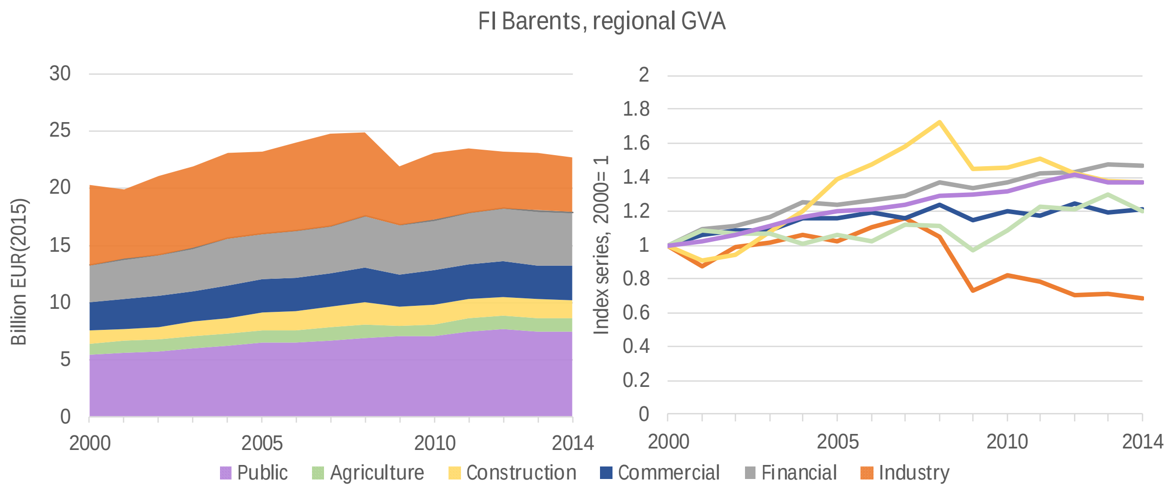

Figure A10. Finland's Barents regional GVA from 2000 to 2014.

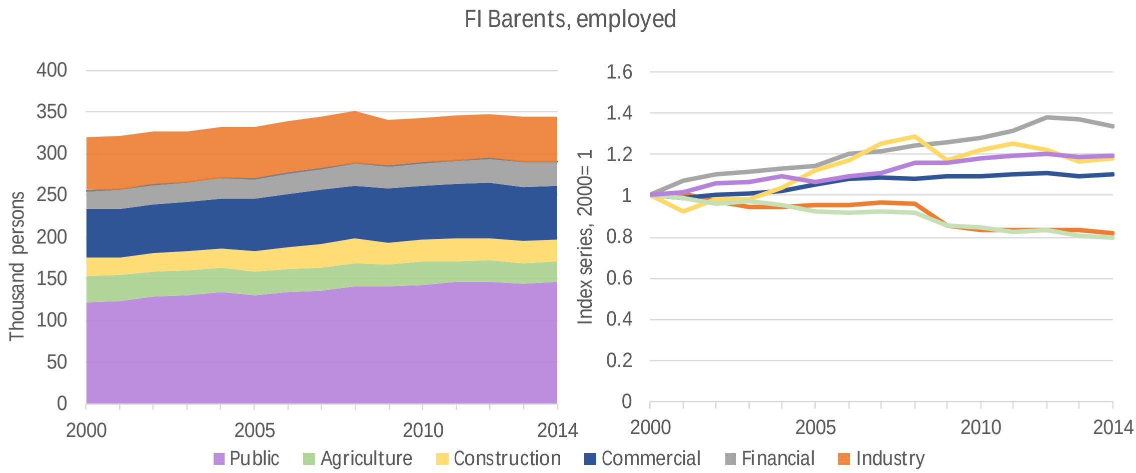

Figure A11. Number of employed in Finland's Barents from 2000 to 2014.

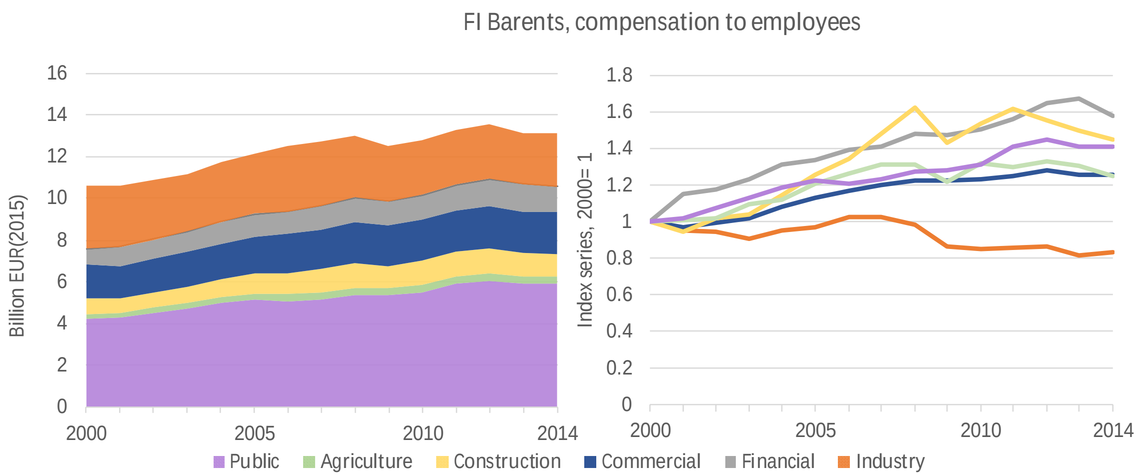

Figure A12. Compensation to employees from 2008 to 2014 in Finland's Barents.

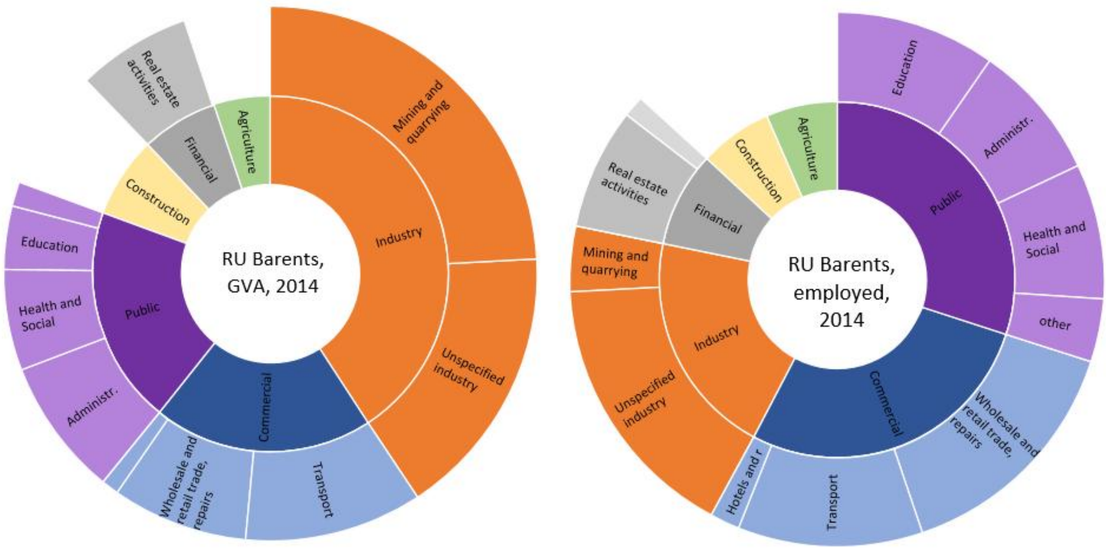

Figure A13. Russia's Barents regional GVA and number of employed presented in a detailed sectoral split in 2014.

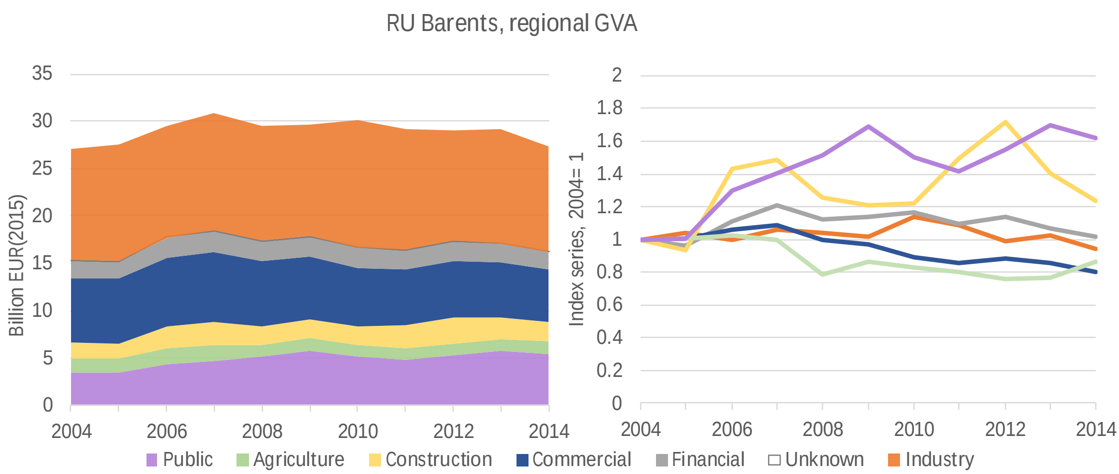

Figure A14. Russia's Barents regional GVA from 2008 to 2014.

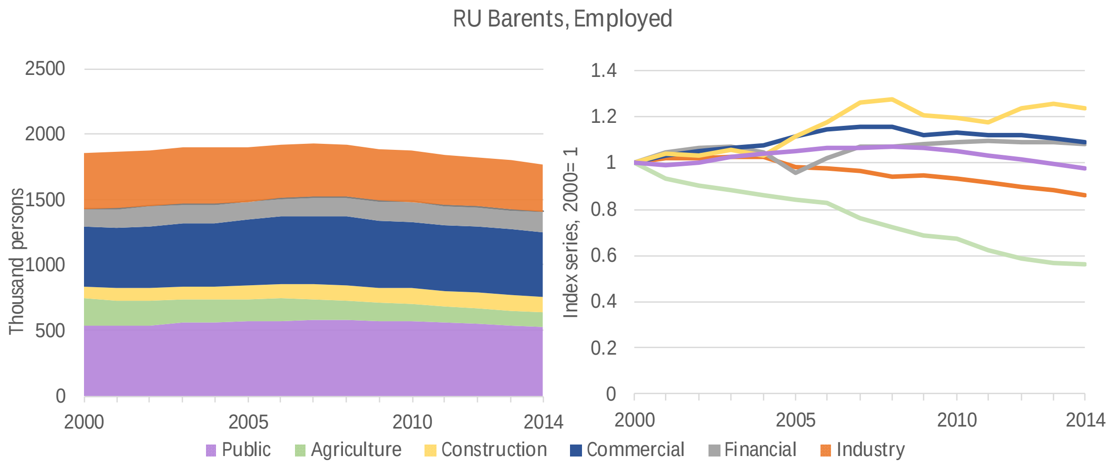

Figure A15. Number of employed in Russia's Barents from 2000 to 2014.

No sectoral employee compensation data was available from Russia.

Russia	Finland	Norway	Sweden	Sectors in this study
Total	Total	Total	Total	Total
Agriculture, hunting and forestry	01 Agriculture and hunting	Agriculture and forestry	Producers of goods	Agriculture, forestry, fishing, and aquacultu
Fishing, fish farming	02_03 Forestry; Fishing	Fishing and aquaculture	Agriculture, forestry and fishing	Industry, including energy
Mining	05_09 Mining and quarrying	Mining and quarrying	Mining and quarrying, manufacturing	Mining and quarrying
processing industries	10_12 Food industry, etc.	Oil and gas extraction including service	Electricity, gas, steam and air conditic	Oil and gas extraction
Manufacture and distribution of electricity, ga	13_15 Textile, clothing and leather industri	¬ Oil and gas extraction	Construction	Manufacturing
Building	16 Woodworking industry	¬ Service activities incidental to oil and		food products, textiles
Wholesale and retail trade, repair of motor ve	17_18 Paper industry; Printing	Manufacturing	Producers of services	paper, pulp, printing
Hotels and restaurants	19_22 Chemical industry	¬ Food products, beverages and tobacc	Wholesale and retail trade	chemicals
Transport and communications	23 Manufacture of other non-metallic mine	¬ Textiles, wearing apparel, leather	Transport and storage	basic metals
Financial activities	24_25 Manufacture of basic metals; Manufa	¬ Wood, wood products and paper proc	Hotels and restaurants	machinery, equipments
Operations with real estate, renting and busin	26_27 Manufacture of electrical and electro	¬ Printing and reproduction of recorde	Information and communication	Electronics
Public administration and defence; compulso	28 Manufacture of machinery and equipme	¬ Refined petroleum, chemical and pha	Financial services and insurance activi	Other manufacturing
Education	29_30 Manufacture of transport equipmen	¬ Rubber, plastic and mineral products	Real estate activities	Energy, water, waste
Health care and social services	31_33 Manufacture of furniture; Other mar	¬ Basic metals	Professional, scientific, technical and	other industry
Other community, social and personal service	35_39 Water supply and waste managemen	¬ Machinery and other equipment n.e.	Public authorities and national defen	Construction
	41_43 Construction	¬ Building of ships, oil platforms and m	Education	Commercial
	45_47 Trade and repair of motor vehicles, e	¬ Furniture and other manufacturing n.	Human health and social work activiti	Wholesale and retail trade, repairs
	49_53 Transportation and storage	¬ Repair and installation of machinery .	Personal and art services	Transport
	55_56 Accommodation and food service ac	Electricity, gas and steam	Not allocated by activity	Hotels and restaurants
	58_63 Publishing activities; Audio-visual ac	Water supply, sewerage, waste		Financial
	64_66 Financial and insurance activities	Construction		Financial and insurances
	681+68209+683 Other real estate activities	Wholesale and retail trade, repair of m		Real estate activities
	68201_68202 Letting and operation of dwel	Transport via pipelines		other business
	69_75 Professional, scientific and technical	Ocean transport		Public
	77_82 Administrative and support service a	Transport activities excl. ocean transpo		Administration
	84 Public administration and social security	Postal and courier activities		Education
	85 Education	Accommodation and food service activ		Health and Social
	86_88 Human health and social work activi	Information and communication		Arts, entertainments, other
	90_96 Arts, entertainment and recreation,	Financial and insurance activities		Unknown
	97_98 Household service activities	Real estate activities		
		Imputed rents of owner-occupied dwe		
		Professional, scientific and and technic		
		Administrative and support service act		
		Public administration and defence		
		Education		
		Health and social work		
		Arts, entertainment and other service activities		

Appendix B: Description of the TIMES-VTT model

The TIMES-VTT model is a partial equilibrium model of the global energy system based on linear optimization. Assuming efficient markets and perfect foresight, the model calculates a market equilibrium solution through cost minimization for energy production, transformation and end use under the given energy demand projections, technology assumptions and policies (e.g. targets for emission levels or global temperature increase).

TIMES-VTT is a bottom-up model of the energy system and it includes a large database of energy technologies. The production chain starts from the extraction of energy resources, continues through transformation and distribution steps, and ends at energy end-use where final-energy is used for a wide variety of energy services in five end-use sectors (industry, residential, transportation, commercial and agriculture). A simplified outline of this structure is presented in Figure B1.

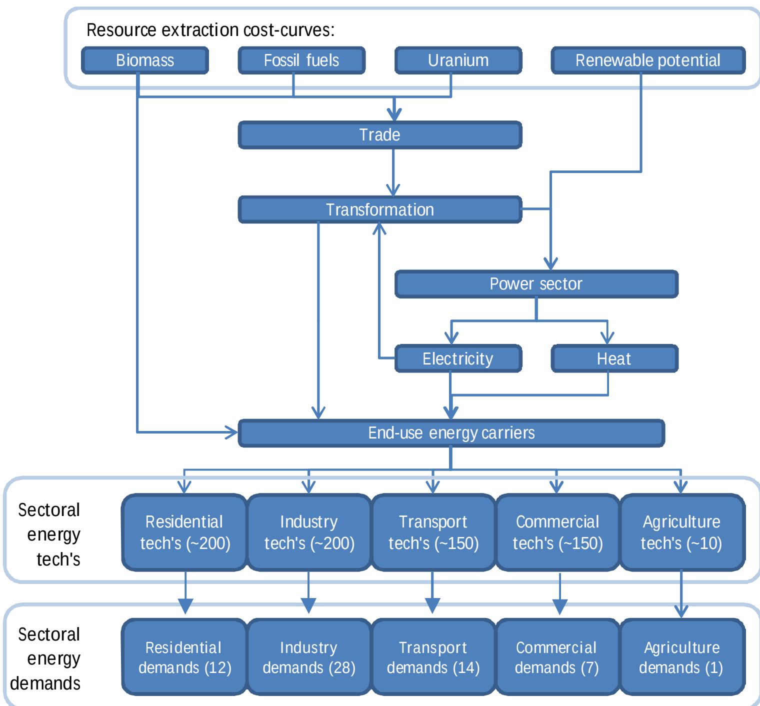

Figure B1. A simplified structure of the energy system in the TIMES-VTT model in one region. The numbers in parenthesis refer to the numbers of end-use energy technologies and the numbers of energy services.

The model uses the TIMES modelling approach, and is originally based on the TIMES integrated assessment model (Loulou et al. 2016), to which a number of modifications have been made at VTT. TIMES-VTT and its input data has been documented also in several studies (Matthews et al. 2015 and Kallio et al. 2015). Specific assumptions used in this study are described in the chapter below.

The model runs in 10-year time steps. In this Barents project, we run the model up to 2100 though scenario results are shown up to 2050. TIMES has intra-year variability on the production or consumption of selected technologies and energy forms (e.g. day-night variation with solar power). In total, the model has 24 time slices for every year modelling the changing seasons (4 seasons), weekdays (week-day or weekend), and daytime (day, night, peak demand).

The main model inputs are:

- Energy resources: quantities, marginal cost extraction costs
- Energy and emission reduction technologies: investment costs, lifetimes, O&M costs, efficiencies, availability factors, emission factors, etc.
- Future energy demands, per energy service and time step
- Energy and environmental/climate policy: taxes, emission targets, etc.

The main model outputs are:

- Flows of energy and emissions, per energy form/emission type, region and time step
- Investment, capacity and activity of energy and emission reduction tech-nologies
- Climatic variables: atmospheric GHG concentration, radiative forcing, temperature increase
- Marginal values of different energy forms /emission types (as shadow prices from the optimization)

Series title and number

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Title	**Barents 2050 – Impacts, opportunities, and risks of climate change and climate change mitigation**
Author(s)	Tommi Ekholm, Tomi J. Lindroos, Laura Sokka, Kati Koponen & Tiina Koljonen
Abstract	The Barents region can contribute to the Paris Agreement's aims to mitigate climate change in numerous ways. At the same time, the Barents region will face the impacts of a changing climate, particularly if the Paris Agreement will not be effective in limiting global greenhouse gas emissions. The transformation to a sustainable, low-carbon society will create both pressure for businesses to adapt to changing conditions and also offer a number of new opportunities and markets. Enhanced policy action is necessary to achieve the ambitious goals of the Paris Agreement and realize the opportunities in each sector. Political action is needed on national, regional, and municipal level, but these levels should work together and complement each other. This report describes the current economic and demographic structure of the Barents region, portrays long-term energy and emission scenarios on how the Barents region countries could achieve the Paris Agreement targets, and how a changing climate might affect the region and its economic activities by 2050. This study explores opportunities how the most important economic sectors in the Barents region could contribute to the mitigation action. In addition, we explore possible benefits, threats, and risks that climate change and climate change mitigation poses to these sectors in the Barents region.
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