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Regional economic effects of the green transition in the Nordic Region

Harry Flam and Nora Sánchez Gassen (Eds.)

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Stockholm, Sweden, 2024

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1. Introduction

In order to mitigate climate change, the Nordic countries have committed to reducing greenhouse gas (GHG) emissions to net zero by 2050, a process commonly referred to as the 'green transition'. Ambitious policies and initiatives are needed towards this end, with profound implications for Nordic economies and societies (Flam & Hassler 2023, Tapia et al. 2022).

The impacts arising will not be evenly distributed across the Nordic countries (Dixon et al. 2023, Rodríguez-Pose & Bartalucci 2023). Rather, the more dependent a region or community is on energy-intensive and carbon-heavy industries, the greater the transformation faced. This not only implies changes in production routines, but also potential job losses and company closures. On the other hand, those regions with access to renewable energy and raw materials will likely benefit from investments, expanded economic activity and job creation.

Analysing the regional impacts of the green transition is therefore vital for identifying regional opportunities, obstacles and challenges; maximising benefits and reducing disruptions; and supporting affected workers and communities (OECD 2023). Conducting such an analysis is, however, challenging due to the uncertainty surrounding emission forecasts, technological advancements and the precise policies that will be pursued. In addition, various other processes – such as ongoing automation, digitalisation and demographic shifts – intersect with the green transition, making it difficult to separate out the impacts of each.

Against the above backdrop, this report explores the challenges to and regional impacts of the green transition in the Nordic Region. More specifically, the subsequent chapters each focus on a particular Nordic country and a key challenge it faces in achieving its climate targets. These chapters seek answers to the following questions:

- What is the nature of the challenge and how can it be met?
- What are the impacts on output, income and employment?
- Do the impacts differ across regions?
- How could regionally concentrated negative impacts be mitigated?

The remainder of this introductory chapter unfolds thus. Section 2 provides an overview of Nordic and European climate goals and policies, as well as current GHG emission levels by sector, with the latter indicating a relevant key challenge in each Nordic country. Section 3 then summarises the report's five country chapters, before section 4 presents some overarching conclusions and reflections.

2. Nordic climate goals and climate challenges

2.1 Nordic and European climate goals

All five Nordic countries have committed to ambitious climate goals (Table 1). In the shorter term, this means GHG emission reductions of between 40% (Iceland) and 70% (Denmark) by 2030 (compared to 1990 levels). In the longer term, Finland, Iceland and Sweden aim to achieve carbon neutrality by, respectively, 2035, 2040, 2045. Carbon neutrality – or 'net zero' carbon emissions – implies a net balance between the amount of carbon emitted into the atmosphere

Table 1. Medium- and long-term climate goals in the Nordic countries

	Medium-term climate goals (2030)	Long-term climate goals (2040–2050)	Source
Denmark	Reduction of GHG emissions by 70% by 2030 (compared to 1990)	Climate neutral by 2050	LOV nr 965 af 26/06/2020
Finland	Reduction of GHG emissions by 60% by 2030 (compared to 1990) Carbon neutrality by 2035	Reduction of GHG emissions by 90–95% by 2050 (compared to 1990)	Ilmastolaki/Klimatlag 423/2022
Iceland	Reduction of GHG emission by 40% by 2030 (compared to 1990)	Carbon neutrality by 2040	Lög um loftslagsmál 2012 nr. 70 29. júni
Norway	Reduction of GHG emissions by 55% by 2030 (compared to 1990)	Reduction of GHG emissions by 90–95% by 2050 (compared to 1990)	Lov om Klimamål LOV-2017-06-116-60
Sweden	Reduction of GHG emissions by 63% by 2030 (compared to 1990)	Carbon neutral by 2045	Klimatlag SFS 2017:720 and Klimatpolitisk ramverk

and the amount absorbed from the atmosphere via carbon sinks. Denmark aims to be climate neutral by 2050. Norway, meanwhile, has declared it intends becoming a 'low-emission society' by 2050, which translates into GHG emission reductions of 90–95% compared to 1990 levels.

In addition to their national climate goals, the Nordic countries are bound by climate targets at the European Union (EU) level, which stipulate that net domestic GHG emissions be reduced by at least 55% by 2030 compared to 1990 levels. Moreover, the EU aims to achieve climate neutrality by 2050 – that is, union-wide net zero GHG emissions. As EU member states, Denmark, Finland and Sweden are legally bound to take action, while not-EU members Norway and Iceland have reached agreement with the EU to cooperate on reaching these climate targets (Lind et al. 2023). The latter two countries also participate in the EU Emissions Trading System (ETS) and are negotiating national targets for non-ETS emissions (see below). As such, the EU's climate goals matter for all five Nordic countries. While the nationally defined Nordic climate goals are for the most part more ambitious than current EU targets, recent efforts at the EU level to intensify climate ambitions has narrowed the gap substantially, in some cases removing it entirely.

2.2 Climate policies

In order to achieve the climate goals, both the EU and the Nordic countries have implemented a diverse set of climate policies. At EU level, the most important initiatives when it comes to reducing GHG emissions are the ETS, the Effort Sharing Regulation (ESR) and the Land Use, Land Use Change and Forestry (LULUCF) Regulation (Dixon et al. 2023).

- The **European ETS** was the world's first carbon market and remains one of the largest, covering EU member states as well as Iceland, Norway and Liechtenstein. It is based on a 'cap and trade' principle, which involves setting an annual limit ('cap') on the total amount of GHG emissions that can be emitted under the system.[3] This cap is lowered every year in order to bring emissions in line with EU climate targets. Emitting entities (such as large industrial facilities and installations) must purchase allowances at auctions for each tonne of CO_2 equivalents they plan to emit. Alternatively, companies can buy allowances from each other ('trade'). Some high carbon-emitting industries receive free allowances so that they can remain competitive relative to third-country exporters. Companies are required to monitor and report annual emissions to the European Commission – if they exceed the acquired allowances, sanctions are imposed. Revenue from the ETS mainly flows into the national budgets of participating countries, where it is used for green investments such as renewable energy or low-carbon technologies. The ETS covers electricity and heat generation, industrial manufacturing, as well as intra-European aviation[4] and maritime transport, which together account for roughly 40% of EU-wide emissions. Since 2005, emission levels covered by the system have decreased by 47% (European Commission n.d.a). In 2023, a new emissions trading system (ETS2) was created, covering emissions from buildings, road transport and other sectors, and is set to be implemented from 2027 (European Commission n.d.b). At the same time, a Social Climate Fund will address the social impacts of ETS2 and support vulnerable groups. Moreover, a carbon border adjustment mechanism (CBAM) is being introduced gradually, meaning that by 2026 exporters to the EU will have to pay a tax equal to the cost of ETS allowances.

- The **ESR** sets binding annual GHG emission limits for each member state for the period 2021–2030. It applies to sectors not covered by the ETS, including domestic transport (except aviation), buildings, agriculture, small industry and waste treatment. Together, these sectors account for around 60% of EU-wide emissions. The ESR's overall goal is to achieve a 40% reduction in joint EU emissions by 2030 compared to 2005 levels. Each member state is assigned a reduction target for 2030, as well as an annual emissions allowance subject to certain flexibilities. Denmark, Finland and Sweden all have a reduction target of 50%, while

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[3] Unused allowances are saved in the so-called 'market stability reserve' and can be used later.

[4] Temporary exceptions exist for Icelandic aircraft operators due to Iceland's geographical location and stronger dependence on air transport (Dixon et al. 2023).

Norway's and Iceland's contributions are set to be revised in the near future, likely resulting in similar targets. While national reduction targets are set at the EU level, it is up to member states to implement the necessary measures and policies, backed up by EU-wide actions. For example, all new cars and vans in the EU must be zero-emission vehicles from 2035 (European Commission n.d.c). The new ETS2 system will also support member states in achieving ESR targets.

- The **LULUCF Regulation** sets out how CO_2 emissions and removals from land use and land use change – including forest, grassland, cropland, wetlands and settlements – should be accounted for. It applies to all EU member states, as well as Norway and Iceland. Land management can contribute both to releasing GHGs into the atmosphere (e.g. through deforestation) and carbon sequestration (e.g. via afforestation). The regulation stipulates that up until the end of 2025, emissions from LULUCF sectors should not exceed removals. Thereafter, from 2026 onwards, net emissions should be negative – in other words, the sector is to act as a carbon sink. For the EU area as a whole, the LULUCF Regulation specifies the net removal target of 310 million tonnes of CO_2 equivalents ($mtCO_2e$) by 2030. Similar to the ESR, a national target will be set (applicable from 2026) for each member state, with the respective government responsible for putting in place domestic legislation and policy instruments (European Commission n.d.d).

The EU's increasingly ambitious policy framework means national climate policies have a crucial role to play in meeting emission reduction goals, particularly in the ESR and LULUCF sectors. Nordic countries have also used national-level policies to lower emissions beyond what is required by EU legislation, including in sectors covered by the ETS system (Flam & Hassler 2023). Norway, for example, has imposed additional carbon taxes on petroleum extraction and domestic aviation (Golombek & Hoel 2023).

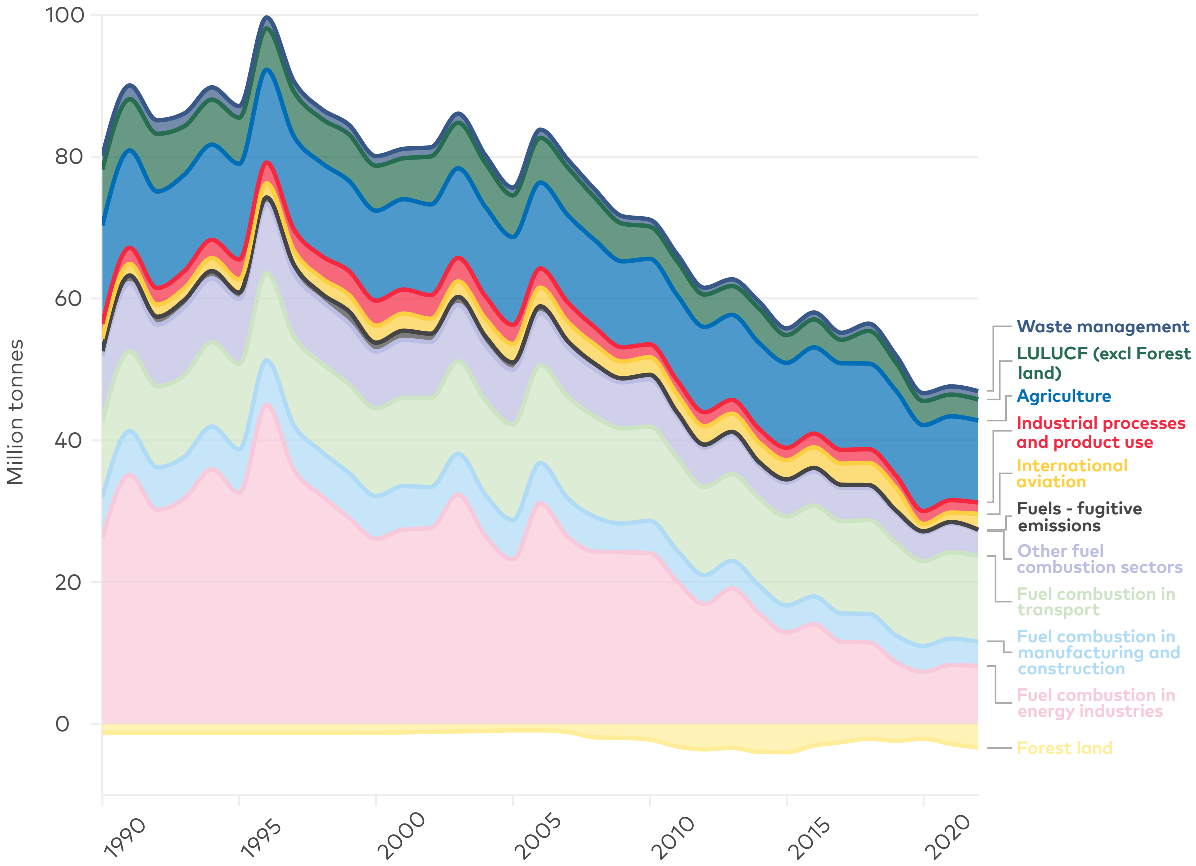
2.3 Greenhouse gas emissions in the Nordic countries

Nordic national climate policies vary in terms of scope and targets (Flam & Hassler 2023). This is at least partly a reflection of the differing climate challenges each of the five countries face in light of their respective economic specialisations and energy mixes (Dixon et al. 2023). Figure 1 provides an overview of GHG emissions by sector for each Nordic country, showing how emission trajectories have changed over time. As can be seen, a number of interesting similarities and differences between countries emerge (see also Lind et al. 2023).

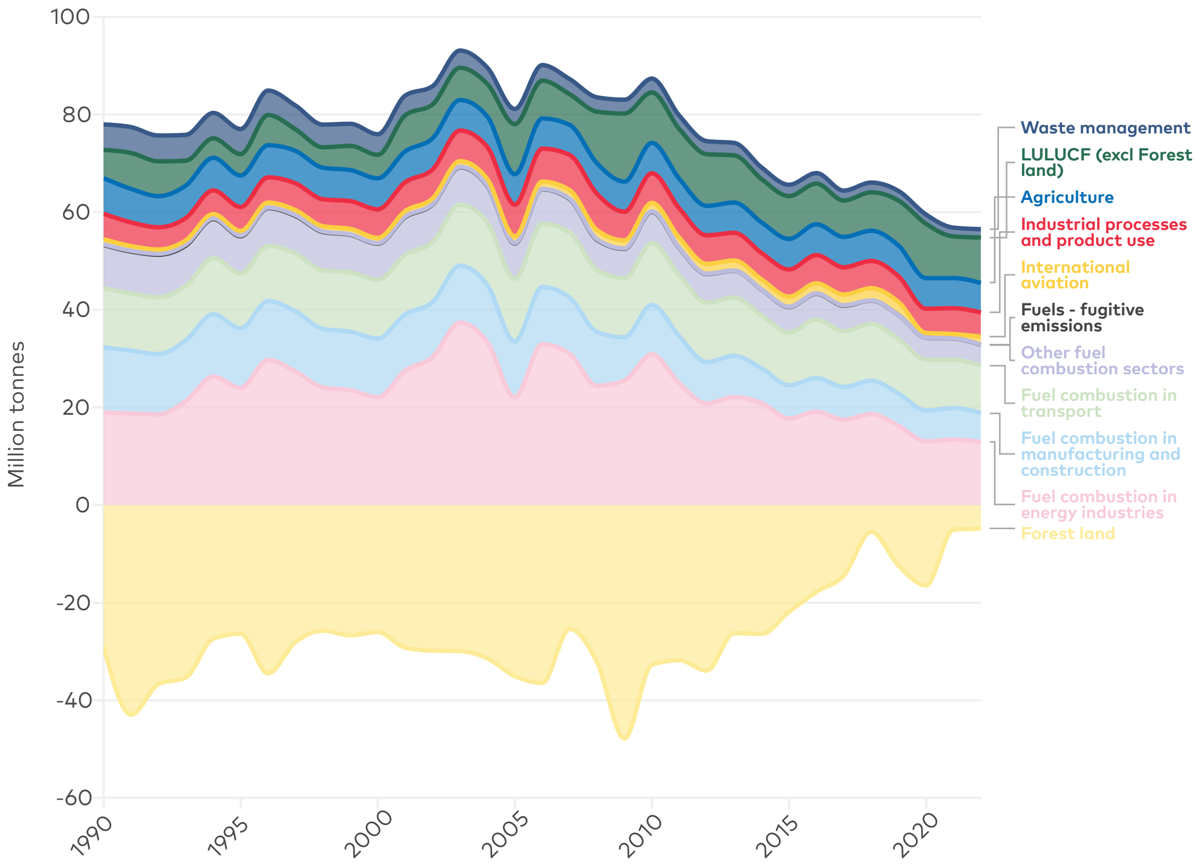
In Denmark, Finland and Sweden, total annual GHG emissions declined between 1990 and 2022. This trend was most pronounced in Denmark, which saw emissions (excluding negative emissions from forestry) fall from 80 $mtCO_2e$ in 1990 to 47 $mtCO_2e$ in 2022 (a 41% reduction). In Finland and Sweden, emissions declined by 28% and 39% respectively over the same period. The declines seen in Finland and Denmark were driven in particular by successively lower emissions from fuel combustion in energy industries, including public elec-

Figure 1. Greenhouse gas emissions by source sector, 1990–2022 (in million tonnes of CO_2 equivalents)

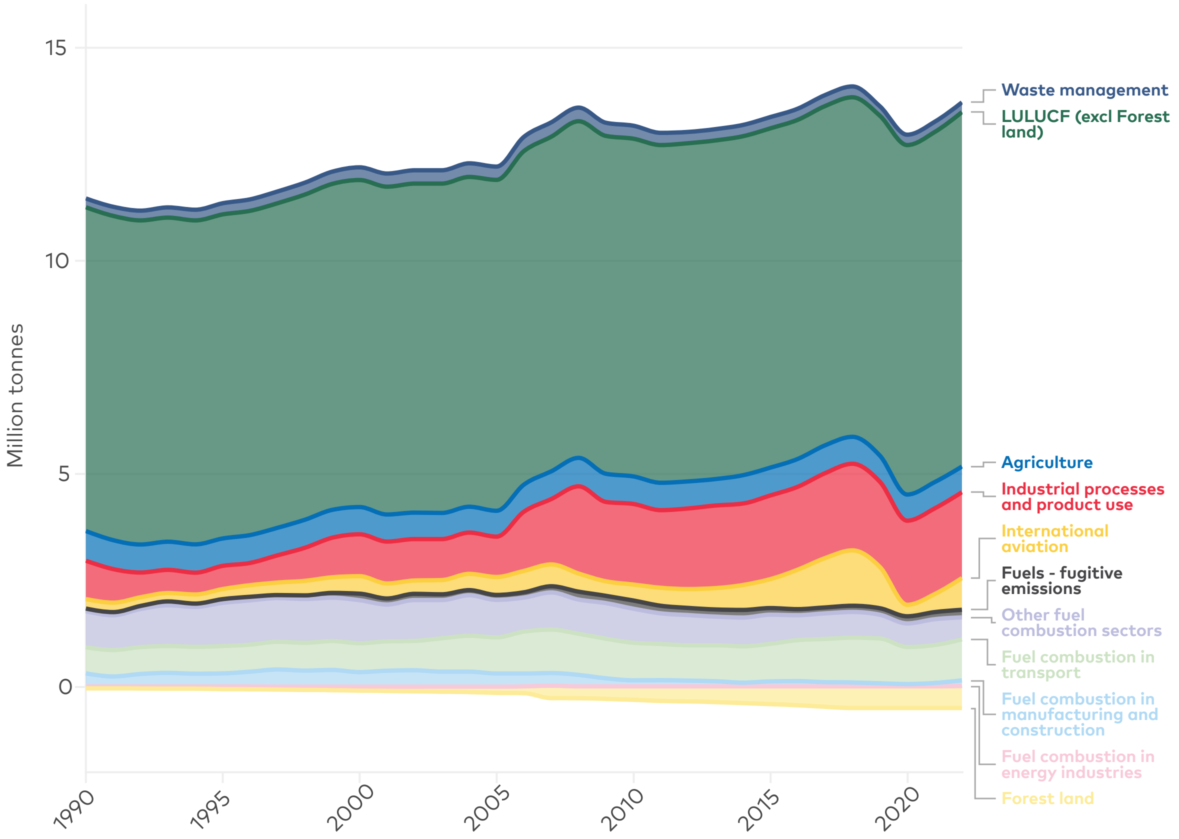
Denmark



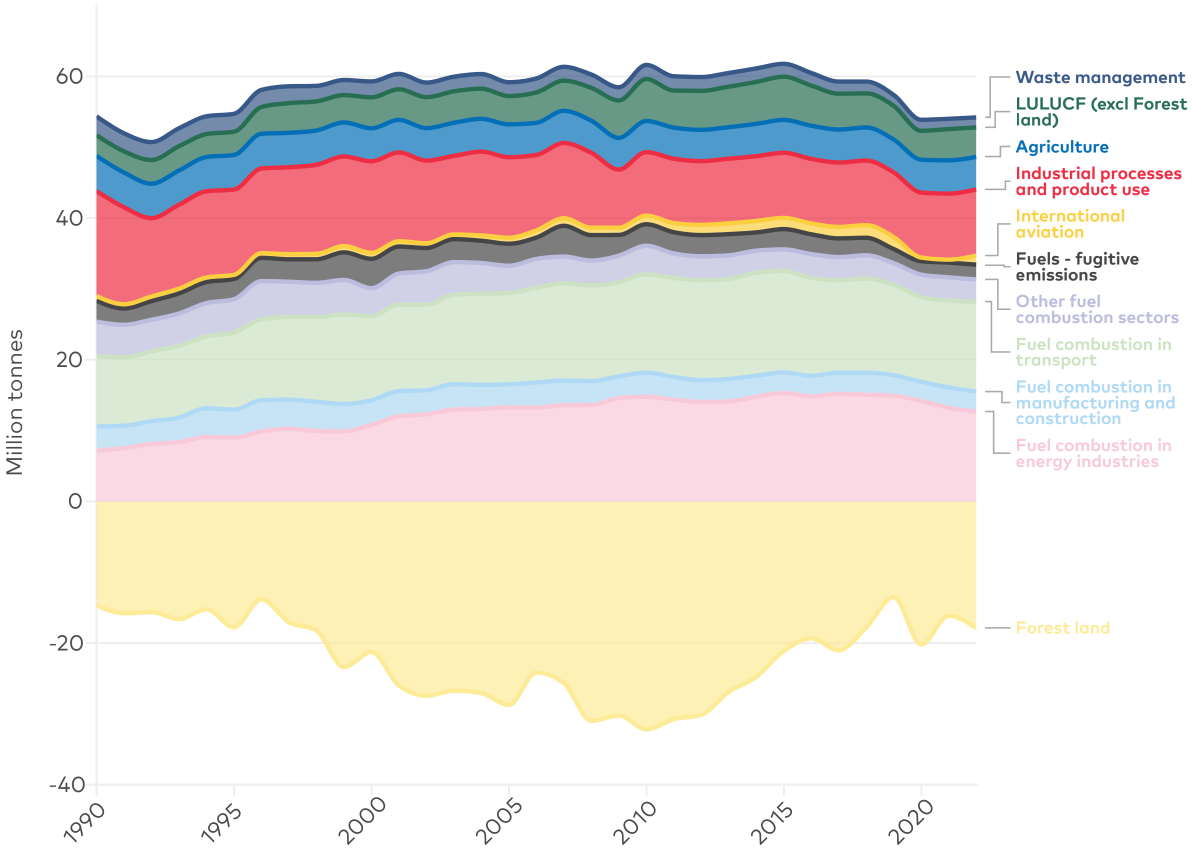
Finland



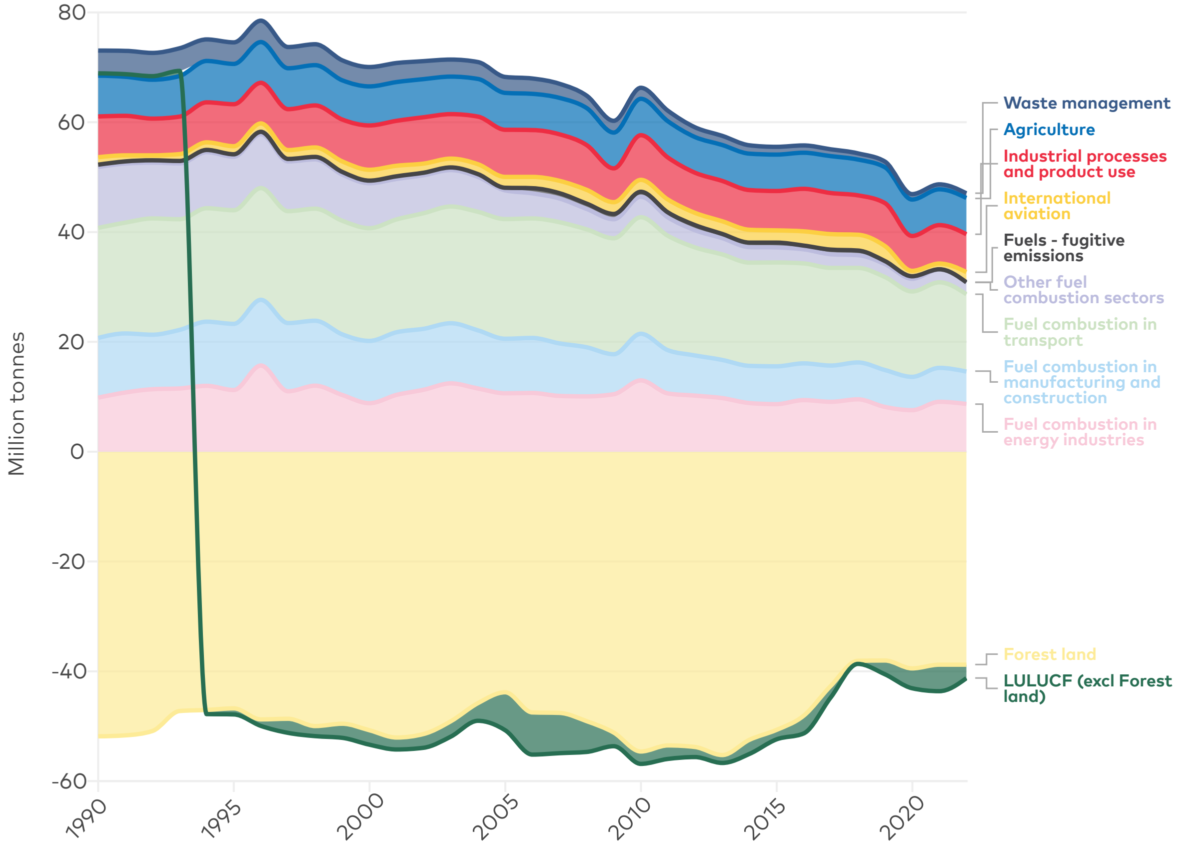
Iceland



Norway



Sweden



Note: The figures show GHG gas emissions (including CO_2, N_2O, CH_4, HFC, PFC, SF_6 and NF_3, the latter all measured in CO_2 equivalents) from various sectors. The figure excludes memo items, with the exception of international aviation.[5]
Source: Eurostat (env_air_gge).

tricity and heat production. In Sweden, emission reductions took place across various sectors, including fuel combustion in manufacturing industries and construction, other fuel combustion sectors, which includes households, and in transport. By contrast, GHG emissions increased in Iceland between 1990 and 2022, mainly driven by industrial processes and product use, including aluminium production, as well as fuel combustion in transport and international aviation. In Norway, total emission levels have remained relatively stable since the mid-1990 and have only declined somewhat in recent years.

In 2022, fuel combustion in transport was one of the biggest sources of GHG emissions in all Nordic countries. In addition to that, fuel combustion in energy industries, including in oil and gas extraction and petroleum refining, was a large emission source in Finland and Norway. Regarding the former country, it is also worth noting that the forest sector's role as a carbon sink has been much reduced over the past ten years. In Iceland, the LULUCF sector, industri-

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[5] In the United Nations Framework Convention on Climate Change's GHG emission reports, memo items refer to emissions from international aviation, marine bunkers and multilateral operations, as well as CO_2 emissions from biomass. These are not accounted for in the calculation of total GHG emissions for the respective country.

al processes and product use as well as international aviation – the latter two tied at least in part to tourism – had the largest emission shares, while in Denmark, this status goes to agriculture. Finally, in Sweden, fuel combustion in energy industries and industrial processes and product use were responsible for large shares in emissions.

3. Chapters summaries

The report examines the specific challenges faced by each Nordic country, together with the green transition's regional impacts in terms of employment and output. More specifically, the focus is on the agricultural and LULUCF sectors in Denmark; the forest sector (including its role as a carbon sink) in Finland; the tourism sector (including the role of transport) in Iceland; and the oil and gas sector in Norway. The case of Sweden is somewhat different. Given the large-scale investments made in fossil-free steel-making and battery manufacturing in the country's north, the relevant chapter focuses on the challenge of how to support private sector expansion through providing sufficient public sector labour.

3.1 Denmark: Curbing greenhouse gas emissions from agriculture and land use

In order to meet its national climate goals and EU-level obligations, Denmark must cut its GHG emissions – of CO_2, methane and nitrous oxide – in the agricultural and LULUCF sectors by 3.3 mtCO_2e. Bearing this in mind, Stewart and Berg's chapter analyses three sets of policies aimed at reducing GHG emissions in agriculture and LULUCF, with the social costs calculated in terms of loss of gross domestic product (GDP) and loss of employment in agriculture and food production. The chapter also considers the regional implications and possible effects on income distribution. Towards this end, the authors employ a dynamic computable general equilibrium model of the Danish economy, enriched with detailed sector-specific modelling of the agriculture and LULUCF sectors.

The first set of policies consists of gradually introducing a tax of €100 per tonne of CO_2-equivalent emissions from agriculture – the LULUCF sector is excluded – over the course of 2027–2030. Throughout, the balance of the government budget would remain constant, with proceeds from the tax directed in lump sum fashion to households. As a result, agricultural product prices will increase relative to other prices in the economy, prompting households to shift their demand away from agricultural products towards other goods and services. The prices of livestock sector products will increase relatively more than the prices of products derived from crops, as the tax depresses the price of land, meaning the latter sector's prices do not rise as fast as the former's. Under this scenario, land prices fall by as much as 18%, with some of the least productive land no longer used. Overall, total emissions are reduced by 1.9 mtCO_2e – much less than the goal of 3.3 mtCO_2e.

Here, the short-term loss in GDP is negligible, as agriculture's value-added share of Danish GDP is only 1.3%. Short-term loss of employment is also relatively small, amounting to a few thousand workers among the roughly 3 million strong Danish labour force. As a percentage of the 65,000 people employed in agriculture, however, the loss is sizeable.

Although the agricultural sector is spread across Denmark, Northern Jutland – which has the highest share of labour in agriculture and food processing (6%) and the lowest income per capita – will be particularly affected. In terms of absolute numbers, Mid-Jutland and Southern Denmark will be the most affected, as these regions have more people employed in agriculture and food processing, as well as a higher share of livestock in their agriculture.

The second set of policies examined by the chapter involves subsidies for afforestation and the flooding of carbon-rich soils, introduced on top of the €100 per tonne tax on GHG emissions. While the subsidy for afforestation only has a small effect on emissions in the short term (by 2030), it becomes substantial over the longer term. By contrast, a €40,000 per hectare subsidy for creating wetlands would have a substantial effect by 2030. Overall, the additional policies would reduce emissions by a further 0.4 $mtCO_2e$ by 2030, for a total reduction of 2.3 $mtCO_2e$.

One drawback of taxing GHG emissions from agriculture is so-called 'carbon leakage', whereby the resultant fall in Danish agricultural and food production leads to increased production elsewhere. Thus, carbon leakage will, to some extent, negate the global effects of Danish GHG taxation. Carbon leakage effects are, however, subject to a high degree of uncertainty, with different studies finding significantly different levels of carbon leakage arising from changes in Danish agricultural production. Nonetheless, carbon leakage does provide an argument for subsidising carbon abatement technologies. An example of such a subsidy is the €300 per tonne of CO_2 needed to support the conversion of biomass into carbon-rich biochar and its subsequent storage – a form of carbon capture and storage (CCS). Other technologies require different (lower) levels of subsidy.

Under the third set of policies, the chapter therefore looks at the combined effect on GHG emissions of a €50 per tonne carbon tax, subsidies to afforestation and wetland creation on carbon-rich soils, and subsidies to various carbon abatement technologies. Together, these polices yield an estimated reduction of 2.9 $mtCO_2e$ by 2030. Breaking this figure down, LULUCF emissions fall by 1.2 $mtCO_2e$, half of which stems from afforestation and the wetting of carbon-rich soils, and the other half from the production and storage of biochar. The remainder of the reduction (1.7 $mtCO_2e$) comes from a fall in agricultural emissions, almost matching the amount seen in the first two policy scenarios, despite the carbon tax being lowered from €100 to €50. This is due to the implementation of various carbon abatement technologies in agriculture.

It should be stressed that these results, which arise from a very large and complex model of the Danish economy, rely on an array of parameter values and assumptions, and are therefore quite uncertain. The chapter's authors are well aware of this, and as such investigate how sensitive the quantitative results are to changes in parameter values and assumption. The overarching conclusion is that, if climate goals are to be met and regulations adhered to, policymakers must monitor the effects of their climate policies and be constantly prepared to reassess tax rates and other measures.

3.2 Finland: Increasing carbon uptake in Finnish forests

About 75% of Finland's land area is covered by forests, with the forest sector – forestry and forest-based industries – accounting for about 3% of Finland's GDP, 2.5% of its employment and 20% of its goods exports. Employment in forestry and forest-based industries (producing wood products, pulp and paper) is almost exclusively located outside the country's main cities, in rural areas and small cities. Given this, the forest sector has a much greater role in rural Finland that the aggregate figures suggest.

The role of Finland's forests as a carbon sink is crucial to the country's climate policy and ambitious goal of climate neutrality by 2035. In setting that goal, it was assumed that forests would absorb 21 million tonnes of CO_2 in 2035. However, while Finland's forests have historically absorbed very large amounts of carbon, this has declined drastically over recent years. Here, the analysis focuses specifically on CO_2 (thus excluding methane and other non-CO_2 GHGs) and the carbon stocks and stock changes of live trees. These stocks are not only large, but the least uncertain elements of the LULUCF sphere. The carbon sink of Finland's live trees peaked in 2009 at about 48 million tonnes, fell as low as 6 million tonnes in 2018, and has since fluctuated around the 10 million tonne mark. Thus, the gap between the projected 21 million tonnes in 2035 and present day levels poses a considerable challenge for Finnish climate policy.

There are various reasons behind the decline in carbon absorption by Finland's forests, one of which is their age structure, with recent years seeing an abatement of the accelerated growth that took place over previous decades. Another issue is increased harvesting of forests due to growing product demand and a reduction in raw wood imports following the imposition of export tariffs by Russia in 2006, and the complete halt in imports following Russia's full-scale invasion of Ukraine in early 2022.

Kauppi and Honkatukia's chapter thus evaluates – with the help of a quantitative model – several policy measures aimed at increasing carbon absorption by forests. The first such measure is to intensify forest growth, with a 10–20% gross increment potentially leading to an increased annual absorption of 9–23 million tonnes of CO_2. This could be achieved by, among other means, improving forest management, fertilising poor soils, ensuring adequate watering and engaging in better logging practises. All this is feasible within the relevant time period.

The second measure is to reduce harvesting. If the current annual 70–78 million cubic metres of harvesting were taken down to 60 million, annual carbon uptake would potentially increase by 14–25 million tonnes of CO_2 within 2–5 years. There are, however, several negative side-effects, including higher prices if imports are not increased to compensate for the fall in harvesting, or alternatively carbon leakage if this increase does occur. Moreover, the measure would result in income and employment losses in forestry.

The third measure is more efficient production, using less wood for a given output. For example, modern pulp mills have become more efficient in using wood, recovering chemicals in the process and producing energy. Increasing efficiency in wood-using industries is feasible within the timeframe, provided the necessary actions and investment takes place.

The fourth measure is to import roundwood and possibly pulp. Finland's carbon emissions would potentially fall by 1.4 million tonnes of CO_2 for every million cubic metres of wood imported to replace Finnish wood. In recent years, Finland has imported roundwood from Sweden, Brazil, the United States, Poland and other countries. While pursuing this measure would help Finland reach its climate goals, it would decrease carbon absorption in the exporting countries and so not lead to a global reduction in emissions.

The fifth measure is to capture and store CO_2 emissions in forest industries. More than half of a modern paper mill's wood input is used as energy and combusted, emitting CO_2. Although CCS technology is being developed, it is unclear whether it can be implemented before 2035 or how much CO_2 can be captured and stored.

In summary, it seems possible that Finland can, through a combination of the proposed measures, sufficiently increase absorption of CO_2 in its forests to reach the required annual carbon sink of 21 million tonnes by 2035. To achieve this, however, the government would need to provide economic incentives to forest owners and forest industries, as well as introduce appropriate regulations.

3.3 Iceland: Curbing CO_2 emissions from the tourist industry

Tourism plays an important role in Iceland's economy. In 2022, tourist services, such as land and air transport, hotel and restaurant services, accounted for 9% of the country's GDP, 13% of its employment and 31% of its exports. By comparison, fishing and fish processing accounted for 4% of GDP, 40% of exports and 4% of employment.

Tourism and fishing have about the same carbon footprint: 32% and 28% respectively of Iceland's total CO_2 emissions. The emissions from tourism mainly stem from two sources – air travel (60% of tourism's total) and road transport – while those from fishing and fish processing mainly come from diesel fuel combustion by fishing vessels.

Karlsson, Grönfeldt and Tryggvadóttir's chapter deals primarily with policies aimed at reducing CO_2 emissions from tourism-related land transport. More specifically, it looks at the effect these policies will have on the number of tourists visiting Iceland, along with the regional impacts on income and employment.

Iceland is well on course to reach the EU goal of a 40% emissions reduction in the ESR sectors by 2030 compared to 2005 levels, with the government targeting an even more ambitious 55% reduction. Towards this end, Iceland's parliament has approved a climate action plan for land transport (which is part of the ESR). The plan includes support for purchasing electric vehicles, sustainable fuels for heavy vehicles, and charging stations.

It is clear that both the measures already in effect and those planned for the future will increase the cost of land transport for tourists (as well as air transport costs). While the chapter refrains from estimating these cost increases and the impact on demand, a study of Australia's tourist industry places the estimated price elasticity of demand at -0.36, which means demand will fall by 3.6% in response to a 10% price increase (Divisekera 2010). Here, it can be presumed that the elasticity of demand is higher for air travel to Iceland than it is for land travel within the country.

Income from and employment in tourism is unevenly distributed across Iceland. Most tourists visit Reykjavik and the surrounding area, together with the country' south, particularly along the coast. About 12% and 36% of wage income is directly attributable to tourism in, respectively, the Reykjavik area and the South Peninsula. Here, it should be noted that these figures do not encompass the indirect effects of tourism activities, despite various other parts of the country's economy being dependent on the tourism sector to some degree.

Turning to the regional impacts of a decrease in tourism on income, the sparsely populated parts of the south and the interior would be most affected in percentage terms, while Reykjavik and its surrounding area would be most affected in absolute terms. In some parts of the south and interior, tourism accounts for nearly half of wage income, whereas the corresponding figure in the Reykjavik area is in line with the national average (12%).

Overall, Iceland should be able to achieve climate neutrality at a relatively low cost, as it is endowed with considerable hydro and thermal energy. These resources are used to heat homes and three aluminium smelters, and could be used to produce hydrogen for land, air and sea transport. Thus, Iceland's main challenge is ensuring the substitution of sustainable alternatives for fossil fuel in transportation.

3.4 Norway: Making the oil and gas sector carbon free

The oil and gas sector plays an all-important role in the Norwegian economy. As of 2024, it is estimated to account for 20% of GDP, 31% of state revenue, 20% of total investment and 44% of exports. In terms of the number of people employed, direct and indirect (in related activities) employment amounted to an estimated 205,000 people in 2019, or about 10% of total employment in Norway.

The sector's activities are located along the long Norwegian coastline, from the southwest to the very north, with a particular concentration in and around the city of Stavanger on the southwest coast, in Rogaland region. As many as 73,000 people are employed in Rogaland's oil and gas sector, or 31% of the region's total employment. In Vestland, the region north of Rogaland, the share of total employment is 11%, while along the rest of the coast the figure is around 5%.

The oil and gas sector is also the greatest emitter of GHGs. In 2023, it was responsible for 25% (11.5 mtCO2e) of the country's emissions, slightly more than manufacturing and mining. The sector's emissions arise primarily from burning diesel fuel in turbines on platforms at sea. While emissions from oil and gas have been largely constant for several years, emissions from manufacturing have been falling rapidly.

At present, the oil and gas sector must buy emission permits via the EU ETS, as well as pay a national carbon tax. In 2023, the combined cost of these two measures was €132 per tonne of CO_2. Going forward, the government aims to increase the tax, with the envisaged sum cost reaching €200 per tonne of CO_2 in 2030. This will not, however, curb emissions sufficiently for Norway to reach its goal of a 55% reduction by 2030. The sector is very profitable given current oil and gas prices, meaning the cost of electrifying oil and gas extraction is high compared to the costs of paying for emissions. Moreover, it is possible that placing a high price on emissions will result in some carbon leakage, with extraction in Norway transferred to other parts of the world, where emissions may also be higher.

If the country's 2030 goal is to be achieved, oil and gas extraction will have to switch from fossil fuels to sustainable energy derived from wind and hydropower. This means large investments in wind turbines, bolstered by substantial government subsidies. Most of this new capacity will probably have to be built at sea, as there is often opposition from environmentalists and reindeer-herding Sami to land-based wind turbines. Reaching the goal will also require large-scale CCS in depleted wells, a technology where Norway is a leader. In the longer term, the oil and gas sector must turn to the production of hydrogen from gas, alongside CCS, in order to become climate neutral.

Aside from technological uncertainties, the main obstacle to Norway's climate policy is political conflict around several contentious aspects of the oil and gas industry, specifically: expansion or contraction of industry; expansion in the north; building wind turbines (both on- and off-shore); and connecting the Norwegian and European electricity grids, which most experts assume will lead to higher electricity prices in Norway. Both the country's main parties – Labour and the Conservatives – favour maintaining the policy followed in the past, namely expanding and greening the oil and gas sector, in combination with paying for emissions or their abatement in other parts of the world.

3.5 Sweden: Effects on public sector employment of new mining and manufacturing in the north

In recent years, Sweden's two northernmost regions – Norrbotten and Västerbotten – have seen large investments in mining and manufacturing aimed at supporting the transition to carbon neutrality. The most prominent examples include a battery plant, carbon-free steel production and the mining of certain minerals. Overall, switching from fossil fuels to sustainable energy in making steel is projected to reduce Sweden's total CO_2 emissions by 10%.

Increased economic activity in mining and manufacturing creates increased demand for labour. A recent report estimates that the private sector in Norrbotten and Västerbotten will need 36,000 more employees over the course of 2024–2026, translating into a 20% increase in employment (SKR 2023). Increased private sector employment in turn requires increased public sector employment in health and social care, education, infrastructure, and administration. Thus, the projected increase in the two regions' public sector employment over the same period is 11,600, which equates to a 17% increase.

This increased demand for private and public sector employees cannot be met by increased labour supply within the two regions. Rather, it requires a net inflow of labour roughly corresponding to the additional number of workers needed. This poses a huge challenge not only for Norrbotten and Västerbotten, but for the national government.

Another feature of the green transition investments made in manufacturing and mining in these regions is that the private sector tends to pay (often much) higher wages than the public sector. This poses another challenge for regional and municipal governments – how can they prevent employees from leaving while also attracting replacements for those who do go?

Adjej, Eriksson and Lundberg's chapter deals primarily with the latter challenge. Based on the expansion of mining and manufacturing seen in the two regions in 2006–2008, the authors estimate the extent to which a given increase in private sector employment will lead to employment being reallocated from the public to the private sector, as well as the specific impacts on different parts of the private sector (health and social care, education and administration). They also estimate the degree to which different types of employees – in terms of age, income, educational level and type of education – will be affected.

The main finding is that the private sector primarily attracts younger individuals employed in public administration with a relatively high income and a social sciences university education. Public sector employees in the education sector are much less affected, while health and social care employees are barely affected at all. The reason underlying this difference is presumably that public sector employees with the former profile possess general skills demanded by both the public and private sectors.

The demand for more mining and manufacturing labour in 2006–2008 was small compared to the envisioned increase in labour needed for 2024–2026. In the previous instance, most of the private sector demand could be met by reallocating labour from the local public sector, rather than resorting to recruitment from outside the regions. Considering that the transition to a greener economy will inevitably lead to some labour being poached by the private sector from the public sector in the two regions, the public sector will need to recruit more than the projected 11,600 employees mentioned above. These new employees will have to be attracted either from other parts of Sweden or abroad.

The chapter suggests a number of potential policies for attracting labour to the public sector. One is increasing relative wages in the public sector. Another, perhaps just as important, is raising the status of public sector employment among young people in the process of choosing education and employment. This is not a task that can or should be undertaken by the local public sector alone, whether regional or municipal. Rather, national policymakers must also share responsibility.

Three municipalities in particular are affected by the green transition in manufacturing: Boden and Luleå – where investments in fossil-free steel production are taking place – plus Skellefteå, where the Northvolt battery factory is located. These municipalities face huge financial risks, having financed the building of new infrastructure through greatly increasing their debt. They are also under considerable administrative strain.

While private investments made in making carbon-free steel have received substantial public subsidies – including from EU funds – in the form of grants and loan guarantees, very little subsidies have been directed towards the large infrastructure investments municipalities have been forced to make. Given that both private and public investments are necessary to meet Sweden's climate goals, it is legitimate to ask whether municipalities should bear all the financial risk in anticipation of future benefits. If a municipality's investments fail, it will be saddled with an unsustainable debt burden, forcing central government to step in.

4. Key findings

The topics covered by this project were chosen on the basis of the key challenges faced by the Nordics in pursuit of a green transition, and what meeting these challenges may entail for the various regions of the countries in question.

Common to all the Nordic countries is that they follow EU climate policy, although two of them – Iceland and Norway – do so voluntarily by formal agreements. This means emissions from the ETS sector of the economy are regulated at the EU level. While emission targets for the LULUCF sector are set by the EU, measures to achieve them are decided at the national level. The same currently applies to the ESR sector. Starting from 2027, however, emissions from road transport, small-scale industry and the heating and cooling of buildings – which together account for most of the ESR sector – will be regulated by a new emission trading system, ETS2. In contrast to the EU ETS, suppliers of combustible fuels – not end users – will have to buy emission allowances.

The main challenges to meeting the Nordic countries' 2030 climate goals can be found in the ESR sector in Iceland (road transport) and Norway (fossil fuel extraction), and the LULUCF sector in Denmark (agriculture and land use) and Finland (forestry). Sweden is the exception – here, the challenge is supplying appropriately skilled labour to the public (and private) sector in order to enable fossil-free steel-making and battery production.

All five countries have detailed climate action plans, meaning there is a wealth of measures available for achieving their respective climate or labour supply goals. The issue is therefore not so much one of finding appropriate measures, but rather whether political obstacles can be overcome: is the ruling party or coalition willing to pursue a given measure, and can it muster a majority in parliament? Experience shows that climate policies can be highly contentious. The reindeer-herding Sami in Norway and Sweden oppose the land-based wind turbines and new mineral mines required for the green transition; municipalities in Sweden oppose land-based wind turbines unless they receive economic compensation for the environmental impact; and people living in rural areas who are dependent on cars for transportation oppose making fossil fuels more expensive.

There is also considerable uncertainty around, among other things, emission forecasts, which are used to set emission-abatement goals. For instance, the Danish goal of cutting GHG emissions from the LULUCF sector by 3.3 $mtCO_2e$ in 2023 was lowered to 1.5 mtCO2e in 2024 due to new emission and uptake forecasts. Another source of uncertainty is technological, with one example being CCS. It remains open to question whether the Norwegian CCS project will prove to be feasible, and in particular whether sufficient economic incentives will be put in place to ensure use of the technology. The latter depends on the resource cost, the price of ETS allowances and the amount of CCS credits (provided a carbon credit system comes into being).

Turning to the regional effects on income and employment of pursuing national-level climate goals, it is broadly clear which parts of the Nordic countries will be most affected. Nevertheless, estimating the extent of these effects is difficult, as it depends on the specific policy measure; how it is applied and to what extent; and the relation between a policy measure and the outcome, which in turn may depend on technological, behavioural or scientific uncertainty.

Here, increasing the carbon uptake of Finland's forests offers a useful example. It is evident that increasing forest growth or reducing harvesting will raise costs and reduce profitability for forest owners, who are spread throughout the country and are largely individuals rather than corporations. Increasing the yield per unit of input in saw, pulp and paper mills requires investment, thereby potentially making some mills unprofitable and forcing their closure. In this case, the effects are concentrated in small communities across Finland, many of which are dependent on a single mill. There is also a great deal of uncertainty regarding how many measures need to be taken, and to what extent they should be implemented, as their effects on carbon uptake are not currently clear.

Overall, it seems the effects of maintaining social equity through dealing with regional income and employment impacts are quite limited at the macro level. The affected share of total employment is very small in Denmark, Finland and Sweden, although it is a slightly larger in Iceland and Norway. In all cases, compensation for any negative effects encountered should not pose a problem for the respective countries' public finances. More significant negative distributional effects may occur, however, in cases where these effects are highly localised, particularly in Norway and Sweden, and to a lesser extent Finland and Iceland.

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Regulation of emissions from agriculture and LULUCF: A modelling approach in the GreenREFORM model

Louis Birk Stewart[1] **and Asbjørn Kehlet Berg**[2]

ABSTRACT

A carbon tax on emissions from agriculture, as well as land use, land use change and forestry (LULUCF), is widely regarded as a necessary tool if Denmark is to achieve its greenhouse gas reduction obligations. In assessing the impact of levying such a tax, the present study finds that the combination of a carbon tax of €50 per tCO_2e, combined with subsidies for emission-reducing technologies, would provide roughly three-quarters of the remaining national reduction required by 2030. These results are based on the GreenREFORM model: a dynamic multisector model focused on the interactions between economic and environmental policies. Crucially, given a significant portion of emission reductions are achieved through drops in agricultural and food processing production, the results are reliant on assumptions made about the market structures of these sectors, especially regarding export elasticities and expectations around future prices. The study investigates, through a series of sensitivity analyses, how altering these assumptions impacts emission reductions. The drop in production is expected to have different impacts on e.g. employment and production in different regions of Denmark, as some regions have a larger share of production within the agriculture and food processing sectors than others.

At the time of editing (October 2024), political negotiations are ongoing with respect to an implementation of a carbon tax on the Danish agricultural sector. Nothing is settled yet, but all things point towards a political agreement that could be characterized as a softer version of this paper's "Scenario 3". The headlines are a tax of €40 per tCO_2e (in 2030) on livestock emissions with a 60 percent bottom deduction along with subsidies for afforestation, re-wetting of organic soils as well as technology subsidies. Politically, the softer approach has been made feasible by the development in the latest Danish green-house-gas emissions forecast (the Climate Outlook 2024). In the 2024-edition, the projected outstanding reductions have been reduced by 2.5 $mtCO_2e$. The reduction-effects found in the paper remain up-to-date irrespective of this latest development in the Danish reduction needs.

Keywords: Agriculture, LULUCF, climate mitigation, climate policy, CGE modelling, green transition, green technology adoption

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1. Introduction

Denmark is subject to a dual obligation in terms of reducing greenhouse gas (GHG) emissions: at a supranational level, the country is required by the European Union (EU) to reduce emissions, while at a national level, it has adopted legislation requiring a 70% reduction in GHG emissions by 2030 relative to 1990 levels (Lov om klima 2020). Additionally, a national-level sub-target was negotiated in 2021 for, firstly, the agricultural land use sector, and, secondly, the land use change and forestry (LULUCF) sector, with both required to achieve 55–65% emissions reductions by 2030 (Regeringen et al. 2021). In the longer term, the Danish government aims to reach net-zero emissions by 2045 (Regeringen 2022).

At the current trajectory, there will be a 4.2 mega tonnes of CO_2e ($mtCO_2e$) reduction deficit when it comes to reaching the 70% target by 2030. Moreover, to meet the national targets for agriculture and LULUCF, at least 3.3 mega tonnes of this 4.2 $mtCO_2e$ shortfall needs to come from these two sectors. With respect to meeting EU targets, the current trajectory will leave a 7.6 $mtCO_2e$ reduction gap in 2030 under the Effort Sharing Regulation. Over recent decades, emissions from the agricultural and LULUCF sectors have undergone a decline: down by 40% in 2022 compared to 1990 levels.[3] This trend is not, however, set to continue under current policies. With other sectors expected to undergo an emissions reduction of 74% by 2030, emissions from the agricultural and LULUCF sectors are consequently expected to constitute around half of Denmark's total emissions by this time. Thus, regulation of these emissions are pivotal to the country reaching its climate goals – both for 2030 and in the longer run.

1.1 Carbon taxation in Denmark

Although Denmark has had a carbon tax since the early 1990s, the taxation of emissions has been very uneven across sectors and emission sources (Klimarådet 2022).[4] In 2022, the national carbon tax was reformed – based on the recommendations of an Expert Group on Green Tax Reform (Ekspertgruppen for en Grøn Skattereform 2022) – with an increased focus on emissions from the industrial sector. This led to a more uniform carbon tax rate, an expansion of the tax base and a substantial increase in the carbon tax rate going forward: when fully phased in, the tax rate is set to reach €100 (DKK 750) per tCO_2e in 2030, though numerous exceptions exist to the uniform rate.[5]

While the 2022 reform expanded the tax base for Denmark's carbon tax, a range of sectors were left out – most prominently the agricultural and LULUCF sectors. Consequently, non-energy emissions from these two sectors

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[3] Around half of this decline (4.4 $mtCO_2e$) stems from increased carbon stock in forests; roughly 20% (1.7 $mtCO_2e$) from drained organic soils releasing their stored carbon into the atmosphere and so ceasing their emissions; approximately 10% (1.1 $mtCO_2e$) from decreased emissions from energy use; and the remainder (2.1 $mtCO_2e$) from reduced N_2O and CH_4 emissions arising from husbandry and fertiliser use. At the time of writing, 2022 is the latest available historical year with consolidated data.

[4] For further background on Denmark's CO_2 Tax Act, see: https://info.skat.dk/data.aspx?oid=2060515.

[5] Exceptions are the Emissions Trading Scheme (ETS) sectors and non-energy emissions outside the ETS sectors, heating and transportation.

remain exempt from carbon taxation. The sectors not covered by the reform are set to be addressed in another round of legislation in 2024, which will rely on a second report by the Expert Group published in February 2024 (Ekspertgruppen for en Grøn Skattereform 2024). The new recommendations revolve around three taxation 'models', each with a different emphasis:

- The first model emphasises achieving reduction targets at the lowest social cost. In short, it achieves reductions through a €100 per tCO_2e tax on emissions from enteric fermentation, manure management, manure applied to fields, inorganic fertilisers applied to fields, and liming.
- The second model emphasises achieving reductions while also cutting carbon leakage, as well as mitigating the structural effects of the tax. Like the first model, the marginal tax rate is set at €100 per tCO_2e, but farmers can secure so-called 'bottom deductions' per animal and per hectare of farmland, resulting in an effective tax rate of €50 (DKK 375) per tCO_2e.
- The third model puts an even higher emphasis on reducing carbon leakage and mitigating the tax's structural effects. Thus, the marginal tax rate on emissions from enteric fermentation and manure management is reduced to €33 (DKK 250) per tCO_2e. It is envisaged that the lost reductions caused by the lower marginal tax rate will be offset by a subsidy for negative emissions arising from the production and storage of biochar.

Across all three models, the Expert Group recommends schemes for re-wetting organic soils and subsidies for afforestation.

At the time of editing (October 2024), political negotiations are ongoing with respect to an implementation of a carbon tax on the Danish agricultural sector. Nothing is settled yet, but all things point towards a political agreement that could be characterized as a softer version of this papers "Scenario 3". The headlines are a tax of €40 per tCO_2e (in 2030) on livestock emissions with a 60 percent bottom deduction along with subsidies for afforestation, re-wetting of organic soils as well as technology subsidies.

Politically, the softer approach has been made feasible by the development in the latest Danish green-house-gas emissions forecast: the Climate Outlook 2024. The present analysis uses the Climate Outlook 2023 as its vantage point. In the 2023-projections the outstanding reductions were more than 4 $mtCO_2e$. In the 2024-projections the outstanding reductions have been reduced to 1.5 $mtCO_2e$, with the biggest drivers of change being revisions of uptake in forest (-1.7 $mtCO_2e$), emissions from organic soils (-1.8 $mtCO_2e$), and waste incineration (+1.0 $mtCO_2e$). Though projections and reduction targets have changed, the economic forecast for agriculture has not changed much with the Climate Outlook 2024. Furthermore the organic soils emission in the present analysis was updated in the last minute to reflect 2024-data. Lastly, even though forest-uptakes have been revised with the Climate Outlook 2024, the expected uptakes from afforestation has (the revision of forest uptakes is only a revision of uptake in forests-remaining-forest). We therefore maintain that the reduction-effects in the present analysis largely remains up-to-date and relevant.

1.2 Scope and structure of the chapter

In analysing how different regulation schemes affect both Denmark's macroeconomy, agricultural production and its emissions, the chapter sets out to answer the following questions:

- What are the effects (both on the macroeconomy, agricultural production and emissions) of a regulation incentivising a reduction of agricultural and LULUCF emissions at the same tax rate as that imposed on industry (€100 per tCO_2e), i.e. the same tax rate as in the first model of the Expert Group?
- How are these effects impacted if the concept of a uniform carbon taxation is abandoned, and a lower tax rate is levied on the agricultural sector than on the industrial sector? Further emission reductions in the agricultural sector could then be pursued by subsidising abatement technologies (e.g. feed additives reducing methane emissions from enteric fermentation), thereby mitigating some of the economic burden on farmers.
- Finally, how will the economic (income, employment) and environmental (nitrogen leaching) effects of the various regulation schemes differ across Denmark's regions?[6]

Our analysis has been carried out using the same workhorse model as in the second report of the Expert Group, namely the GreenREFORM model. The model was developed with the aim of bridging the gap between economic and environmental policies, and so can be used to analyse how, for example, climate policies affect the macroeconomy and vice versa. It consists of a dynamic multisector computable general equilibrium (CGE) model, with sub-models that compute agricultural production and non-energy-related emissions (mainly nitrous oxide and methane) and LULUCF emissions (mainly CO_2), as well as how the two interact.

Three main scenarios for carbon tax and subsidy schemes were developed, involving a carbon tax on non-energy emissions from agriculture and LULUCF of between €50 and €100 per tCO_2e, supplemented by different subsidy schemes. Although these policy scenarios resemble those of the Expert Group on Green Tax Reform, they differ – most importantly – in terms of the applied export elasticities. All the analyses give results for Danish climate obligations, regional effects (employment and nitrogen leaching), and standard macroeconomic variables such as the gross domestic product (GDP) components.

As will be elaborated on in remaining sections, our results show that imposing a carbon tax of €100 per tCO_2e (Scenario 1) will reduce agricultural emissions by almost 2 $mtCO_2e$ by 2030, with agricultural production falling alongside reduced demand arising from higher Danish food product prices. The decline in production will be most pronounced in the cattle sector, which has the greatest baseline emissions intensity, translating into a loss of around 5,000 agriculture and food industry jobs. With cattle – and husbandry more generally – concentrated in Jutland, 90% of these lost jobs will be situated there. Crop and vegetable prices will only undergo a limited rise, as land prices will decrease due to higher production costs. The tax will only have a limited effect on the total area of agricultural land in production.

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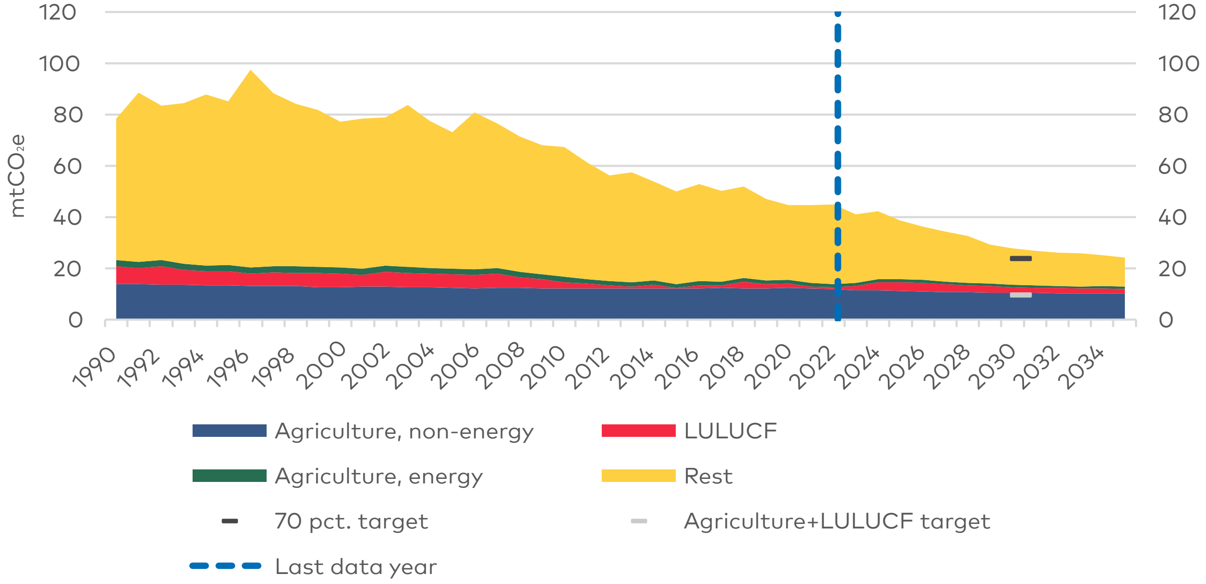
[6] Section 2.4 elaborates on what nitrogen leaching is, as well as its environmental impact.

Figure 1. Danish greenhouse gas emissions and reduction targets, past (1990-2022) and projected (2023-2035) trends



Source: Danish Energy Agency (2023), Regeringen et al. (2021) and Lov om Klima (2020).

Adding subsidies to afforestation and the wetting of carbon-rich soils (Scenario 2) increases emission reductions by 0.4 $mtCO_2e$ in 2030, making for a total reduction of 2.3 $mtCO_2e$.[7] Most of this additional reduction stems from wetting carbon-rich soils, since afforestation has a limited effect on short-term emissions. Carbon uptake will increase in the longer term. Reducing the tax rate to €50 alongside an emphasis on subsidising emission-reducing technologies (Scenario 3) will increase emission reductions by around 0.6 $mtCO_2e$ compared to Scenario 2. Hence, subsidies to technological emission reductions more than offset the effect of the reduced tax rate, which also mitigates the impact on agricultural production and employment.

The remainder of the chapter proceeds as follows. Section 2 outlines the Danish context for climate policies targeted at agricultural and LULUCF emissions. Section 3 then describes the GreenREFORM model, particularly the sub-models for agriculture and LULUCF. Next, section 4 presents the model results from our three primary policy scenarios, together with perspectives on the regional economic and environmental effects. To assess the robustness of the model results, we conducted multiple sensitivity analyses that evaluate the

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[7] When organic soils are kept underwater – as they were before being drained – carbon does not react with the oxygen in the air, thus preventing emissions.

effects of altering core parameters and assumptions – these are covered in section 5. Finally, section 6 discusses the results before providing some concluding thoughts.

2. Agricultural and LULUCF sectors in Denmark

2.1 Emissions and reduction targets

Agricultural and LULUCF emissions constitute a large share of Denmark's total emissions, with this share expected to increase over the coming years given current policies (Figure 1). In 2022, non-energy-related emissions from the agricultural and LULUCF sectors constituted 28% of Denmark's total emissions (12.6 mtCO_2e out of 44.8 mtCO_2e). By 2030, while emissions from these sectors are expected to remain largely unchanged (12.0 mtCO_2e), their share of total emissions will have increased to 46% due to declining emissions in other sectors.[8] Against this backdrop, the following sub-sections set out the Danish context in terms of agricultural and LULUCF emissions and reduction targets, as well as the emissions regulation, economic importance and regional distribution of these sectors. Here, it is worth highlighting the fact that the current Danish government has explicitly stated in their Vision for Government that climate targets shall be achieved *without impacting the competitiveness of the agricultural sector* (Regeringen 2022, p. 29).

As mentioned in the introduction, the Climate Law passed by the Danish parliament in 2020 specified a 70% reduction in total emissions by 2030 compared to 1990 emission levels (Lov om klima 2020). The target implies that total emissions in 2030 should be below 23.5 mtCO_2e – given the projected emissions level of 27.7 mtCO_2e, there remains a shortfall in reduction efforts of 4.2 mtCO_2e. Furthermore, the agricultural agreement made in 2021 set a reduction target – based on the same timescale – of 55–65% for the agricultural and LULUCF sectors (Regeringen et al. 2021). This target implies emission reductions of 3.3–5.4 mtCO_2e by 2030 compared to the baseline scenario.

Aside from these national targets, the EU has set reduction obligations for Denmark under the Effort Sharing Regulation (ESR) and LULUCF Regulation. The ESR sets binding annual GHG emission targets for the included sectors, including agriculture.[9] These mean that by 2030 Denmark must achieve a 50% reduction in emissions from ESR sectors compared to 2005 levels. The LULUCF Regulation imposes a 'no debit' rule for the period 2021–2025, meaning Denmark has to ensure emissions from land use are compensated for by equivalent reductions. By 2030, Denmark must reduce net emissions from the LULUCF sector by 0.44 mtCO_2e compared to the years 2016–2018.

2.2 Regulation of emissions

Historically, non-energy GHG emissions from agricultural production and LULUCF emissions have largely gone un-

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[8] These expectations are contained in the 'Climate Outlook 2023' (Danish Energy Agency 2023), an annual publication containing the official Danish projection of GHG emissions. Up until 2023, the publication was produced by the Danish Energy Agency. From 2024 onwards, however, responsibility for the publication will rest with the central administration in the Ministry of Climate, Energy and Utilities.

[9] The full list of regulated sectors under the ESR encompasses domestic transport (excluding aviation), buildings, agriculture, small industry and waste.

Table 1. Emissions, employment and gross value added in agriculture and food industries, 2019

	Emissions		Employment		Gross value added (GVA)	
	Million tonnes	Share of total (%)	1,000 persons	Share of total (%)	€ (billions)	Share of total (%)
Agriculture	16.5	29.0	65.0	2.2	3.4	1.3
Agriculture and food industries	17.4	31.0	112.9	3.9	7.6	2.8

Note: Agriculture includes LULUCF emissions as well as employment and GVA from the forest sector. Emissions include both energy-related and non-energy-related emissions. We look at 2019 data, as it is the last consolidated data year in the national accounts.
Source: Danish Energy Agency (2023) and Danish National Accounts.

regulated in Denmark. Most regulation of the agricultural sector does, however, have indirect effects on such emissions. Here, examples include restrictions on manure applied to fields, local restrictions on expansion of husbandry, requirements on fallowed areas, and regulation of nitrogen leaching to coastal waters. Meanwhile, LULUCF emissions have to some extent been regulated through afforestation subsidies, as well as subsidies for flooding carbon-rich soils since 2015 (Ministeriet for Fødevarer, Landbrug og Fiskeri 2015).

In 2020, the Danish parliament agreed to form the previously mentioned Expert Group on Green Tax Reform tasked with examining possible models for introducing a uniform carbon tax (Regeringen et al. 2020). The Expert Group duly published its first report on the carbon taxation of industrial processes in February 2022, leading to an agreement being adopted by parliament in June 2022 (Ekspertgruppen for en Grøn Skattereform 2022). Following this, a second and final report was published in February 2024 focused on the regulation of non-energy emissions from the agricultural and LULUCF sectors (Ekspertgruppen for en Grøn Skattereform 2024).

2.3 Economic importance

Economically, the agricultural sector plays a smaller role in Denmark relative to its share of Danish emissions, with the same holding true when measuring employment. As shown in Table 1, agricultural gross value added (GVA) was €3.4 billion in 2019, equating to 1.3% of total GVA in Denmark (Table 1). Total employment in agriculture was 65,000 persons, constituting 2.2% of total employment. It is often argued that the food processing industries should be included when measuring agriculture's importance to the Danish economy – doing so would increase GVA to 2.8% and total employment to 3.9%.

As previously noted, despite non-energy-related agricultural emissions constituting a significant part (approximately 28%) of Danish emissions, they remain subject to only limited regulation. Here, a strong argument against further regulation is carbon leakage: in other words, if Denmark reduces its emissions through lower agricultural production levels, then production and emissions will simply increase elsewhere in the world. Hence, carbon leakage becomes an argument for driving climate mitigation through subsidies – thereby maintaining production levels – rather than taxation.[10] It should be noted, however, that some studies have found carbon leakage rates to be substantially below 100% for the agricultural sector (De Økonomiske Råds formandsskab 2021, Beck et al. 2023).

2.4 Regional distribution

Given the majority of Danish GHG emissions are at this point regulated by a carbon tax, any expansion of regulation to encompass agriculture and LULUCF is likely to increase the cost-efficiency of meeting reduction targets. Even so, reductions still come at a cost, which will not be evenly distributed among Danish households. Rising food prices disproportionately hit low-income household budgets, factory workers in the food industries will lose their jobs, and the least profitable farmers will go bankrupt. As Table 2 demonstrates, these characteristics – being a low-income household and/or food industry factory worker or farmer – correlate strongly with living in the more rural parts of Denmark.

In Northern Jutland, 6.1% of the regional workforce was employed in primary agriculture or the food processing industries in 2019.[11] This represents the highest proportion of the total regional workforce employed in these two sectors across all regions. People from Northern Jutland also had the lowest wage levels of all Danish regions. At the other end of the spectrum, the capital region only employs 0.3% of its workforce in the agriculture and food industries and has the highest wage levels.

Aside from regulating GHG emissions, a carbon tax on agriculture has spill-over effects on other agriculture-related externalities, such as nitrogen leaching and ammonia emissions. Nitrogen leaching in particular has repeatedly attracted media attention in Denmark due to its adverse effects on marine wildlife through oxygen depletion of coastal waters.[12] Table 3 shows the present situation and projected status in 2027 for Danish coastal areas

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[10] Carbon leakage was also considered in the re-shaping of the national carbon tax on industry in 2022. Different models were suggested by the Expert Group on Green Tax Reform. In models focused on limiting leakage, a reduced tax rate (€17, or DKK 125, per tCO_2e) on the mineral industry combined with subsidies for carbon capture and storage (CCS) were put forward. The final legislation (*Grøn Skattereform for industri mv. (24. juni 2022)*) adopted this emphasis on reducing leakage and applied a reduced tax rate on the mineral industry, as well as subsidies for CCS.

[11] 2019 is the most recent year with fully consolidated national accounts data.

[12] Nitrogen leached from agricultural soils works as a fertiliser for the sea, spurring, in particular, algae growth. When this additional algae dies, it is broken down by aerobe bacteria on the sea bed. This process depletes coastal waters of oxygen, and in severe cases leads to the death of marine wildlife in affected areas. For further background and information on how, in 2023, Denmark experienced the worst case of oxygen depletion in 20 years, see the Danish Environmental Agency website (https://mst.dk/erhverv/rent-miljoe-og-sikker-forsyning/vandmiljoe/havet/iltsvind and https://mst.dk/nyheder/2023/september/markant-forvaerret-iltsvind). From a search in the online archives of the newspaper Politiken we have compiled a few examples of media coverage of oxygen depletion in Denmark from the past decade: (1) 'Oxygen depletion is developing rapidly', 29 September 2020, https://politiken.dk/danmark/art9550358/%C2%BBIltsvindet-udvikler-sig-virkelig-hurtigt%C2%AB; (2) 'Oxygen depletion is on its highest level in 20 years', 2 October 2020, https://politiken.dk/klima/art7948265/Iltsvind-i-danske-farvande-er-p%C3%A5-h%C3%B8jeste-niveau-i-20-%C3%A5r; (3) 'Impactful oxygen depletion in deep Danish waters', 31 August 2018, https://politiken.dk/danmark/art6682402/Kraftigt-iltsvind-pr%C3%A6ger-dybe-danske-farvande; and (4) 'Fish and lobsters in bulk numbers washed ashore in Limfjorden', 17 June 2014, https://politiken.dk/danmark/art5521076/D%C3%B8de-fisk-og-hummere-i-hobetal-driver-i-land-i-Limfjorden.

Table 2. Employment in Danish agriculture and food industry (2019)

Region	Agriculture and food industries (1,000s employed)	As percentage of employment in region	Total (1,000s employed)	Average hourly wage (€ per hour)
Copenhagen and larger area	2.6	0.3	956.2	47.7
Zealand	10.8	2.7	403.5	40.4
Southern Denmark	34.0	5.8	589.7	40.9
Mid-Jutland	32.3	4.8	669.9	41.4
Northern Jutland	17.4	6.1	284.9	40.0
Total	97.0	3.3	2,904.2	43.4

Note: Data for the regional distribution of employment comes with a relatively high degree of uncertainty. To split the national employment data for the primary agricultural sectors, we rely on tables from Statistics Denmark combined with own assumptions. For food industry, we collected data from Paqle, combined with numbers taken from Danish Crowns website.
Source: For agriculture, Statistics Denmark tables (LONS30, RAS310, JORD1), authors' own assumptions and calculations in the GreenREFORM model. For food industry, authors' own queries on www.paqle.dk and Danish Crowns website, conducted in January 2024.

in terms of reaching a 'good environmental status' under the EU's Water Framework Directive (WFD) Currently, Denmark is obliged to reduce nitrogen leaching in 78 out of 108 coastal areas, with a total reduction need of 13 ktN per year. The table also shows the projected status in 2027 under existing policy. A good environmental status is expected to be reached in most coastal areas under a frozen policy scenario. Only 18 out of 108 coastal areas are expected to have a reduction need in 2027, with a total nitrogen reduction need of 2.8 ktN per year.

Turning to ammonia emissions, ammonia reacts with various compounds in the atmosphere to form particle matter smaller than 2.5 microns in width ($PM_{2.5}$), which has been linked to chronic respiratory illnesses and premature mortality (Wyer et al. 2022). Ammonia is carried by the wind to neighbouring countries, with more than 78% of the adverse effects on human health caused by Danish ammonia emissions estimated to take place beyond the country's borders (Brandt et al. 2023). Table 4 shows the current projected ammonia emissions in 2030, as well as the estimated health-costs associated with these emissions. Regulations that reduce fertiliser use will have a positive impact on nitrogen leaching and ammonia emissions as shown in the analyses in section 4.

3. Model and data description

This section provides a full description of the GreenREFORM model, together with the agricultural, abatement and

Table 3. Nitrogen leaching, current status and 2027-projection

	Current status (Average of 2016-2018)	Projected status (2027)
Number of coastal areas with a reduction need	78 out of 108	18 out of 108
Total reduction need, ktN per year	13.0	2.8

Source: Data graciously shared with the authors by the Danish Environmental Protection Agency.

Table 4. Ammonia emissions (2030) and incurred costs to society

Total ammonia emissions from agriculture (kt NH_3)	Incurred costs to Danish residents, billion EUR	Incurred costs to foreign residents, billion EUR
59.6	0.1	0.3

Note: Effects on Danish residents are 22 per cent of total incurred costs, cf. Table 10 in the source.
Source: Brandt et al. (2023).

LULUCF sub-models used to supplement it.

3.1 The GreenREFORM model

The core of GreenREFORM is a dynamic CGE model, as shown in Figure 2. The CGE model builds on an extended version of the national accounts provided by Statistics Denmark, which disaggregates input-output (IO) tables into 146 sectors instead of the usual 117. For example, the single agricultural sector used in the standard version of the national accounts is split into 13 sectors in the extended version.[13]

Each sector is modelled using a generic constant-elasticity-of-substitution (CES) production function, with capital and energy modelled as complementary. Each sector's energy use is divided into six purposes – 1) transportation; 2) internal transportation; 3) special processes; 4) normal processes; 5) in the emissions trading scheme (ETS); and 6) heating – and split into 26 different energy inputs.[14] The complementarity of energy and capital arises due to the assumption that each sector's representative firm will react to changes in energy prices by switching its production technology to the lowest-cost alternative, with the change in technology based on smoothed marginal abatement cost curves (Berg et al. 2021). The method is implemented utilising data from the technologies (so-called 'technology catalogues') used in producing official Danish emission forecasts. In other words,

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[13] In the GreenREFORM model, the 146 sectors are aggregated into approximately 60 sectors.

[14] 'Special processes' encompasses energy used for mineralogical processes, metallurgical processes, electrolysis, chemical reactions and large-scale horticulture, as well as energy used for the production of electricity and district heating not in the ETS. 'Normal processes' refers to energy not used for heating or special processes.

the abstract modelling of abatement through elasticity of substitution is replaced by abatement through changes in well-described real technologies. Such modelling is useful for the purposes of this chapter, as it provides better estimates when evaluating different levels of taxation and/or subsidies aimed at incentivising technological abatement.

To allow for a more detailed description of environmental and climate effects, the CGE model is accompanied by multiple sub-models. While some sub-models add information to the model (e.g. the LULUCF sub-model), others change the structure of some of the production sectors already accounted for in the CGE model – this is the case for the agricultural model or the above-mentioned abatement technologies. All the sub-models are partial equilibrium models that can be solved independently or simultaneously in combination with the CGE model. For the present analysis, the CGE core was enriched by the agricultural model, the bottom-up technology model tailored specifically for the agricultural model, and the LULUCF model.

3.2 The agricultural sub-model

The agricultural sub-model describes agricultural production and emissions in more detail than the CGE model. Agricultural production is divided into ten different sectors: three of these describe crop and vegetable production; six describe livestock production; and the remaining one describes agricultural contractors hired by the other sectors as a production input.[15] Both crop and livestock production consists of conventional and organic sectors. The production flows of the agricultural sectors are depicted in Figure 3, while Beck et al. (2020) and Stewart and Berg (2023) describe the agricultural model in more detail.

The crop sectors (conventional crops, organic crops and horticulture) produce four goods: 1) a generic non-energy crop composite (e.g. different grains); 2) energy straw; 3) a coarse feed composite; and 4) straw-bedding. The former two are used by other sectors of the economy, including the food industry and agricultural sectors, as well as for final consumption. Flows of these goods are accounted for in the IO tables in the national accounts.[16] Coarse feed and straw-bedding are not represented in the national accounts, but are accounted for in the Agricultural Accounting Statistics, as they are partly comprised of deliveries within the same farm. It is assumed that these products are only delivered to the livestock sectors (organic and conventional cattle, poultry and pigs).

The production structure of the crop sectors (see Appendix B, Figure B1) is modelled using a nested CES production function. The crop sectors use agricultural land as a production input and so compete in the land market over the total amount of agricultural land available (the determination of which

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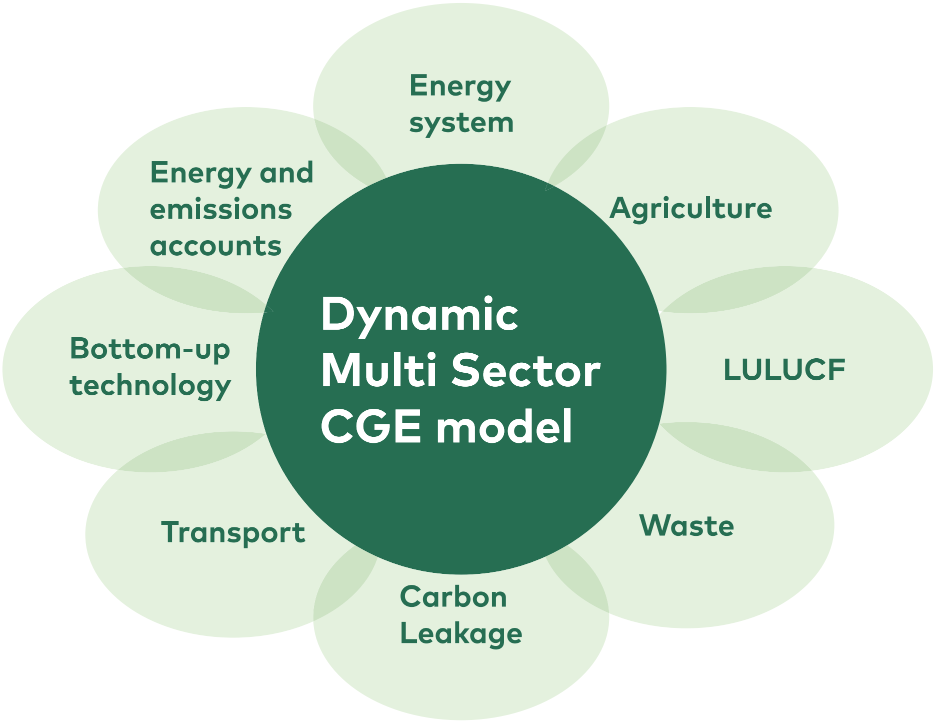
[15] The 13 sectors in the extended national accounts are reduced to 10 sectors in the GreenREFORM model. Cattle related to conventional dairy production and conventional meat production are aggregated into a single sector, with the same applying to their organic equivalents, thus reducing the number of sectors to 11. Additionally, given ‘fur animals’ is almost entirely consisting of the production of mink, and since all mink in Denmark were culled during the COVID pandemic, the sector is removed from the model’s forecasts.

[16] See: www.dst.dk/grønreform.

Figure 2. Overview of the GreenREFORM model



Source: Authors' own illustration.

is described in the *endogenous amount of land* sub-section below). Furthermore, the crop sectors use fertilisers and chemicals as production inputs. Fertilisers may be comprised of manure from the livestock sectors and/or inorganic fertiliser from the chemical industries.[17]

The livestock sectors (organic and conventional cattle, poultry and pigs; Figure 3) produce two goods: manure and a non-energy composite animal good. As with the crop sectors, the composite good is used by a range of sectors in the economy, as well as for final consumption. Manure is assumed to be used only by the crop sectors and is not accounted for in the national accounts. The production structure of the livestock sectors (see Appendix B, Figure B2) differs from the other sectors, as animals, straw-bedding and animal feed are used as production inputs – these are modelled proportionately to building stock.

Non-energy-related emissions

Non-energy-related emissions, which constitute the majority of agricultural sector emissions, are modelled as being proportional to the emitting inputs. Non-energy-related emissions in 2030 are shown in Table 5, which also contains emission intensities calculated as emissions divided by production values in the baseline scenario.

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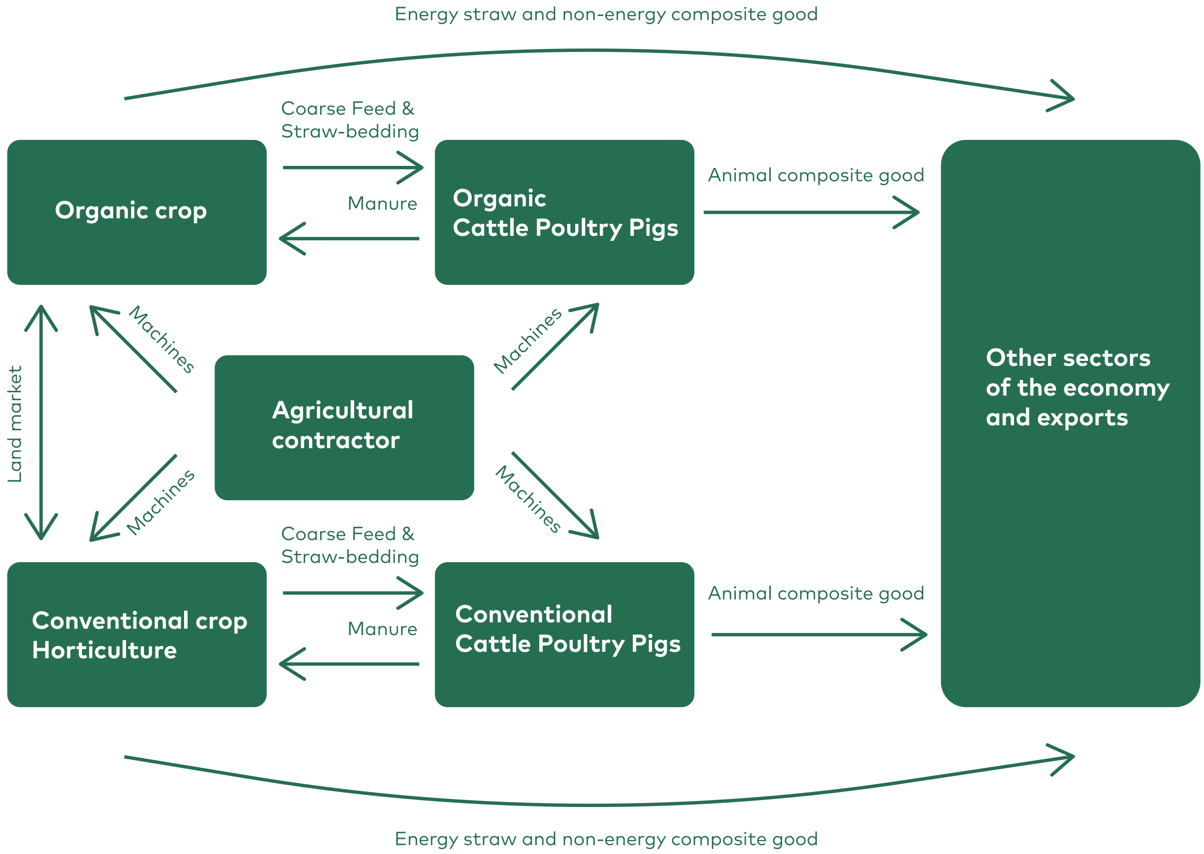
[17] For organic crop production, only manure enters the production function.

Figure 3. Intra-agricultural flows



Source: Beck et al. (2020).

Emission intensities are pivotal to understanding the effects of a carbon tax. The majority of emissions stem from conventional crop production, conventional cattle and conventional pigs, which are also the three largest sectors measured by production value. Within the crop sectors, the main emission categories are fertiliser use; crop residues; nitrous oxide from leaching; and nitrous oxide from organic soils in production. The production inputs responsible for emitting in the model are fertilisers (both organic and inorganic) and agricultural land. For the livestock sectors, the main emission categories are enteric fermentation and manure management, with all emissions linked to the number of animals in production in the model.

Emission intensities are greatest in conventional and organic cattle production.[18] Hence, these sectors are expected to increase prices the most should a uniform carbon tax be introduced. Organic sectors generally have lower emission intensities than their conventional counterparts. This is due, among other things, to organic producers being able to obtain higher output prices compared to conventional producers.

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[18] Defined as emissions per value of production (see Table 5).

Endogenous amount of land

The modelling of the land market – which sets out to capture the heterogeneity of geography, soil quality etc. – distinguishes the GreenREFORM model from the other macroeconomic models normally used for policy analysis in Denmark, which simply depict each sector as an average. The underlying assumption is that the productivity of agricultural land varies, meaning that if a tax were imposed on, say, emissions, some pieces of land would be rendered unprofitable.

The land market is modelled as a two-step procedure (Stewart et al. 2023). Firstly, the total amount of agricultural land in production is determined by a 'land withdrawal function' based on heterogeneity in land productivity. In other words, agricultural land will be taken out of production if an alternative option – such as fallowing, afforestation or flooding of carbon-rich soils – is more profitable.[19] Secondly, the total amount of available land allocated to the three crop sectors is determined based on their relative willingness to pay for the land.

Food industries and market conditions

The IO tables of the national accounts reveal considerable interdependence between the agricultural sectors and the food processing industries. This is especially true for the livestock sectors and the dairy and meat processing sectors. Most of the livestock sectors' outputs are delivered to the dairy and meat processing sectors, which use only very limited amounts of imported agricultural products. This means the effects of a carbon tax on agricultural emissions is very much dependent on how the market conditions of the food industries are modelled.

The market structure built into the GreenREFORM model is based on export elasticities empirically estimated using the BACI dataset, which enables extremely detailed product-level estimates.[20] For example, we estimate export elasticities on 20 different products (e.g. cheese, butter, milk powder), which are then weighted into an average export elasticity for the dairy sector. We also estimate export elasticities for the agricultural sectors' direct exports – in the cases of pigs and poultry, the estimated direct exports are significant (27% and 17% respectively in 2030). Nevertheless, the main driver of the model's results – even for pigs and poultry – is Denmark's food industries, where the majority of the country's agricultural production is processed.

The estimated export elasticities are shown in Table 6. The fact that all elasticities are below -10 and most are around -5 indicate that Denmark's food industries have some degree of market power when exporting food products. That is, demand for their products will not vanish completely if prices are increased – which is the claim often made by opponents of a carbon tax on agriculture. Various factors explain the empirical result, one of which is that Danish companies are able to exert pricing-to-market, thereby allowing them to sell to the markets with the highest prices (Stephensen et al. 2023).

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[19] Fallowed land can still receive EU subsidies if kept as agricultural land.

[20] For more information about the dataset used, see the BACI website: www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37.

Table 5. Non-energy related emissions and emission intensity for agricultural sectors, 2030

	Emissions, mt CO_2e	Production value, billion EUR (2019 prices)	Emission intensity, tCO_2e per million EUR
Crop and vegetable production, conventional	3.5	1.9	1,816
Crop and vegetable production, organic	0.4	0.3	1,258
Horticulture	0.0	0.4	29
Cattle, conventional	3.8	1.8	2,103
Cattle, organic	0.8	0.4	1,878
Pigs, conventional	1.6	2.2	754
Pigs, organic	0.0	0.1	434
Poultry, conventional	0.0	0.3	91
Poultry, organic	0.0	0.1	74

Source: Statistics Denmark, Climate Outlook 2023 and authors' own calculations.

3.3 Abatement technologies

Some non-energy emissions from the agricultural sectors can be abated using technology. For instance, the feed additive Bovaer reduces methane emissions from enteric fermentation in cattle by supressing the enzyme in the cows rumen that combines the hydrogen and carbon dioxide to methane. These technologies are modelled using a *bottom-up approach*, as is the case for abatement technologies in the rest of the model (Beck & Kirk 2020, Stephensen et al. 2020). The main idea behind the approach is to model technologies as approximately discrete choices, as is the case in engineering models. This is in contrast to the normal *top-down approach* in CGE modelling, where technological adaptation is modelled through substitution elasticities in the production functions. Technologies used to abate agricultural non-energy emissions are modelled as end-of-pipe technologies, implying that while the emitting input is kept in production, its emission coefficient is reduced (Stewart & Kirk 2024).

The cost of technologies is fed back into the model as increased demand from other sectors. The standard assumption is that technology costs are related to increased capital demand, but the approach employed in this chapter allows for a more detailed description of technology costs. The technologies used in the current version of the model are shown in Appendix A, Table A1.

3.4 The LULUCF sub-model

GreenREFORM's LULUCF sub-model, which revolves around tracking land use and changes in land use, largely repli-

Table 6. Export elasticities for agriculture and food industry sectors, 2030

	Elasticity	Export share of production
Agricultural sectors		
Crop and vegetable production, conventional	-4.1	37.7%
Crop and vegetable production, organic	-3.0	33.4%
Horticulture	-3.1	19.1%
Cattle	-3.9	2.9%
Pigs	-4.0	29.8%
Poultry	-8.5	18.8%
Food industries		
Production of meat and meat products	-5.0	61.8%
Fishing industry	-3.9	69.1%
Dairy products	-5.4	54.1%
Manufacture of grain mill and bakery products	-9.7	26.6%
Other food industries	-5.6	42.1%

Source: Kirk & Hansen (2023).

cates the official models and methods used to produce Denmark's National Emissions Inventory and its Climate Outlook.[21] The total area of Denmark is split into 12 area categories. These are displayed in Table 7 below, which not only highlights that Denmark is an agricultural land – with roughly 65% of its area designated for agricultural cultivation ('cropland') – but that crop- and grasslands are responsible for significant levels of GHG emissions.

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[21] The Climate Outlook is the official forecast of the National Emissions Inventory. While the LULUCF sub-model encompasses the major sources and sinks in the LULUCF sector, it abstains from modelling the smaller sources and sinks. This modelling choice is made to minimise run-time, while also providing a more accessible model for the end-user. For further detail on the LULUCF sub-model, see the model documentation in Beck and Berg (2023).

LULUCF emissions

Aside from the case of forestry (and a few smaller exceptions), LULUCF emissions are modelled as an emission coefficient multiplied by the area of a particular land use or the change in land use from one area category to another. The most prominent example of this simple modelling are the emissions from drained organic soils, which are the categories 'OC (organic carbon) 6–12%' and 'OC>12%' on both crop- and grasslands in Table 7.

For forestry, emissions are computed as the change in carbon stock. The carbon stock – which consists of stock above ground (stem and canopy), below ground (roots), and in deadwood and forest litter – is modelled as a Markov-chain, whereby forest adhering to certain specifications (e.g. conifers in Jutland aged 10–15 years) transitions to its subsequent age class with a survival probability.[22] Forest that does not 'survive' is renewed as the same species in the 0–5 years age class. Thus, the forest produces an in-flow of harvested wood products (HWP), with emissions in this sector equating to the difference between this in-flow and the depreciation of HWP stock.[23]

Links to the rest of the model

HWP can be divided into two major categories: use wood and energy wood. The flow of these two types is linked to the rest of the model, which determines the domestic supply of use wood and energy wood. The supply of use wood and energy wood is therefore largely fixed to the logging patterns implied by the forest model's survival probabilities. In order to allow prices to clear the markets of use wood and energy wood, the margin (mark-up) between the costs of maintaining/renewing the forest and the prices of the wood products is endogenised.[24]

The exception to use and energy wood supply being completely fixed is afforestation on agricultural land. As discussed in section 3.2, the model's representative farmer faces a choice between, on the one hand, long-term land returns from farming and, on the other, returns from a range of competing land allocations – one of which is afforestation. Thus, land on which afforestation yields the highest return is converted to forest. Perhaps unsurprisingly, sizeable subsidies are required if afforestation is to compete with extensive farming, as well as other uses covered by the EU's common agricultural policy.

4. Results

This section presents the results arising from three main scenarios in which carbon taxes of between €50 and €100 per tCO_2e are levied on non-energy emissions from agriculture and LULUCF, supplemented by different subsidy schemes. We follow the Expert Group on Green Tax

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[22] Forest litter refers to the layer of non-living organic debris, e.g. leaves, bark, twigs, flowers, fruits and other vegetable matter.

[23] The forestry model replicates the official model used in the Climate Outlook and was developed by researchers at the Department of Geosciences and Natural Resource Management at the University of Copenhagen (Johannsen et al. 2022).

[24] It is a long-term ambition to implement a degree of price reaction in the timing of forest renewal, rather than – as is currently the case – the timing of forest renewal being solely determined by the Department of Geosciences and Natural Resource Management's estimated survival probabilities.

Table 7. LULUCF sector areas and emissions, 2022

Aggregate land-categories	Land-categories	Thousand hectares	Share of total area (%)	Total emissions (mio. tCO_2e)
Cropland	Cropland, OC under 6%	2,752	63.9	0.12
	Cropland, OC between 6-12%	28	0.7	0.63
	Cropland, OC over 12%	11	0.2	0.48
Grassland	Grassland, OC under 6%	88	2.1	0.02
	Grassland, OC between 6-12%	43	1.0	0.73
	Grassland, OC over 12%	35	0.8	1.18
	Other	26	0.6	
Forest	Forest	615	14.3	-2.22
	Christmas Trees	30	0.7	(Reported under 'Forest')
Settlement	Settlement	545	12.6	0.28
Wetland	Wetland	72	1.7	0.03
	Water	59	1.4	0.02
	Total	4,306	100	3.05

Note: Cropland and grassland areas are split into three subdivisions based on the level of organic carbon (OC) in the soil.
Source: Background data from the Danish Climate Outlook 2023 (Klimafremskrivning 2023). For organic soils, emissions have been adjusted based on revised data in Beucher et al. (2023).

Reform in refraining from levying a tax on selected emissions considered especially difficult to tax in practice.[25] In the crop sectors, we tax approximately 50% of non-energy-related emissions, which are primarily related to fertiliser use (both manure and inorganic fertilisers). In the livestock sectors, we tax emissions related to enteric fermentation, manure management and deposition

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[25] Emissions exempt from a carbon tax encompass those stemming from crop residues and mineralisation, as well as N_2O from leaching, histosols and indirect N_2O emissions.

from grazing animals, which constitute 99% of non-energy-related emissions.

4.1 Scenario 1: Tax on agricultural emissions

Under Scenario 1, a carbon tax of €100 per tCO_2e is announced in 2024, then phased in linearly from 2027 to 2030. The tax focuses specifically on non-energy emissions from agriculture, with LULUCF excluded. The government budget is kept unchanged compared to the baseline, with the tax revenue given back as a lump-sum transfer to households.

Production response

In order to put the model predictions into perspective, it is useful to do some simple computations based on baseline production and emissions. In this case, tax revenue before behavioural effects (i.e. multiplying the tax rate by baseline emissions) amounts to €0.8 billion in 2030 – or 31% of baseline GVA. Furthermore, simply adding the carbon tax to the final prices of agricultural products in baseline yields a price increase of 10%, although this covers a wide distribution – ranging from 20.2% in cattle production to 0.3% in horticulture (see the 'Price change before behavioural change' column in Table 8).

We now turn to the actual model predictions – i.e. what happens in economic equilibrium, where all behavioural adjustments have taken place. In the case of the livestock sectors, the equilibrium price change after behavioural effects is similar to the change before behavioural effects are accounted for, although the former is lowered somewhat by the ability of these sectors to adopt emission-reducing technologies. This ability is greatest in conventional cattle farming, where feed additives are assumed to reduce emissions from enteric fermentation.[26] The remainder of the price increase is, however, passed on in the supply chain, leading to a significant drop in demand and production (see column "Quantity change in equilibrium" which reports the drop in demand/production).

By contrast, the equilibrium price change for the crop and vegetable sectors is very limited. This is because the tax lowers the price of agricultural land, thereby neutralising some of the tax's effect (land price effects are explored further in the next sub-section).

Higher prices have a relatively small effect on demand for products from the livestock sector. In other words, implicit own price elasticities are relatively low for the agricultural sectors producing livestock.[27] This may appear surprising at first sight, as especially export elasticities (see Table 6) for agricultural livestock products as well as for meat and dairy products are quite high. In this case, the reason behind the fairly low own price elasticities is the strong interdependency between the agricultural sectors and the food industries: the former delivers the majority of its products to the latter, while the food in-

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[26] For example, Bovaer is a feed additive for cattle that suppresses the enzyme in the cow's rumen that would otherwise combine hydrogen and CO_2, turning them into methane.

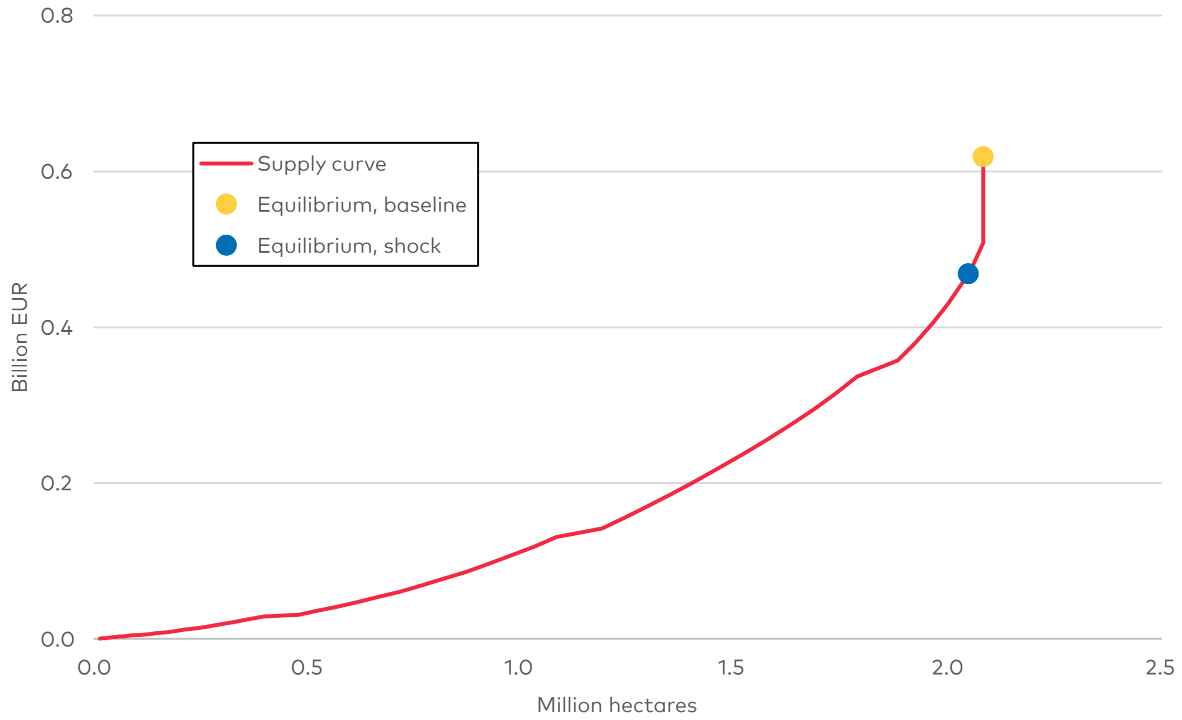
[27] Implicit own price elasticity is defined as the percentage change in output over the percentage change in output price. The measure indicates how price-sensitive demand for a product is when its price increases by a percentage point.

Table 8. Price and quantity change in agriculture and food industries, 2030

	Gross Value Added, baseline (billion EUR)	Tax revenue before behavioural change (billion EUR)	Price change before behavioural change (%)	Price change in equilibrium (%)	Quantity change in equilibrium (%)	Implicit own price elasticity
Agricultural sectors						
Crop and vegetable production, conventional	0.1	0.2	12.4	2.2	-8.0	-3.7
Crop and vegetable production, organic	0.0	0.0	9.8	-0.4	-5.5	13.5
Horticulture	0.2	0.0	0.3	-0.4	0.3	-0.7
Cattle, conventional	0.6	0.4	20.2	16.3	-17.4	-1.1
Cattle, organic	0.2	0.1	17.9	14.5	-13.4	-0.9
Pigs, conventional	0.8	0.1	7.1	6.2	-9.2	-1.5
Pigs, organic	0.0	0.0	4.0	3.6	-3.1	-0.8
Food industries						
Dairy	1.3	-	-	5.4	-13.8	-2.6
Bovine meat products	0.1	-	-	11.3	-26.8	-2.4
Pig meat	1.2	-	-	2.2	-6.3	-2.9
Poultry	0.1	-	-	-0.1	0.2	-1.5
Bread products	0.8	-	-	0.2	-0.6	-3.8
Beverages and tobacco	1.5	-	-	0.2	-2.4	-13.5

Note: Price change before behaviour calculates how much the tax constitutes of production value in baseline, i.e. the price change that would occur, if production and consumption are left unchanged. Price and quantity change in equilibrium are the changes in production prices and quantities in the tax scenario compared to baseline. Implicit own price elasticity is calculated as Quantity change in equilibrium divided by Price change in equilibrium. Gross Value Added for the agricultural and food processing industries do not sum to the numbers in Table 1. This is due some sectors being left out of Table 8 for simplicity.
Source: Author's own calculations in the GreenREFORM model.

Figure 4. Relation between land amount and total production revenue



Note: When total production revenue falls below €0.51 billion, i.e. the kink where the supply-curve goes from being vertical to non-vertical, the least productive areas will be taken out of intensive agricultural production.
Source: Olsen & Pedersen (2022) and author's own calculations in the GreenREFORM model.

dustries have only a limited number of competing imports. Hence, the demand response in the agricultural sectors is mainly driven by the demand response in the food industries.

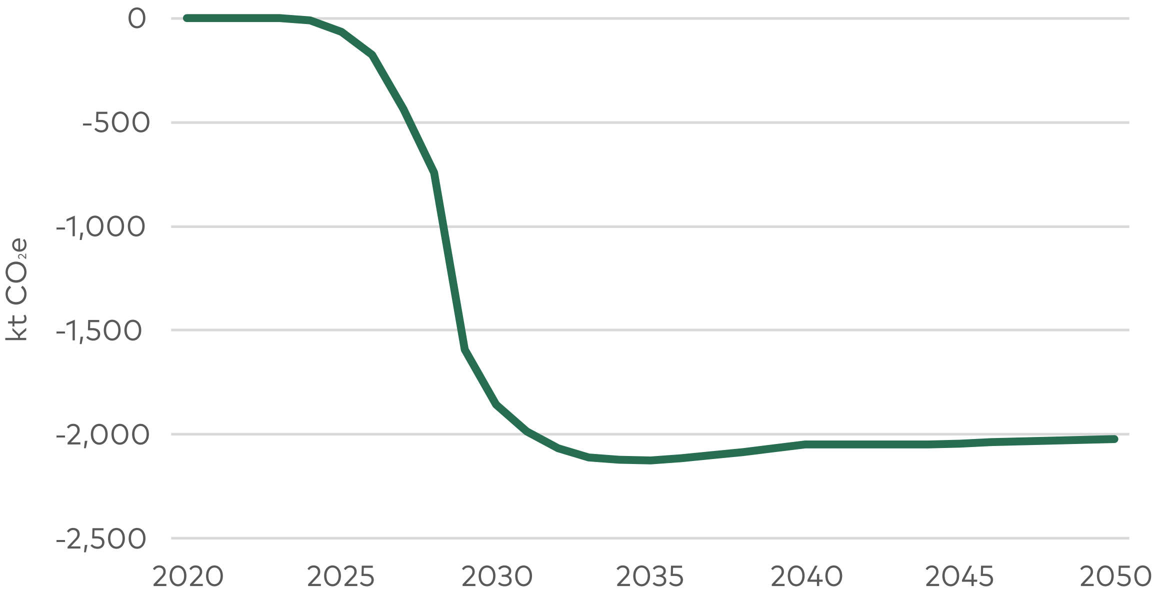
The equilibrium price increase for food industries is about half that of the agricultural sectors – this is because the food industries require various other inputs aside from agricultural products. In 2030, the animal food industries' implicit own price elasticities will fall between -1.5 and -2.9 depending on the composition of exports and domestically supplied products. As such, the demand response in the food industries is significant compared to the price increase. The production decrease in the agricultural sector mimics that of the relevant food industries due to the aforementioned interdependency.

Land market

The land price is calculated as the sum of future discounted revenue from holding land. Introduction of the carbon tax significantly decreases future production value and hence agricultural land prices. At the announcement of the tax scheme, land prices decrease by around 18%, although this is somewhat mitigated by a decrease in the amount of agricultural land in production.

As displayed in Figure 4, the total amount of agricultural land in production in 2030 is estimated to have

Figure 5. Change in total emissions



Source: Authors' own calculations in the GreenREFORM model.

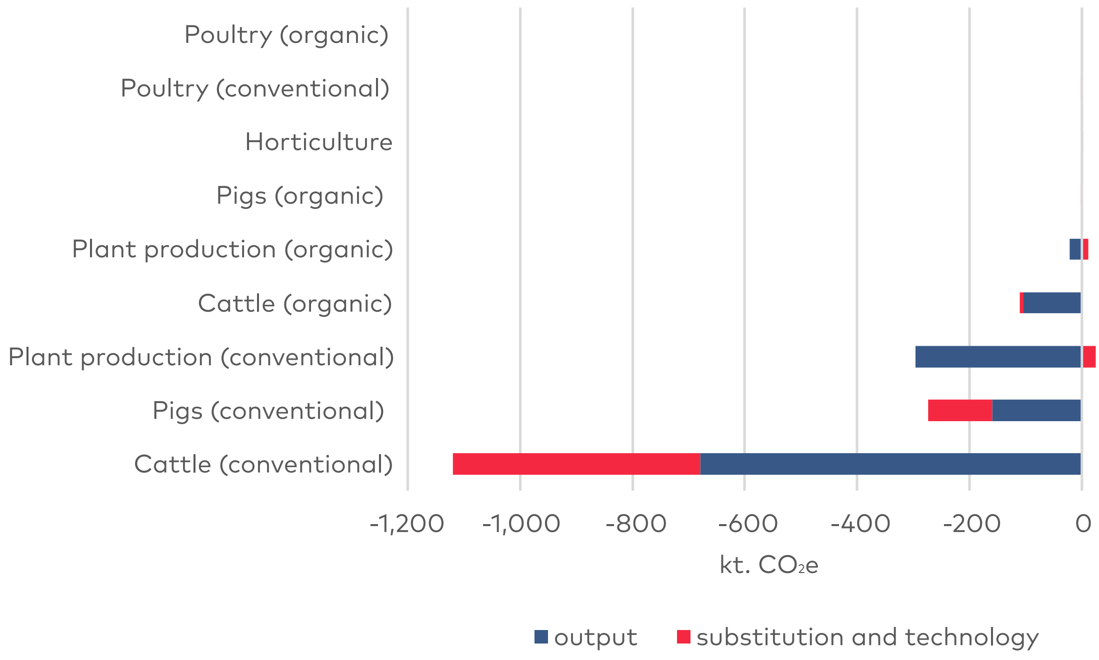
decreased by 36,000 hectares (2%) compared to the baseline scenario. This withdrawal of agricultural land from production dampens the fall in land prices, as output prices on crop and vegetable products increase slightly as supply decreases (scarcity effect). Land use decreases by 4% in the conventional crop sector, whereas land use increases by 10% in the organic crop sector. These sectoral differences are due to different emission intensities at the outset, as well as abatement possibilities.

Emissions

Figure 5 shows that total emissions are projected to have been reduced by 1.9 million tCO_2e in 2030. Reductions then gradually increase until 2033 due to short-term rigidities in the model (adjustment costs on capital, labour market rigidities, and rigidities in export responses), following which, reductions are slowly eroded by productivity gains in the agricultural sectors. This 'erosion' arises from the assumption that the tax rate will be adjusted according to long-run inflation, rather than productivity growth. Hence, when productivity increases, the agricultural sectors will regain some of their competitiveness, as the tax will constitute a smaller share of production value, leading to increased agricultural production.

Changes in emissions vary significantly between the agricultural sectors, as revealed in Figure 6. In absolute terms, emission reductions are greatest in conventional cattle, conventional pigs, and conventional vegetable and crop production, as these are the greatest emitters in the baseline scenario. Emission reductions are divided into reductions due to changes in production quantity (output), and those arising from technological change and-input substitution. The latter is largest in conventional cattle and conventional

Figure 6. Sector-specific emissions change, ktCO$_2$e in 2030



Source: Authors' own calculations in the GreenREFORM model.

pigs, which also gives rise to the largest differences between the mechanic and equilibrium price increases contained in Table 8.[28]

Macroeconomy and welfare

Total investments in the capital-intensive agricultural sectors and food industry drop upon announcement of the carbon tax. Alongside decreases in production, labour moves to less capital-intensive sectors of the economy (see Figure 7). Private consumption and total imports also decrease, but to a lesser extent. Although total exports increase in the short run due to a time lag in the change of production capacity (buildings and machine capital), they decease in the long run. GDP, meanwhile, undergoes a decrease of 0.2% in 2030 and 0.1% in the long run (2040). This very small percentage change is due to the fact that the agricultural sectors constitute only a small share of total Danish production.[29]

Figure 8 shows sectoral changes in employment in the short run (2025–2030) and long run (2040 and 2050). Although total employment decreases in the short run as a result of reduced de-

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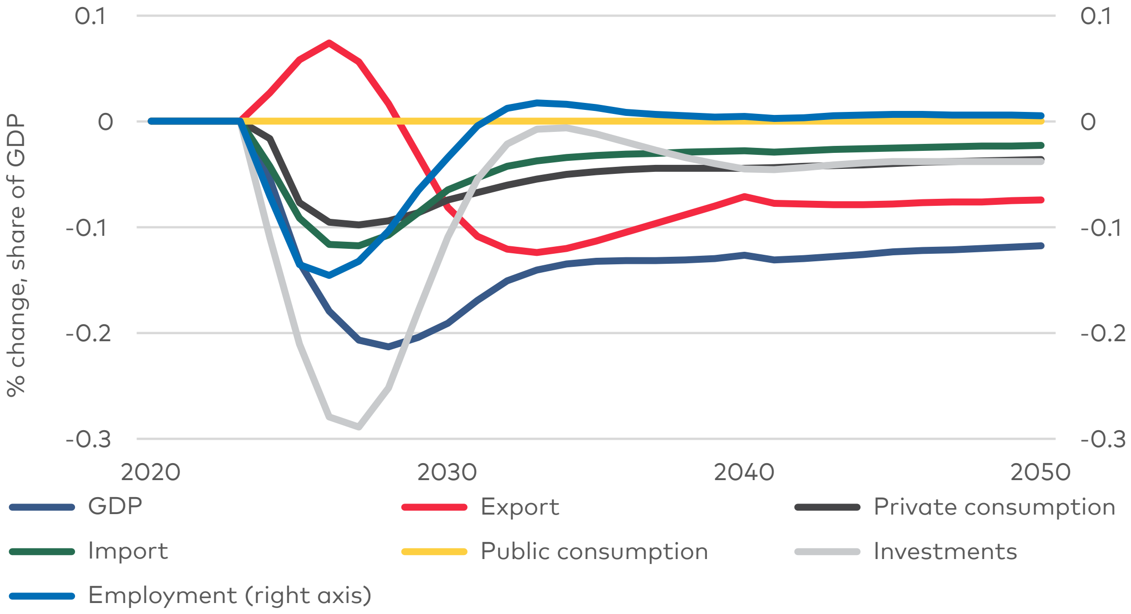
[28] Substitution and technology contribute to increased emissions in the conventional and organic crop sectors. This is due to agricultural land being more of a fixed factor than other production inputs, meaning the amount of land falls less than production output. As there are significant emissions tied to land use, this leads to a positive substitution effect.

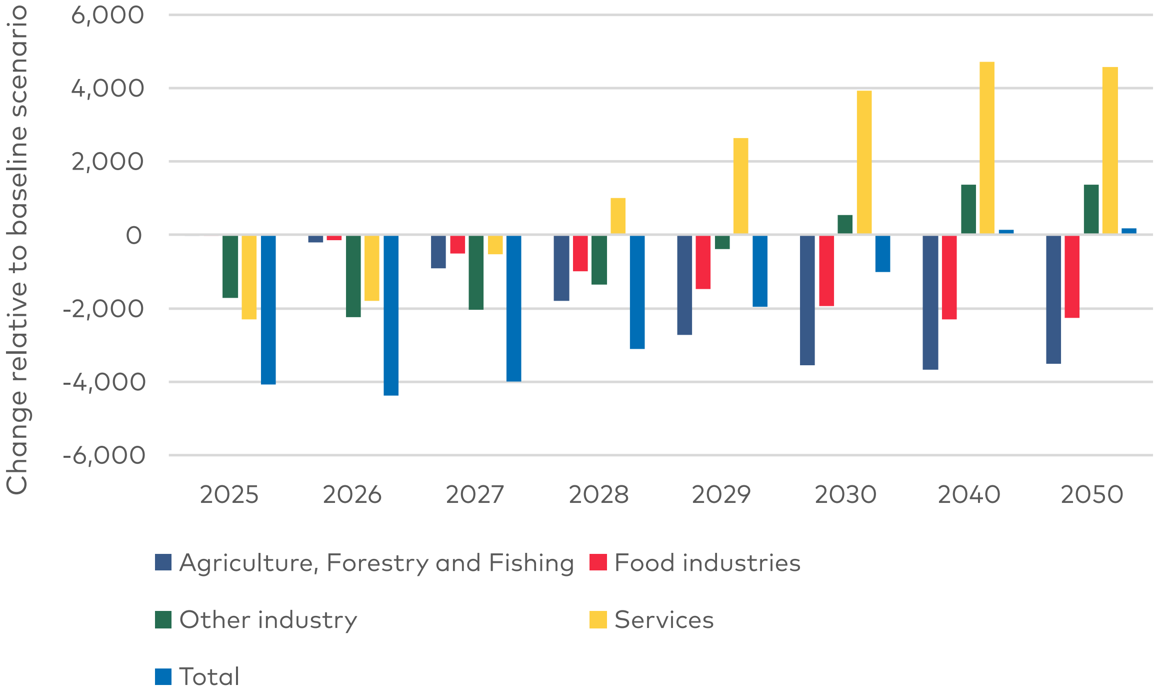
[29] The tax also reduces ammonia emissions, which has positive welfare effects, resulting in a €0.01 billion drop in the social cost of ammonia by 2030 for Danish residents and €0.03 billion for foreign residents (see Table 10, final row).

Figure 7. Change in GDP components (quantities)



Source: Authors' own calculations in the GreenREFORM model.

Figure 8. Change in employment (number of persons)



Source: Authors' own calculations in the GreenREFORM model.

mand, the employment effects are relatively small compared to total Danish employment of around 3 million people. Labour productivity decreases slightly in the long run, leading to a short-term drop in private consumption and investments. The most-affected sectors in terms of having to lay people off are the construction sector (in 'other industry'), due to decreased investments, and the labour-intensive service sectors. In the long run, real wages decrease in order to re-establish equilibrium in the labour market, meaning total employment remains unchanged. However, the sectoral composition differs from the baseline scenario: as expected, employment falls in both the agricultural sector and the food processing industries, while rising in the other industry and service sectors due to increased competitiveness arising from lower wage costs.

Regional effects

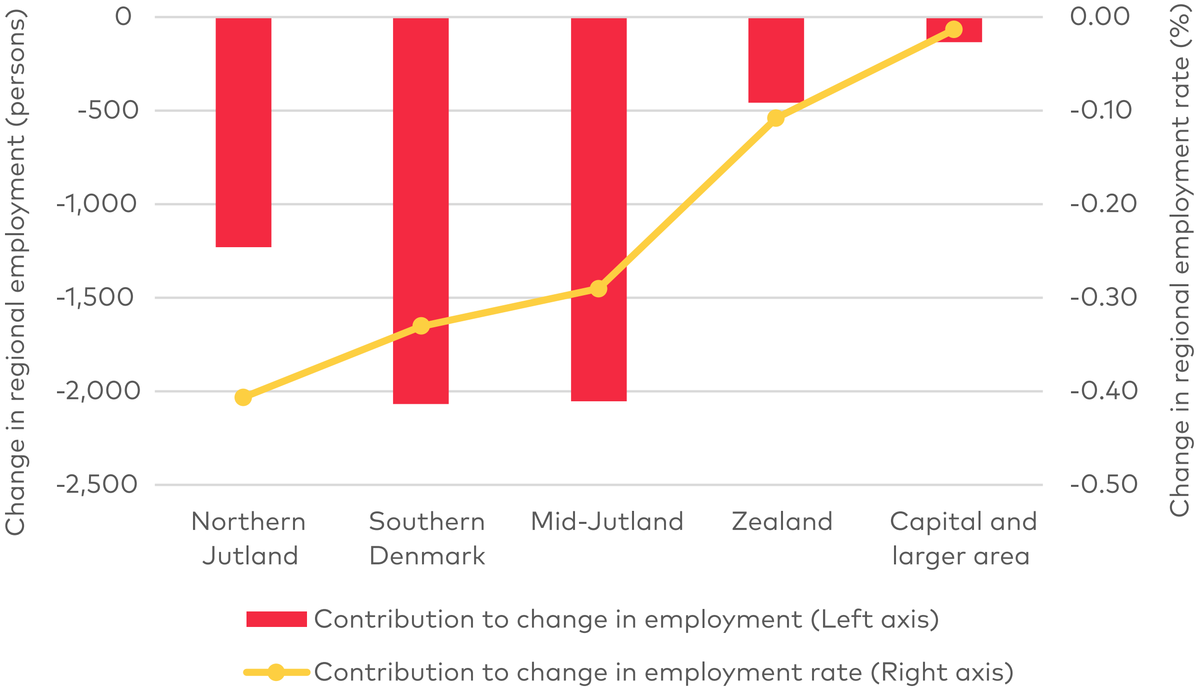
As touched on above, unemployment is temporary in the model, with laid-off agricultural and food industry workers finding alternative work in other sectors of the economy. We therefore zoom in on the partial effect on unemployment caused by the drop in agriculture and food industry vacancies (i.e. before employment moves to other sectors). As shown in Figure 9, employment in agriculture and the food industries (measured in number of persons) is expected to decline the most in Southern Denmark and Mid-Jutland and the least in the capital area. The large reduction in Southern Denmark is due to the region having the largest amount of people working in agriculture and the food processing industries in the baseline scenario. Moreover, Southern Denmark has a large share of cattle production relative to total agricultural production, further contributing to the decrease in employment. Meanwhile, Northern Jutland – which under the baseline scenario has the largest share of people employed in agriculture and the food processing industries – is expected to face the biggest drop in the employment *rate*.

The regulation scheme has a limited effect in fulfilling the EU's WFD, which Denmark needs to comply with by 2027. Introducing the carbon tax reduces fertiliser use in crop and vegetable production, with the use of manure and inorganic fertiliser falling by an average of 11% (47 kilotons N) in 2030 compared to the baseline scenario. The effect is somewhat smaller – only a 3% reduction (13 kilotons N) – in 2027, the year when the tax is phased in. Only a fraction of fertiliser use results in reduced nitrogen leaching. Table 9 shows that total reductions of nitrogen leaching amount to 0.8 and 2.8 kilotons N per year in 2027 and 2030 respectively. Of these reductions, roughly a quarter are in areas that face a reduction need when it comes to fulfilling the WFD. The effect of the carbon tax is limited in 2027, indicating it will not be effective in reaching the target set for that year. In the longer run, however, a carbon tax can contribute both to a positive environmental status in the remaining coastal areas and reducing the total cost of implementing the WFD by diminishing the need to reach the target using other instruments.

4.2 Scenario 2: Tax on both agricultural and LULUCF emissions

Secondly, we explore the effects of expanding the regulation scheme to include LULUCF emissions. Again, we follow the Expert Group on Green Tax Reform and focus on emissions from

Figure 9. Contribution to change in total regional employment from agriculture and food processes (2040)



Note: Data for the regional distribution of employment comes with a relatively high degree of uncertainty. To split the national employment data for the primary agricultural sectors, we rely on tables from Statistics Denmark combined with own assumptions. For food industry we collected data from Paqle combined with numbers taken from Danish Crowns website.
Source: For agriculture, Statistics Denmark tables (LONS30, RAS310, JORD1), authors' own assumptions and calculations in the GreenREFORM model. For food industry, authors' own queries on www.paqle.dk and Danish Crowns website, conducted in January 2024.

carbon-rich soils and emissions/uptake from forests.

Afforestation increases the uptake of CO_2 from the atmosphere, thus holding the potential to lower Denmark's net emissions. As per the Expert Group, we set the maximum potential for afforestation at 250,000 hectares (up to 2045), with the limiting factor being the production of small trees. Against this backdrop, we introduce an afforestation subsidy of €40 per tCO_2e and a subsidy for re-wetting of carbon-rich soils. The process of abating emissions from carbon-rich soils can be broken down into two steps. Firstly, the farmer ceases intensive production in these areas (i.e. stops fertilising and ploughing), which will only have a limited impact on LULUCF emissions compared to the effect on agricultural emissions. Secondly, the farmer floods the area in order to significantly reduce LULUCF emissions. This second stage is much more complex, often requiring coordination between multiple farmers (Klimarådet 2020). As such, a tax scheme alone is not very effective in reducing LULUCF emissions. The subsidy is €40,000 per hectare, which equates to €65 per tCO_2e on average. Regulation of agricultural emissions is the same as in Scenario 1.

Table 9. Change in nitrogen leaching

	2027	2030
Total reduction, ktN	0.8	2.8
Reductions that contribute to WFD, ktN per year	0.2	0.7
Regions with reduction need after regulation	16	16
Reduction need after regulation, ktN per year	2.5	2.1

Note: Estimations were made in 2022.
Source: Data graciously shared with the authors by the Danish Environmental Protection Agency, and authors' own calculations in the GreenREFORM model.

Main results

Including regulation of LULUCF emissions alongside taxation of agricultural emissions lowers total emissions by 2.3 million tCO_2e. As shown in Table 10, LULUCF emissions fall by 0.4 million tCO_2e while agricultural emissions fall by 1.8 million tCO_2e by 2030.

The reduction in agricultural emissions is greater than simply imposing a tax on agricultural emissions (Scenario 1). This is because subsidising afforestation means larger amounts of land are taken out of agricultural production as the need for forest land increases. With regulation of LULUCF emissions, the area used for agriculture decreases by 2.7%, compared to a decrease of 1.7% when only taxing agricultural emissions.

The decrease in land prices is smaller when regulation of LULUCF emissions is included. There are two main explanations for this. Firstly, the increasing amount of land needed for forests and wetlands means agricultural land will become an ever more scarce resource. Thus, all else being equal, agricultural land prices would be expected to increase. Secondly, afforestation is expected to happen in the least productive areas, which therefore have the lowest alternative value in terms of agricultural production. Removing low-productivity areas from agricultural land will increase average productivity, and hence average prices.

Approximately 32% of the decrease in LULUCF emissions expected in 2030 stems from forests, with the remainder arising from the wetting of carbon-rich soils. The relatively low impact of afforestation in 2030 is primarily due to two factors. Firstly, afforestation happens over a timespan of 2025–2045, as shown in Figure 10. Consequently, the lion's share of the 250,000 hectares is not afforested in 2030. Secondly, uptake from the afforested areas is quite limited in 2030, as forest uptake follows an 'S-shape': low uptake in the beginning and end of the growth cycle, and much higher uptake for forests aged 20–60 years. Hence, afforestation will have a limited impact in reaching 2030 climate targets but can contribute with significant uptake from 2035 to 2080, as shown in Figure 11.

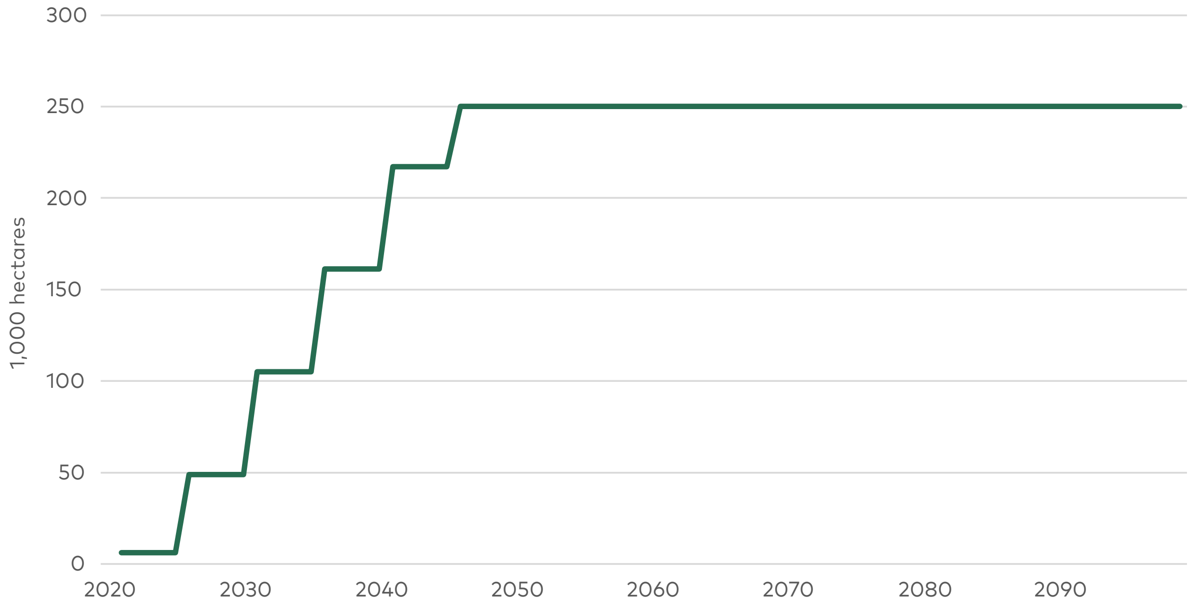
On the other hand, emission reductions from wetting carbon-rich soils are fairly constant over time, and – as

Table 10. Main results of different regulation schemes, 2030

	Scenario 1: Tax on agriculture	**Scenario 2: Tax on agriculture and LULUCF subsidies**	**Scenario 3: Tax and subsidies for agriculture and LULUCF subsidies**
GDP (%)	-0.2	-0.2	0.0
Emissions change, mtCO$_2$e			
Total emissions	-1.9	-2.3	-2.9
Agricultural emissions	-1.7	-1.8	-1.7
– of which from technologies	*-0.6*	*-0.6*	*-1.0*
– of which from output change	*-1.2*	*-1.2*	*-0.7*
– of which from input substitution	*0.0*	*0.0*	*0.0*
LULUCF emissions	0.0	-0.4	-1.2
– of which from technologies	*0.0*	*0.0*	*-0.8*
Residual reduction needs towards national 70% target	2.4	1.9	1.3
Residual reduction needs towards lower bound (55% reduction) in agricultural and LULUCF sector	1.5	1.1	0.4
Production quantity (%)			
Production, conventional cattle	-17.4	-17.6	-10.1
Production, conventional pigs	-9.2	-9.3	-5.1
Production, conventional crop	-8.0	-8.3	-4.7
Employment, 1,000 persons			
Agriculture	-3.3	-3.4	-1.9
Food processing industries	-1.9	-2.0	-1.1
Land market (%)			
Agricultural land, quantity	-1.7	-2.7	-2.7
Agricultural land, price	-18.0	-3.9	6.9
Water Frame Directive,% of outstanding reductions (2027)			
Contribution to outstanding reductions	6.7	3.8	4.0
Ammonia, €billion			
Reduction in social cost (Danish residents/Foreign residents)	(0.01/0.03)	(0.01/0.03)	(0.00/0.02)

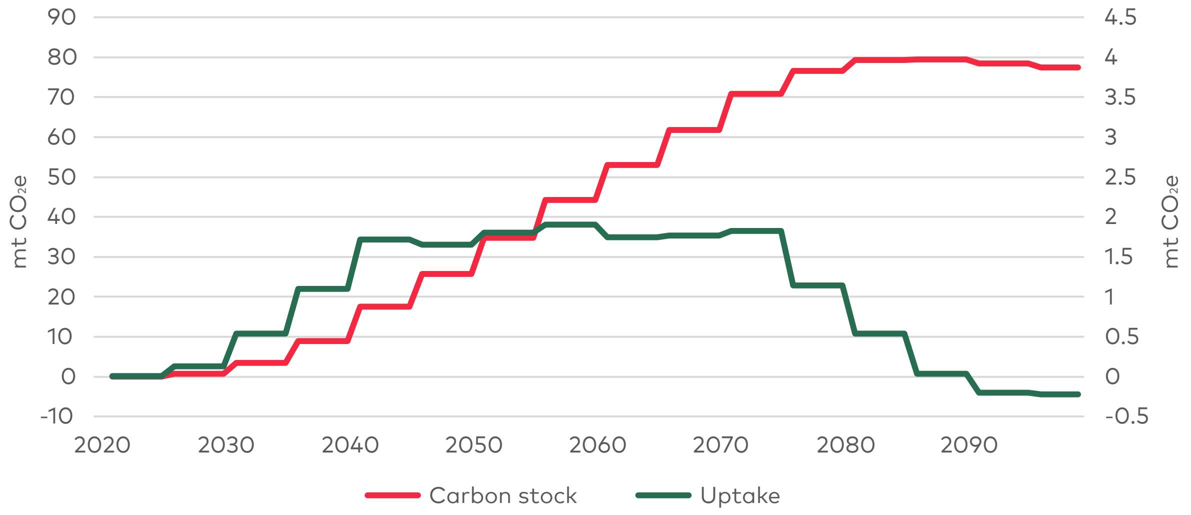
Source: Author's own calculations in the GreenREFORM model.

Figure 10. Change in forest area



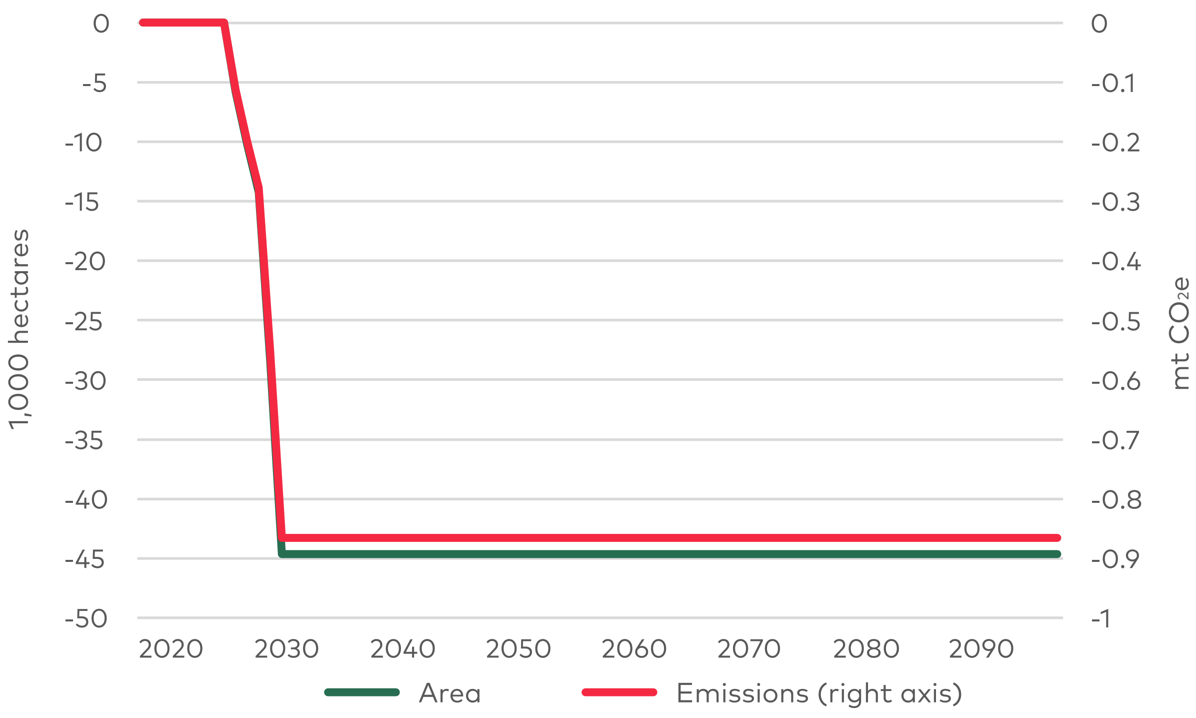
Note: The forest module runs at intervals of five years in order to reduce the dimensionality of the model. Hence, output from the model is 'stair-shaped'.
Source: Authors' own calculations in the GreenREFORM model.

Figure 11. Change in carbon stock and uptake from forest



Note: The forest module runs at intervals of five years in order to reduce the dimensionality of the model. Hence, output from the model is 'stair-shaped'.
Source: Author's own calculations in the GreenREFORM model.

Figure 12. Change in drained area of carbon-rich soils and emissions



Source: Authors' own calculations in the GreenREFORM model.

demonstrated by Figure 12 – will have fulfilled most of its potential by 2030. This is based on the assumption that carbon-rich soils can be wetted fairly quickly, reaching full potential by 2032. The wetting of carbon-rich soils is also assumed to stop most emissions immediately, which is in line with United Nations Framework Convention on Climate Change (UNFCCC) accounting guidelines.

4.3 Scenario 3: Lower carbon tax combined with technology subsidies

Lastly, we explore a scenario in which the emphasis shifts from taxing emissions to subsidising the use of abatement technologies. This scenario reflects how climate policies have been carried out in Denmark thus far. For example, the taxation scheme on industries passed in June 2022 included tax rebates on emission-intensive sectors, while allocating subsidies to, among other things, carbon capture and storage. It is often argued that, aside from cost effectiveness, a greater emphasis on technology subsidies supports the Danish Climate Law's other ambitions such as reduction of carbon leakage and maintaining competitiveness.

Concretely, we impose a carbon tax of €50 per tCO_2e on agricultural non-energy emissions and assume the effects on afforestation and wetting of carbon-rich soils are the same as in Scenario 2. In terms of the subsidy scheme, it is assumed that all relevant technologies have been fully implemented by 2030. As shown in Appendix A, the second most expensive technology is the production and storage of biochar, which costs around €300 per tCO_2e.[30] However, this is also a technology with a large emission removal potential (0.8 $mtCO_2e$). Given biochar generates negative emissions, a subsidy covering the entire technology cost is given. In all other cases, the subsidy is calculated such that the tax plus the subsidy provides sufficient incentive to fully implement the technology in question.

Main results

As shown in Table 10, an emphasis on subsidies for abatement technologies combined with a lower carbon tax leads to emission reduction of 2.9 $mtCO_2e$ in 2030 compared to the baseline. Within this, LULUCF emissions are lowered by 1.2 $mtCO_2e$, half of which stems from afforestation and the wetting of carbon-rich soils, and the other half from the production and storage of biochar. The remainder of the reduction – 1.7 $mtCO_2e$ – comes from a fall in agricultural emissions, almost matching the amounts seen in scenarios 1 and 2, despite the carbon tax in those instances being double that applied in Scenario 3. This is attributable to abatement technologies playing a significantly larger role in reducing agricultural emissions. More specifically, the use of nitrification inhibitors to reduce crop production emissions is introduced in this scenario, requiring a subsidy of around €110–140 per tCO_2e.

The drop in agricultural production is almost halved as a consequence of the lower carbon tax, causing emission reductions related to the change in output to fall from 1.2 to 0.7 $mtCO_2e$. The higher level of agricultural production seen under Scenario 3 also means the negative impact on employment in agriculture and the food processing industries is dampened.

Finally, agricultural land prices increase under this scenario. This is because of the scarcity effect of land, where increased land prices dominate over the fall in production value determined by the reduced carbon tax.

5. Sensitivity analyses

In conducting the three sensitivity analyses described in this section, we restrict our scope to Scenario 2 (i.e. the combination of a tax on agricultural emissions alongside subsidies for the re-wetting of organic soils and for afforestation). Before going into further detail, it is worthwhile setting out the motivation underlying the analyses:

1. In the first sensitivity analysis, we investigate how the model results change when we alter the price elasticities of demand for agricultural goods (including processed goods in the food industry). Here, we explore both a scenario where elasticities in agriculture and the food industry are doubled, and a scenario where they are halved. Given the results of the main analysis rely on the magnitude of the elasticities, discovering how these results change in response to changes in these deep model param-

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[30] Biochar is a carbon-rich residue derived from the pyrolysis of biomass. When ploughing biochar into fields, the carbon is stored rather than released into the atmosphere. As the biomass has taken up carbon in its growth production, the storing of biochar gives rise to negative emissions (the same concept as bio-energy carbon capture and storage).

eters is naturally of great interest.

2. In the second sensitivity analysis, we investigate what happens if the more productive cattle and pig farmers buy up the less productive farmers. Highly productive farmers produce output more efficiently, and one of the ways this manifests in data is through lower CO_2e input per value created.
3. In the third sensitivity analysis, we investigate what happens if farmers abroad are also subject to some degree of climate regulation. Should other countries pursue similar agriculture-related climate regulation, this may water down the effects of Denmark's climate policy, as the carbon tax will have less of an impact on Danish competitiveness if foreign farmers are faced with a comparable situation. Although this would potentially corrode Danish reduction efforts, foreign regulation would contribute to reducing carbon leakage, thereby resulting in greater global emission reductions than a Danish standalone tax could achieve. On this point, it should be noted that climate regulation of agriculture is already part of the current outlook within the EU, where agriculture is regulated under the ESR.

5.1 The effect of higher/lower response in demand to changes in price

The scope of this sensitivity analysis is to see how the main results of Scenario 2 are affected by changes in the demand elasticities of the agriculture and food industry sectors. More specifically, we explore two cases: in the first (Sensitivity 1), we set demand elasticities to half of what they are in the main analysis, and in the second (Sensitivity 2) we double them. The results are displayed in Table 11 below.

The effect of halving demand elasticities

Halving demand elasticities results in a 'loss' of 0.3 $mtCO_2$e in emission reductions, arising from production that would otherwise have shut down under the usual demand elasticities. This is reflected by the fact that production in agriculture as a whole falls by 6.5% compared to 9.5% in the main analysis.

Meanwhile, reductions from abatement technologies remain roughly the same, as the technology incentive resulting from the tax remains unaltered by the change in elasticities. In fact, reductions from abatement technologies increase slightly, as the larger remaining production provides a greater potential base for the technology to be applied to.

When it comes to land prices, halving demand elasticities has a positive effect, as a larger portion of the tax can be passed on to suppliers and, ultimately, consumers. This reduces the drop in land prices caused by the tax. More importantly, we assume that the subsidy for afforestation is sufficiently large that 250,000 hectares of cropland will still be converted to forestland. This scarcity of cropland in turn pushes up returns on land still in agricultural production. While the scarcity effect is also at work in Scenario 2, it is only in conjunction with low demand elasticities that the net effect is an increase in land prices.

Finally, job losses in agriculture and food industries are, unsurprisingly, also lower in light of the halved demand responsiveness, with 1,700 jobs in these sectors 'saved'.

Table 11. Main results from sensitivity analyses 1 and 2, 2030

	Scenario 2: Tax on agriculture and LULUCF subsidies	**Sensitivity 1: Low demand elasticities (½ of baseline)**		**Sensitivity 2: High demand elasticities (2 times baseline)**	
		Change compared to baseline	Change compared to scenario 2	Change compared to baseline	Change compared to scenario 2
GDP (%)	-0.2	-0.1	0.1	-0.3	-0.1
Emissions change, mtCO$_2$e					
Total emissions	-2.3	-1.9	0.3	-2.8	-0.5
Agricultural emissions	-1.8	-1.5	0.3	-2.3	-0.5
– of which from technologies	-0.6	-0.6	0.0	-0.5	0.0
– of which from output change	-1.2	-0.9	0.4	-1.8	-0.6
– of which from input substitution	0.0	-0.1	0.0	0.0	0.1
LULUCF emissions	-0.4	-0.4	0.0	-0.4	0.0
– of which from technologies	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Production quantity (%)					
Agricultural, total	-9.5	-6.5	3.0	-14.0	-4.5
Production, conventional cattle	-17.6	-12.2	5.3	-25.2	-7.6
Production, conventional pigs	-9.3	-5.8	3.5	-14.1	-4.7
Production, conventional crop	-8.3	-6.2	2.1	-13.0	-4.8
Employment, 1,000 persons					
Agriculture	-3.4	-2.3	1.1	-5.1	-1.7
Food processing industries	-2.0	-1.4	0.6	-2.8	-0.8
Land market (%)					
Agricultural land, quantity	-2.7	-2.7	0.0	-3.0	-0.3
Agricultural land, price	-3.9	6.0	9.8	-11.4	-7.5

Source: Authors' own calculations in the GreenREFORM model.

The effect of doubling demand elasticities

Doubling demand elasticities results in an additional emissions reduction of 0.5 mtCO_2e, stemming from an additional closing down of agriculture production by 4.5%. This translates into, respectively, 1,700 and 800 more jobs being lost in primary agriculture and the food industry.

5.2 The effect of highly productive cattle and pig farmers buying out their less productive counterparts

In the agricultural sub-model, the sectors are modelled using so-called 'representative farms' – that is, the model describes the economic behaviour of the 'average' farm. In practice, there will be a degree of heterogeneity between farms, including the productivity of individual farmers when it comes to CO_2e emissions (i.e. the carbon intensity of production). For instance, the fourth quantile of cattle farmers produce roughly €34 worth of output per kg of CO_2e emitted, whereas the first quantile only produces €26 worth. The idea underling this sensitivity analysis (Sensitivity 3) is that a sufficiently high tax will push the first quantile of cattle farmers out of business, to be bought up by the less carbon-intensive farmers. The net result is that emissions are lowered but at smaller loss of production than would be the case if only the representative farm is considered.

We use data on cattle and pig farmers from Klimarådet (2023) and apply it as described by Stewart (2024). In essence, we apply the productivity data in the same fashion as we apply end-of-pipe technologies to agriculture. This method keeps the production input mix largely unchanged, which was an attractive feature in this case, as there has not – to our knowledge – been any in-depth studies of the underlying mechanisms leading to observed variations in emission intensity.[31]

As shown in Table 12, the effect of low-emission intensity farmers 'taking over' farms operating with high emission intensities leads to significant emission reductions: a further 0.5 mtCO_2e reduction compared to Scenario 2. Aside from the emission reductions, the results closely resemble those seen in Scenario 2, which was the outcome aimed for with the chosen modelling approach.

5.3 The effect of agricultural climate regulation abroad

In this sensitivity analysis (Sensitivity 4), we investigate the effects of foreign agricultural sectors also being subject to a degree of climate regulation. As we do not have a model for other countries' agricultural and food processing sectors, the analysis is approached in an abstract but simple manner: we assume that climate regulation is going to be milder abroad and that it will have effects symmetrical to those seen in Danish agriculture. More specifically, we assume that price levels in foreign agriculture and the food industry follow their Danish counterparts, but with half the Danish magnitude. For instance, in the analysis there is an 18% increase in the price of outputs from Danish cattle farming, which translates into a 9% price increase in outputs from foreign cattle sectors.

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[31] Emission intensity defined as emissions per produced value (e.g. kg of CO_2e per euro).

Table 12. Main results from sensitivity analyses 3 and 4, 2030

	Scenario 2: Tax on agriculture and LULUCF subsidies	**Sensitivity 3: Increased average productivity from concentration on most productive farmers**		**Sensitivity 4: Foreign agricultural climate policy**	
		Change compared to baseline	Change compared to scenario 2	Change compared to baseline	Change compared to scenario 2
GDP (%)	-0.2	-0.2	0.0	-0.1	0.0
Emissions change, mtCO$_2$e					
Total emissions	-2.3	-2.8	-0.5	-1.9	0.4
Agricultural emissions	-1.8	-2.3	-0.5	-1.5	0.4
– of which from technologies	*-0.6*	*-1.0*	*-0.5*	*-0.6*	*0.0*
– of which from output change	*-1.2*	*-1.2*	*0.0*	*-0.8*	*0.4*
– of which from input substitution	*0.0*	*0.0*	*0.0*	*-0.1*	*0.0*
LULUCF emissions	-0.4	-0.4	0.0	-0.4	0.0
– of which from technologies	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Production quantity (%)					
Agricultural, total	-9.5	-9.6	-0.1	-6.2	3.3
Production, conventional cattle	-17.6	-17.6	0.0	-11.3	6.2
Production, conventional pigs	-9.3	-9.5	-0.2	-5.9	3.5
Production, conventional crop	-8.3	-8.3	0.0	-5.9	2.4
Employment, 1,000 persons					
Agriculture	-3.4	-3.4	0.0	-2.2	1.2
Food processing industries	-2.0	-2.0	0.0	-1.4	0.6
Land market (%)					
Agricultural land, quantity	-2.7	-2.7	0.0	-2.7	0.0
Agricultural land, price	-3.9	-3.9	0.0	8.6	12.4

Source: Authors' own calculations in the GreenREFORM model.

To briefly sum up the results, also shown in Table 12, we find that agricultural production falls by 6.2% compared to 9.5% in the main analysis. This smaller drop in production leads to a 0.4 $mtCO_2e$ lower reductions in emissions, mainly driven by cattle production falling by only 11.3% compared to 17.6% in the main analysis.

The qualitative effects of this simulation are unsurprising. The interesting part, however, is getting the model to quantify the risks posed to Danish climate regulation of agriculture by foreign counterparts enacting similar policies. In this respect, the risk looks to be significant, even is it is assumed that foreign agriculture is subject to milder policies that those imposed on Danish farmers. The upside of foreign climate regulation of agriculture is, of course, that it reduces the leakage issue and most likely leads to larger reductions globally.

The increase in foreign prices means consumers have less reason to substitute away from Danish agricultural products, which in turn means a larger portion of the tax is passed on to them. This, combined with the subsidies for afforestation, re-wetting of organic soils and the scarcity effect discussed in sub-section 4.2, ensures farmers experience substantial capital gains in the form of an 8.6% land price increase.

6. Conclusion and discussion

In setting out to analyse different regulation schemes incentivising emission reductions in the agricultural and LULUCF sectors, our research finds that a tax on non-energy emissions from agriculture, combined with subsidies aimed at cutting LULUCF emissions, would lower total Danish GHG emissions by 2.3 $mtCO_2e$ in 2030 compared to the baseline scenario. Hence, regulation can contribute just over half the reductions necessary to fulfil Denmark's 70% emissions reduction target, as well as 70% of what is needed to fulfil the national reduction target for the agricultural and LULUCF sectors. The remaining reductions must therefore be achieved through even stronger regulation of the agriculture and LULUCF sectors than has been investigated in this chapter, or further regulation of other sectors (or, alternatively, a combination of the two).

Around 0.6 $mtCO_2e$ of these reductions stem from emission-reducing technologies, with feed additives playing a major role. This contribution from technologies is relatively limited due to two factors: firstly, only a limited number of technologies are sufficiently mature to have a reliable effect in 2030, and secondly, some technologies have higher costs than the marginal incentive of €100 per tCO_2e (e.g. biochar and nitrification inhibitors).

A regulation scheme with a lower tax rate of €50 per tCO_2e, combined with subsidising emission-reducing technologies, improves the total reductions delivered by the agricultural sector. While the drop in agricultural output, and hence emissions, is around half of what occurs with a tax rate of €100 per tCO_2e, this loss of emission reductions is more than compensated for by increased reductions arising from emissions-reducing technologies. Most significantly, the production and storage of biochar contributes 0.8 $mtCO_2e$ in reduced emissions from the LULUCF sector.

These quantitative reduction effects are highly dependent on the model assumptions, as also demonstrated by the sensitivity analyses. Reduction technology effects rely heavily on assumptions made about reduction potentials, as well as the time scales for phasing in technologies currently unproven at a larger scale. From a regulatory point of view, it would be wise to take into account the uncertainties surrounding these calculations. One way of doing so would be to incorporate rules into the legislation increasing/decreasing the general carbon tax if reductions appear to be lower/higher than expected.

The research anticipates that the regulation schemes will only have a limited effect in achieving the targets set by the EU's WFD. This is mainly based on the assumption that 'targeted regulation' will have significantly lowered nitrogen leaching by 2027, by which time only 17% of coastal areas will need to further reduce nitrogen leaching. Hence, an overall drop in fertiliser use does not offer a very effective means of achieving the remaining reduction demand. The regulation schemes analysed in this chapter will, however, make some of the targeted regulation redundant. Given that several studies have argued targeted regulation comes with significant costs (Jacobsen 2017), this would lower the costs of the carbon tax.

The three regulation schemes explored all have a very limited effect on the macroeconomy: GDP falls by 0.0–0.2%, while total employment drops by around 0.1% in the short term. This is not an unusual result when it comes to measuring the macroeconomic effects of climate policies – the costs of achieving significant reductions in emissions are very limited when measured as a share of GDP (De Økonomiske Råds formandsskab 2021).

Nevertheless, the costs faced by individual sectors, firms or persons may be significant. Our model predicts an 18% fall in agricultural land prices under regulation that solely consists of levying a €100 per tCO_2e tax on agricultural emissions. A fall in land prices of this magnitude implies an approximately €5.5 billion drop in the value of land. Unless compensated for, this would significantly decrease current land owners' assets. Moreover, employment in agriculture and the food processing industries would fall by around 5,000 persons, with Northern Jutland and Southern Denmark – which have the largest share of employment in these sectors in the baseline scenario – bearing the greatest unemployment costs. Even for these two regions, however, the unemployment effect is negligible, as the jobs lost would only constitute less than 0.5% in regional employment.[32] In addition, the numbers involved are somewhat negligible when placed alongside the roughly 700,000 people who change jobs every year in Denmark (Statistics Denmark 2024).

GreenREFORM is a macroeconomic model and so not built to explore the distributional effects of climate policies. Thus, to answer questions about the effect on, for example, income inequality or the solvency of specific firms, other models or calculation principles are required. The Expert Group on Green Tax Reform has combined average change in income and asset values from the

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[32] As displayed in Figure 9, the partial contribution to unemployment in Northern Jutland from job losses in agriculture and the food industries amounts to just 0.4% in 2040.

GreenREFORM model with farm-level accounting data in order to calculate each farm's default risk. Similarly, average changes in prices and income have been used to calculate the expected effects on average disposable income and the Gini-coefficient. Here, the Expert Group found that its 'toughest' tax scenario – resembling Scenario 2 in the present analysis – led to a 0.26% fall in real disposable income for the lowest income decile, and that the change in Gini-coefficient was zero (when rounded to two decimals) (Ekspertgruppen for en Grøn Skattereform 2024).[33]

The calculations in our analyses are based on the assumption that consumer preferences are unaffected by a particular policy scenario. This means it is only relative prices that can change food consumption from animal to vegetable foodstuffs. As such, some of the decrease in Denmark's production of animal foodstuffs is substituted by imports. According to international comparisons, Danes' food consumption has a relatively high climate impact, and in recent years there has been increased focus on changing the country's dietary preferences (Klimarådet 2021). If this were to occur on a large scale, in conjunction with emissions regulation, there could be a radical shift from the consumption of animal foodstuffs to Danish-produced plant products, with their associated lower emissions. At this point, however, we leave the interaction between changes in dietary preferences and the regulation of emissions to future research.

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[33] We would have like to have quoted the exact change in Gini-coefficient, but the Expert Group on Green Tax Reform has only published the change in Gini-coefficient rounded to the first two decimals.

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Forest sector transitions: Product mix, energy system and carbon sink

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ABSTRACT
Forests have a number of crucial roles to play in the green transition. This is especially so in Finland, which has the largest forest resources per capita in the EU. Here, forestry is fundamentally a rural profession, while the forest industries are geographically scattered across small- or mid-sized cities located in the vicinity of rivers, rail crossings or harbours. While Finnish forest products are primarily made using domestic wood, they mainly serve customers abroad.

This chapter sets out six policy options for promoting Finland's forest carbon sink. Based on the analysis presented, *reducing domestic harvests* and/or *importing roundwood or pulp* would promote carbon accumulation in Finland's domestic forests but require incremental harvesting abroad. Meanwhile, *improving the material efficiency of wood processing and increasing the gross annual increment* through forest growth and other silvicultural actions would not only contribute to Finland's green transition, but strengthen the country's regions socially and economically. Finally, research and development are currently underway into *modernising the palette of forest products* and *implementing BioCCS* (carbon capture and storage from bioenergy), although these only hold the potential for limited positive impacts by 2035 – the government-set date for Finland to achieve net zero.

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1. Introduction

The term 'green transition' refers to the process of shifting from traditional – often fossil fuel-based – energy systems and practices to more sustainable, environmentally friendly alternatives. This process encompasses a range of strategies aimed at reducing carbon footprints; promoting renewable energy sources (e.g. solar and wind); and improving energy efficiency in sectors such as transportation, agriculture and industry. The ultimate goal of the green transition is to not only mitigate the impact of climate change, but ensure a sustainable, resilient future for the planet and its inhabitants. As such, the transition requires collaboration across governments, industries and communities worldwide.

Forestry can contribute to the green transition through carbon sequestration, biodiversity conservation and sustainable resource management. Sustainable forestry practices allow for the harvesting of timber without degrading the environment. This involves managing forest regeneration, maintaining biodiversity and using the best logging methods to ensure woodland can provide resources over the long term.

Trees absorb carbon dioxide from the atmosphere as they grow, which helps to mitigate the effects of climate change. Thus, sustainable forest management ensures forests can continue to act as carbon sinks without diminishing their capacity through overexploitation. Moreover, given forests are home to a significant portion of the world's terrestrial biodiversity, protecting them helps preserve a wide range of species and maintains ecological balance, which is crucial for the planet's health.

The stock of carbon embedded in forests changes over time, either negatively (thus triggering CO_2 emissions, 'source') or positively (thus removing CO_2 from the atmosphere, 'sink'). Trees capture CO_2 through photosynthesis and release it during biomass decomposition, combustion and harvest removals. The difference between CO_2 gains and CO_2 losses defines the strength of the carbon source/sink, which is estimated and reported annually at both a global and national scale.

Beyond carbon storage and biodiversity, forests provide a range of ecosystem services, including water regulation, soil conservation and pollution control, all of which are essential for maintaining environmental quality and supporting agriculture and human well-being. In addition, biomass from forestry, such as wood and wood waste, can – when managed sustainably – be used as a renewable energy source.

Sustainable forestry can also stimulate local economies through jobs in planting, management, logistics and the processing of forest products. Such economic activity can be particularly important in rural areas where other employment opportunities are limited. Forests can also help landscapes adapt to the effects of climate change, for instance by improving watershed management, reducing flood risks and combating desertification. Meanwhile, urban forestry helps improve air quality, provides cooling effects, reduces energy usage in buildings, and enhances urban quality of life.

Incorporating sustainable forestry practices into national and international environmental policies is crucial for leveraging these benefits and advancing the green transition more broadly. Forests are particularly important to the green transition in Finland, as the country's woodlands are large and easily accessible, with many people engaged in jobs related to forest management and the forest industries.

1.1 Objectives of this report

The Finnish government has set a national target for the country to become carbon neutral by 2035. This will be difficult to achieve simply by reducing fossil fuel consumption. As such, maintaining the carbon sink of forest vegetation and increasing renewable energy production represent vital planks in Finland's climate policy. Against this complex backdrop, this chapter attempts to address the following questions:

- Can the role of Finland's forest carbon sink be enhanced?
- What options exist to achieve this goal?
- What would the regional-level implications be for Finland's forest and energy sectors in terms of economic growth and employment?

The remainder of the chapter proceeds as follows. Section 2 describes Finland's climate policy goals and CO_2 emission trends. Next, section 3 presents past developments of the Finnish forest carbon sink, while section 4 describes the economic and regional characteristics of Finland's forest sector. Section 5 then outlines six strategies for promoting the contribution of forests to climate change mitigation and discusses the opportunities and constraints associated with implementing these various strategies, particularly in terms of their regional impacts. Section 6 concludes by outlining the limitations and uncertainties of the study's analysis.

2. Policy goals and emission trends in Finland

The national government has formulated Finland's climate policy in 2022, setting emission reduction targets for both the medium and long term. By 2030, emissions shall decline by 60%, compared to the levels in 1990. By 2050, an emissions decline of 90% shall be reached. Carbon neutrality shall be achieved already in 2035. By 2030, emissions must be reduced to 28.5 million tonnes of CO_2 equivalents (CO_2e), corresponding to -60% from the 1990 baseline. At the EU level, it has been agreed that the carbon sink provided by Finland's land use sector must amount to -17.8 million tonnes of CO_2e in 2030 (Ministry of the Environment 2023).

Fossil fuels in Finland are mainly used in energy production and domestic traffic (Dixon et al. 2023). In the industrial sector, steel industries are large consumers of fossil fuels. The energy production sector's fossil CO_2 emissions peaked in 2003, before decreasing over time. Combined CO_2 emissions from energy production and domestic traffic amounted to 30.6 million tonnes in 1990, increased to 49.6 million tonnes in 2003, and then decreased to 22.3 million tonnes in 2022.

In 2023, new wind power was installed, and a new 1,600 megawatt (MW) nuclear plant was completed and taken into operation (Olkiluoto 3). In response, the CO_2 emissions decreased by 11% compared to those in 2022 (Statistics Finland 2024). In 2023, national total CO_2 emissions excluding the LULUCF sector were reported at 31,673 thousand tons with 27,500 thousand tons related to energy for the production of heat, power, industrial processes and traffic/transport (Statistics Finland n.d.).

In 2024, energy production emissions and domestic traffic emissions are roughly equal, contributing about 10 million tonnes of CO_2 each. In addition, Finland's steel and cement industries emit 5–6 million tonnes of CO_2 each year. Despite the significant progress in 2003-2023, further reductions in emissions are likely to prove challenging. Combustion engines are set to remain in widespread use in the near-to-mid-term despite the active promotion of electric vehicles.

If the trends observed over the 2003–2023 period are linearly extrapolated, energy and traffic emissions will not be completely negated by 2035, although emissions would be relatively low: about 3–4 million tonnes of CO_2. This projection is, however, optimistic given the slow pace of Finland's vehicle fleet evolution. Moreover, the prospects are uncertain regarding CO_2 emissions from the steel and cement industries by 2035.

In light of the 60% reduction target for 2030, emissions from Finland's energy production and its domestic traffic would need to be reduced to 10–15 million tonnes by 2030. Despite the active modernisation of the former and the adjustments made to the latter, achieving this objective will be challenging as things stand. Searching for options to maintain and enhance the role of forests in the green transition is relevant in this context.

National statistics include both CO_2 and the contribution of certain other greenhouse gases (methane and nitrous oxides) converted to CO_2 equivalents. In this report we address CO_2 only, excluding other greenhouse gases.

3. Forest carbon sink trends

The role of forests in climate change mitigation is subject to active debate in Finland. While reducing emissions from fossil fuel combustion remains the government's main policy objective, reaching carbon neutrality by 2035 will be near impossible without significant contributions from carbon sinks.

The National Forest Inventory programme, which has been in operation since the 1920s, forms the basis for assessing forest carbon sinks (Aakala et al. 2023). Originally – and even now – the primary motivation behind the relatively expensive, technically elaborate programme has been estimating the sustainable limits of timber harvests. The programme's main reported attributes include Finland's forest growing stock, as well as the annual increment of trees in Finland expressed as cubic metres/cubic metres per year (stem volume including bark). In terms of carbon sink assessments, volume metrics are converted to carbon mass, specifically the mass of CO_2 sequestered annually from the atmosphere into forest biomass.

The carbon sink in forest trees can be empirically assessed using two independent methods: the stock method and the flow method (Kauppi et al. 2022).

3.1 Stock method

The stock method relies on estimates of the total stem wood volume – often referred to as 'growing stock' (GS) – of all trees in a given area (in this case, Finland) at two points in time separated by an interval of multiple years. The annual change in growing stock is determined

Table 1. Growing stock as observed in Finland's forests, 1990-2020

Year	Growing stock (Mm^3)
1990	1,874
2000	2,003
2010	2,306
2020	2,529

Source: Forest Research Institute (1992, 2001, 2012), Natural Resources Institute Finland (Luke) (2023).

based on the difference between two consecutive estimates. If the growing stock expands, the forest is a CO_2 sink. If it shrinks, the forest is a CO_2 source. Although the conversion from stem wood volume to whole-tree carbon stock involves some uncertainties, the method is robust, highlighting any significant change in growing stock. With this in mind, Table 1 shows how the growing stock of Finland's forests has evolved over the period 1990–2020.

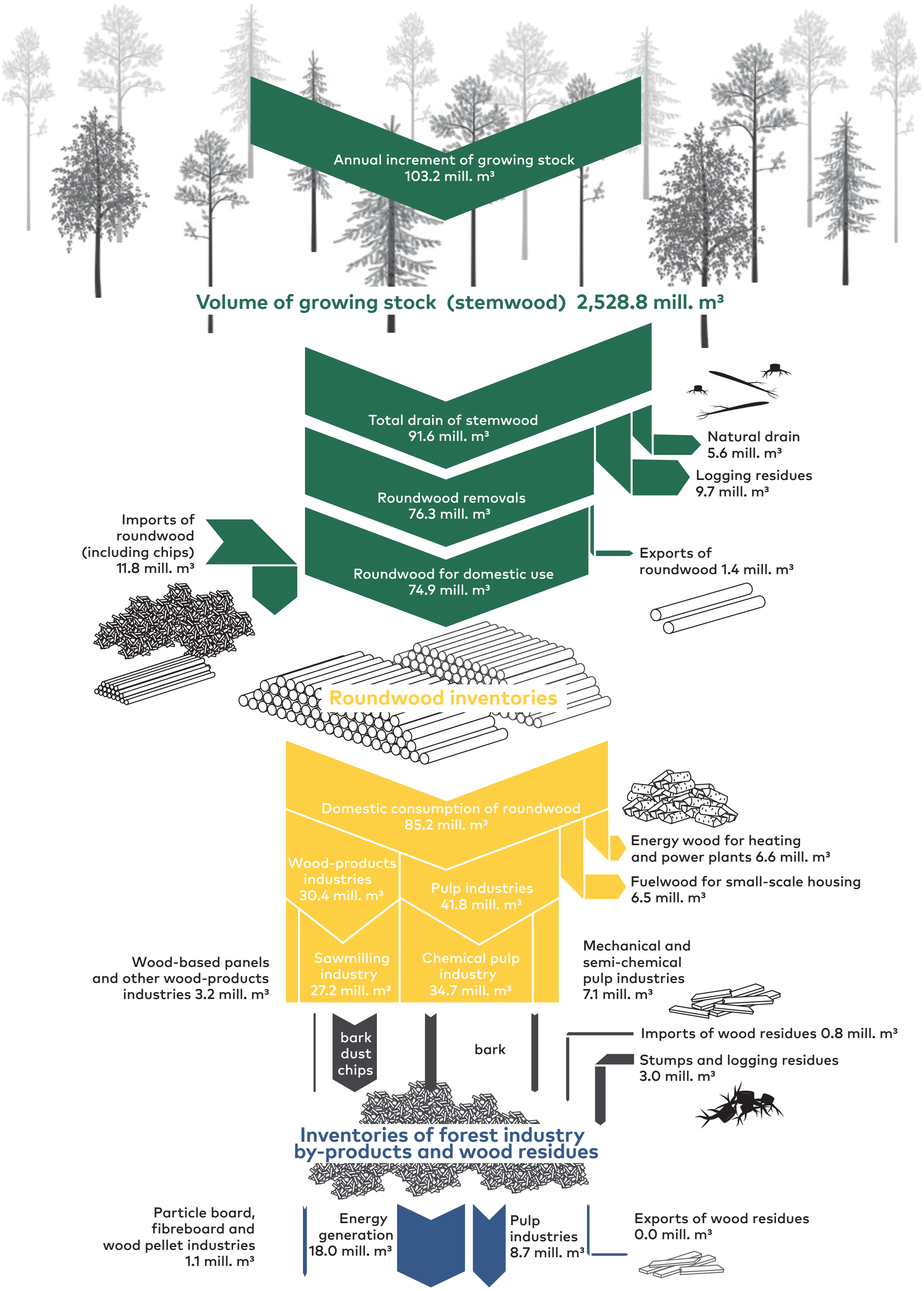
Over the course of 30 years, Finland's growing stock has expanded by 655 million cubic metres (Mm3), which equates to a 35% increase. Here, it should be noted that there are uncertainties related to sampling and measurements, and the rotating fieldwork means measurements do not refer to any exact year. Moreover, there are inter-annual fluctuations arising from, among other things, growing seasons being subject to differing weather conditions and harvest rates responding to business cycles. However, this change from 1,874 Mm^3 to 2,529 Mm^3 is so large that forest resources have, beyond doubt, acted as a significant and continuous carbon sink during this time.

The stock method suggests that, using a standard conversion, the average annual forest carbon sink amounted to nearly 30 million tonnes CO_2 annually during the period in question. The method indicates that the sink was largest from 2001 to 2010 (2,306-2,003=303) and then declined from 2011 to 2020 (2,529-2,306=223). If the latter sequestration rate is sustained alongside the downward trend in fossil fuel combustion referred to above, the prospects for Finland becoming carbon neutral by 2035 are good. However, more detailed data for the 2011–2020 period obtained using the flux method raises concerns.

3.2 Flux method

The flux method is a slightly more complicated procedure than the stock method, requiring a variety of measurements and statistics. All attributes in the flux method are estimated at annual intervals, with wood decrements for any given year subtracted from the corresponding wood increments. If increments are larger than decrements, the forest is a carbon sink, and vice versa. Increments are measured in the National Forest Inventory as the gross annual increments of stem wood volume, including bark. Decrements, meanwhile, include natural mortality, harvest removals and harvest losses. Figure 1 provides an example wood flows in Finland in 2021, distinguishing between increment and various sources of decrement.

Figure 1. Finland's wood flows, 2021



Source: Natural Resources Institute Finland (Luke)(2023).

Table 2. Annual changes of growing stock and carbon sequestration attributes, 2006–2023

Year	Gross anual increment (I)	Annual decrement (D)	Harvest procurement	Unharvested decrement	Net roundwood import	Net change growing stock (=I-D)	Net CO_2 sequestration in live trees (MTons)	International change of growing stock	International net CO_2 sequestration
	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mtons	Mm^3	Mtons
2006	99.5	69.1	56.9	12.1	19.2	30.4	41.9	11.3	15.5
2007	99.5	76.8	63.9	12.9	16.0	22.7	31.3	6.8	9.3
2008	105.5	71.5	58.3	13.1	14.7	34.0	46.8	19.3	26.5
2009	105.5	60.3	48.3	12.0	7.3	45.2	62.1	37.9	52.1
2010	105.5	73.0	59.7	13.3	9.4	32.5	44.7	23.1	31.8
2011	105.5	73.8	60.4	13.4	8.9	31.7	43.6	22.8	31.4
2012	105.5	73.1	59.9	13.2	8.5	32.4	44.5	23.9	32.8
2013	107.8	79.3	65.3	14.0	10.0	28.5	39.2	18.5	25.5
2014	107.8	79.3	65.3	14.0	8.9	28.5	39.2	19.6	27.0
2015	107.8	82.4	68.0	14.3	8.5	25.5	35.0	16.9	23.3
2016	107.8	84.8	70.3	14.5	8.5	23.0	31.6	14.5	19.9
2017	107.8	87.2	72.4	14.8	7.5	20.6	28.3	13.1	18.1
2018	107.8	93.7	78.2	15.5	9.1	14.1	19.4	5.1	6.9
2019	103.2	88.0	72.9	15.1	9.8	15.2	20.9	5.5	7.5
2020	103.2	83.4	68.9	14.5	9.7	19.8	27.3	10.1	13.9
2021	103.2	91.6	76.4	15.3	9.8	11.6	15.9	1.8	2.4
2022	103.7	89.5	75.1	14.4	3.9	14.2	19.5	10.3	14.2
2023	103.7	86.8	72.7	14.1	3.3	16.9	23.2	13.6	18.7
TOTAL	**1890.3**	**1443.4**	**1192.9**	**250.6**	**172.9**	**446.8**	**614.4**	**273.9**	**376.6**

Note: A standard conversion from stem wood volume (cubic metres) to whole-tree CO_2 sink (tonnes) is to multiply by a factor of 1.375 (when growing one cubic metre of stem wood, trees need to sequester 1.375 tonnes of CO_2 from the atmosphere). "Net CO_2 sequestration in live trees" refers to trees within Finland, and "International net CO_2 sequestration" is calculated deducting the impact of "Net roundwood imports" from domestic sequestration.
Source: Natural Resources Institute Finland (Luke); based on Nöjd et al. (2021) including updates 2022-2023.

The pulp (41.8 Mm^3yr^{-1}) and wood product (30.4 Mm^3yr^{-1}) industries are the largest, economically most important elements of the forest bioeconomy. Heating, power plants and wood combustion in private homes consumes 13.1 Mm^3yr^{-1}, although this does not give a full picture of wood's role as a primary source of energy in Finland. If industrial residues such as bark, saw dust, residual lignin and hemicellulose are taken into account, approximately half of Finland's domestic wood harvests enters into energy combustion. Industrial forest products made in Finland are predominantly exported, while energy flows – which are mainly industrial by-products – remain within the country.

While natural mortality ('natural drain') is worth noting, it is the industrial consumption of roundwood ('roundwood removals') that acts as the main driver of decrements. Domestic roundwood is the main raw material used by the wood product industries, though imported wood has also been used. Finland has for decades been a net importer of roundwood.

Completing a flux calculation of the forest carbon sink requires annual increment and decrement estimates. The decreasing trend in the forest carbon sink revealed in Table 2 gives cause for national concern.

As Table 2 indicates, 2009 saw the largest estimated change in growing stock (+45.2 Mm^3). This occurred in response to the 2008 financial crisis, with industrial roundwood consumption plummeting from 58.3 Mm^3 of domestic harvests (along with 14.7 Mm^3 of imported wood) the previous year to 48.3 Mm^3 of domestic harvests (and 7.3 Mm^3 imported wood) in 2009. Exceptionally, less than half of the annual increment was actually harvested in 2009. In terms of carbon sequestration, the estimated change corresponded to +62 million tonnes of CO_2 (= 45.2 x 1.375). Even if the decrements abroad are taken into account, the sink in 2009 was very high (52.1 million tonnes of CO_2).

Overall, the results produced by the flux method are broadly consistent with those of the stock method, with the cumulative change in growing stock over the period 2011–2020 estimated at +239 Mm^3 using the former method, and +223 Mm^3 using the latter. The sink has, however, decreased over time, with a minimum level estimated for 2021 (15.9; internationally only 2.4 million tonnes of CO_2).

All these estimates, using stock method and flux method, refer to sequestered CO_2 in live trees. The eventual carbon sinks/sources in forest detritus, harvest residues, peat soils, forest mineral soils, aquatic ecosystems in forested landscapes, or carbon in harvested wood products are not included.

4. Forestry and the forest industries in Finland's regional economies

This section provides a comprehensive overview of Finland's forest sector, focusing in particular on its regional and temporal patterns and its role in the energy sector.

4.1 Regional and temporal patterns of Finland's forest sector

In Finland, forests are prevalent in rural regions, while forest industries are scattered across small and mid-sized cities. The sector's manufacturing industries face increasing challenges in modern Western economies, but still have an im-

Table 3. Forestry and forest industries in the national economy of Finland

Sub-sector	Share of GDP	No. of jobs
Forestry	1.1%	11,300
Forest product industries	2.6%	38,400
Upstream industries (machinery and equipment)	0.2%	3,700
Logistics and road transport of roundwood and products	0.3%	7,200

Source: Statistics Finland, National Accounts and Finnish Forest Industries (2023).

portant role to play in generating medium- and high-income jobs (Smil 2020). Finland's peripheral regions – which often have difficulties offering alternative employment – benefit in particular from the forest sector.

The majority of Finland's forests are privately owned – indeed, the country has some 600,000 owners of forest land. Meanwhile, the Finnish Forest Service (Metsähallitus, Forststyrelsen) governs public forests, which account for about a third of the country's woodland. Industrial facilities are almost exclusively privately owned.

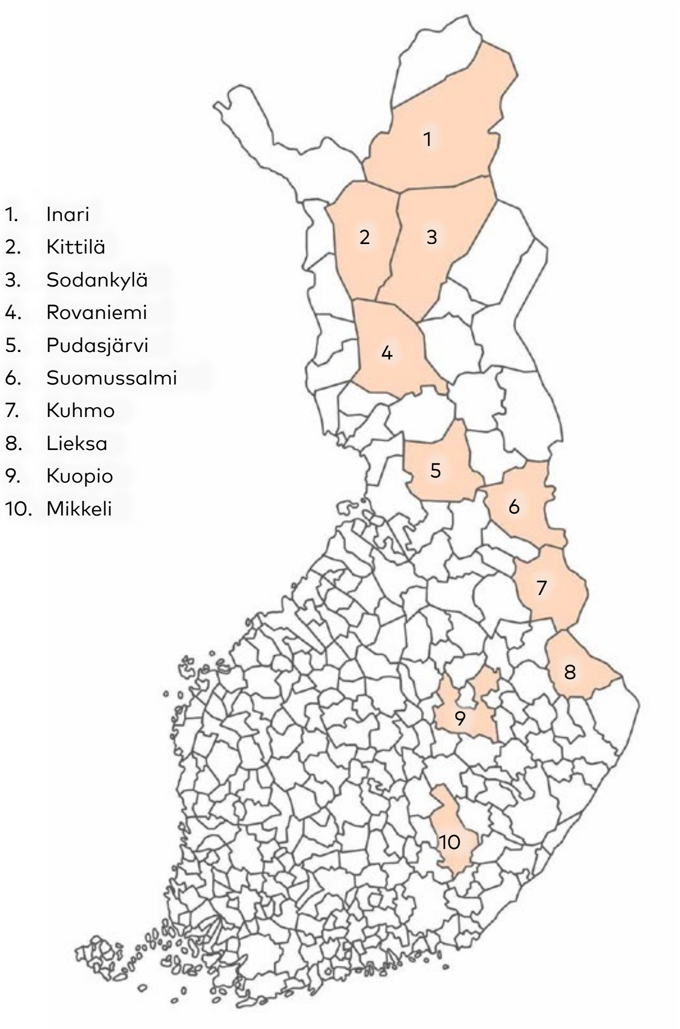
Wood-based industries generate a diversity of products and services, including sawn wood, laminated wood, board, pulp, printing paper, tissue paper, stickers, veneers, chemicals, solid and liquid fuels, industrial steam, heat and electricity. Finland's forest products are mainly shipped to international markets, with the largest country recipients of Finnish exports ranked as follows (2022): Germany 11.7%; China 9%; USA 8.4%; UK 6.7%; Japan 5%; and Sweden 4.9%. About 60% of Finland's forest products were delivered to other EU countries, while only a small fraction of production was delivered to the domestic market.

Mechanical products (lumber, laminated wood, veneers, etc.) are used for construction; board is used for packaging (both in business applications and retail); and pulp is partly used in the domestic board and paper industries, and partly delivered directly to corresponding foreign industries. Global demand for printing paper has declined with the transition to digital communication, while demand for board, sanitation paper and lumber has increased. Overall, Finland's forest industries have remained relatively competitive in the international market as indicated by the rising forest harvests. Investments in industrial capacity have continued over recent years, including the Kemi pulp mill (completed in 2023) – the second largest investment in Finland's industrial history. The share of gross domestic product (GDP) and number of jobs provided by forest sub-sectors in 2021 are shown in Table 3.

While these numbers may seem relatively small, the 2023 share of forest products in Finland's total exports came to 21%, while sales of roundwood amounted to around €3 billion.

The most abundant timber resources are found in northern, central and eastern Finland, with the ten mu-

Figure 2. The ten municipalities hosting the largest timber resources in Finland



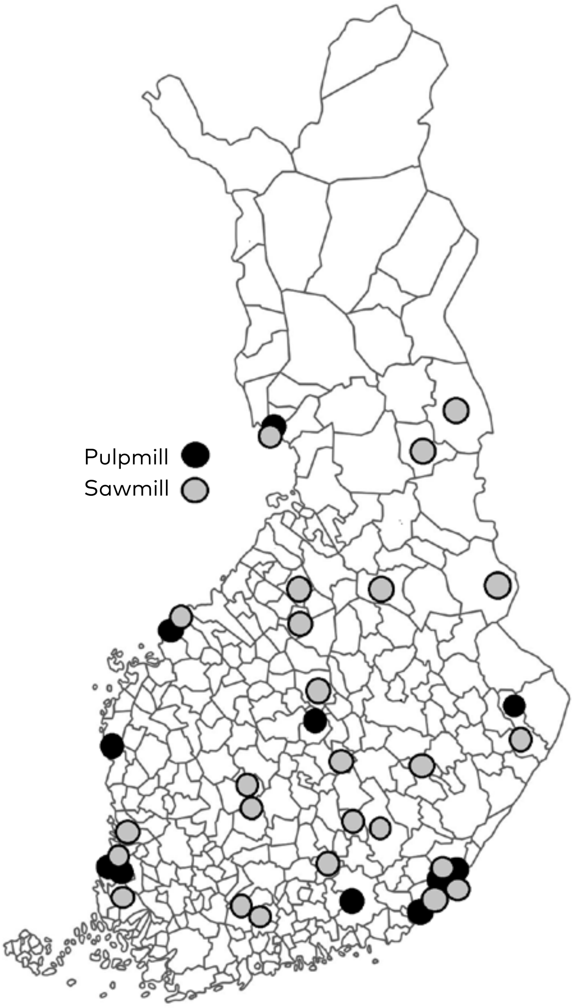
Source: Figure created by Mats Stjernberg (Nordregio), based on Natural Resources Institute Finland (Luke).

nicipalities highlighted in Figure 2 hosting the largest reserves of growing stock – in total, about 430 Mm^3. By contrast, the growing stock in the Helsinki metropolitan region (the cities of Helsinki, Espoo and Vantaa) only came to 7 Mm^3. As this suggests, forests are truly a rural resource.

The regional geography of Finland's wood-processing industries does not correlate with the location of forest resources, nor the location of the country's main population centres. Instead, the largest mills are to be found near water courses, rail connections or harbours in relatively small industrial communities scattered across the country (Figure 3).

As of 2024, Finland is estimated to have a population of 5.6 million people. Of these, only 1.15 million live in municipalities where large wood-processing industries are located, with such industries mostly absent in many of Finland's large cities, including Helsinki, Espoo, Vantaa and Turku.

Figure 3. Locations of Finnish wood-processing industries

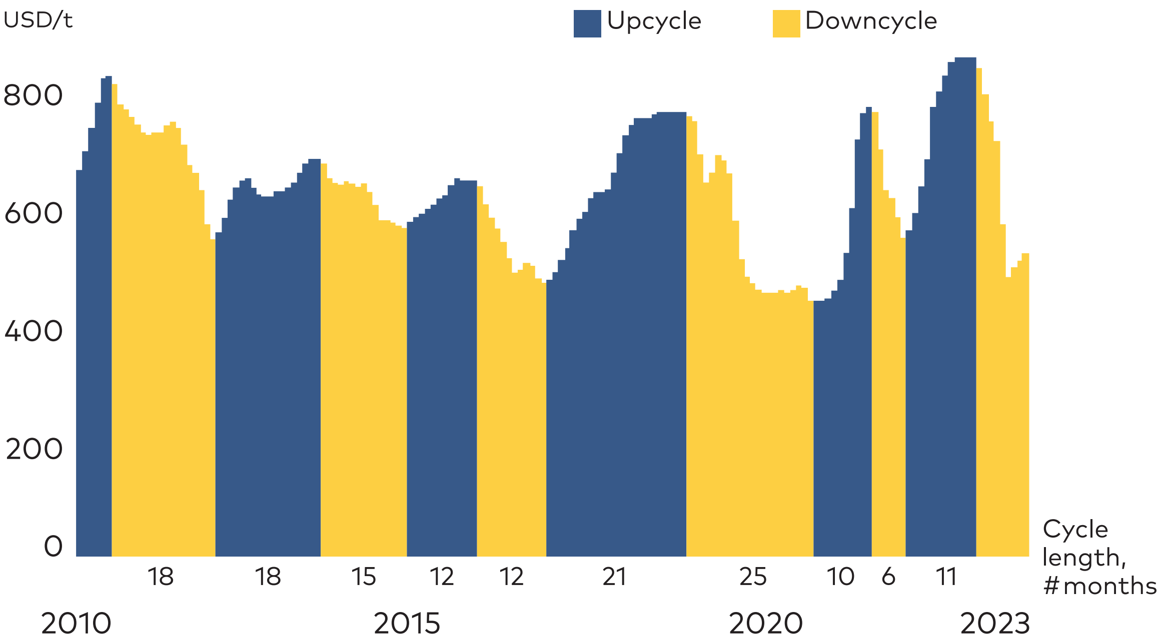


Source: Own illustration based on Finnish Forest Industries (www.metsateollisuus.fi/tilastot).

Finland's wood-processing industries have evolved over time, with the long-term trend – aside from a swift phase-out of printing paper production since 2008 – being a slow expansion of production volumes. Even so, a rapid expansion in other industrial and service sectors since the 1970s has meant a gradual decline in the relative economic and social importance of the country's wood-processing industries.

Over the past few decades, the international market for forestry-related items has experienced fluctuating cycles of about 2–4 years (Figure 4). More recently, the COVID-19 pandemic generated an unforeseen upturn. Lockdowns and remote work policies prompted people to spend more time at home, in turn leading to an increase in home improvement projects and swelling demand for associated wood products such as lumber. Moreover, the surge in online shopping arising from the pandemic meant higher demand for packaging materials, much of which is derived from wood pulp. Demand for other forestry-related items, particularly disposable health-

Figure 4. Pulp price volatility



Note: Business cycles generate inter-annual variation in the demand for industrial wood. This figure exeplifies this by showing variation of international market price of short-fiber pulp. Source: AFRY (2023).

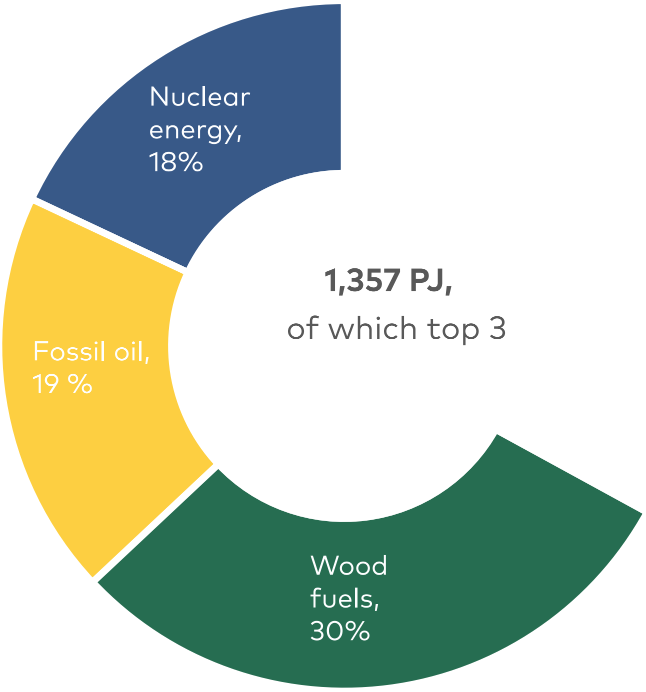
care and sanitation products (e.g. paper towels, toilet paper, cardboard partitions), was also heightened during this time. Inevitably, this upswing was followed by a downturn, which intensified following Russia's February 2022 invasion in Ukraine.

4.2 Role of wood in Finland's energy sector

Bioenergy is regarded as carbon neutral due to the fact that biomass combustion recycles CO_2 previously extracted by photosynthesis back into the atmosphere (Pyne 2021). This perception of bioenergy as carbon neutral reflects the established Intergovernmental Panel on Climate Change (IPCC) view but has been challenged by arguments related to the short-term 'opportunity cost' of combustion, as well as the 'carbon debt' depleting the forest carbon stock (Holtsmark 2012, Searchinger et al. 2009).

Energy generation is a by-product of the Finnish forest sector, rather than a strategic primary product, with the value added lower than in producing paper, board, tissue, veneers or lumber. Even so, about half of Finland's harvested timber ends up in combustion due to the large volumes of bark, sawdust, lignin and hemicelluloses that cannot be used as raw materials for high-value products (see Figure 1). Biomass combustion is economically unattractive to the forest products industries, which perceive it more as a waste management solution than a means of energy generation. Regardless, the incinera-

Figure 5. Top three sources of primary energy in Finland, 2021



Note: The remaining 33% of total energy consumption (not shown in the figure) was derived from smaller energy sources, such as hydropower, coal, natural gas, peat, electricity imports, wind and solar power.
Source: Statistics Finland (2022).

tion of industrial waste provides surplus power that is delivered to the grid, especially from modern pulp mills.

Finland's sawmills and pulp and paper mills are almost entirely energy self-sufficient and fossil free. The 2023 COP28 meeting in Dubai called for 'transitioning away from fossil fuels in energy systems', which lends support to sectors such as the forest product industries, which can operate without fossil fuels in their industrial processes (albeit fuel is required for road and vessel transport).

There is a small bioenergy market that is separate from the forest product industries. About 15% of Finland's bioenergy is produced by combusting small-sized trees in the furnaces of municipal district heating systems, farms or small-scale industries. In addition, the traditional wood-fired stoves and cookers used in some Finnish homes consume a small fraction of national timber harvests. It is, however, bioenergy production within the forest product industries – based on the combustion of wood fractions, which do not qualify for products – that is quantitatively decisive.

The role of forests in Finland's energy production is exceptional within the European Union (EU), comparable only with Sweden. Although producing bioenergy is only a marginal goal for the forest sector, wood biomass is nevertheless the most important source of primary energy in Finland (Figure 5). Industrial products are mostly shipped abroad, while industrial waste combustion serves the domestic energy market and is thus reflected in domestic energy statistics.

4.3 Leakage and the global demand for wood products

If the forest product industries were scaled down across the EU region, including Finland, harvests elsewhere would increase to meet international demand for wood-based products (Kallio et al. 2018). Such a shift from one area to another is referred to as 'leakage' or 'teleconnection' (see Mayer et al. 2005, Roux et al. 2022).

Wood-based products are not irreplaceable within modern, middle-class lifestyles: printing paper can be replaced by electronic media; lumber by steel or concrete; board packaging by plastics; and wood fuels by other sources of primary energy (e.g. fossil fuels, nuclear energy, wind and solar power).

According to Kallio et al. (2018), if forest harvests in the EU were reduced, incremental non-EU harvests would fill 80% of this reduction, as increased international prices for products would lower demand. This could trigger transitions from wood-based products to alternative products, leading to both positive and negative effects on the green transition that lie beyond the scope of this chapter.

5. Enlarging Finland's forest carbon sink

This section explores how the Finnish authorities might go about increasing the country's carbon sink, setting out the current situation regarding land use and land cover changes, before going on to outline six policy changes that could – potentially in combination – address the challenges faced.

5.1 Land use changes

Land use changes affect the carbon balance. Clearing forests for urban development (e.g. building roads, power lines, new arable lands, wind farms) is a source of carbon emissions, while the reverse process provides a carbon sink. At the global scale, land cover conversion from forest to non-forest (deforestation) is a significant problem (Moreira-Dantas & Söder 2022). This is not, however, the case in Finland. Since 1950, the land area covered by forests has remained largely unchanged, with the abandonment of former agricultural (and other) lands roughly equalling land demand for new settlements and infrastructure. Boreal forest vegetation has covered Finland continuously throughout human history, with moderate areas of land reserved for agriculture, animal husbandry and settlements since the Middle Ages. Finland has about 20 million hectares of forest and about 2 million hectares of agricultural land, most of which has been cleared from forests. Although agricultural land could in theory be converted back to woodland, such a programme – even if implemented at a large scale – would only contribute marginally to enhancing the carbon sink by 2035, as it takes 20–40 years for forest vegetation to build up on newly forested lands.

5.2 Land cover changes

Given the relative consistency of Finland's forested area over time, the country's carbon sink since the turn of the century has been maintained almost entirely by increased forest biomass density: trees in Finland have become more numerous, with stems becoming on average taller and thicker (Kauppi et al. 2006, Henttonen et al. 2019). In other words, while land use is not changing, land cover is.

Given how crucial enhancing the forest carbon sink is, the question arises of how best to promote forest density change within the current 2024–2035 timeframe. Is it realistic to expect the number of trees in existing forests to continue rising indefinitely? How can the average tree become thicker and taller, year after year? Can current trends persist alongside the harvesting of sufficient trees to fulfil industrial and energy demand? As the latter question implies, reconciling harvests with the carbon sink is at the core of these debates.

5.3 Climate mitigation policy options

Option 1: Increase the gross annual increment

Finland's gross annual carbon sink increment for 2023 was recorded at 103.7 Mm^3y^{r-1} (Table 2). If this figure was increased using silvicultural actions to 110 or 120 Mm^3y^{r-1}, this would strengthen the carbon sink rate and contribute to sustainable harvests. The incremental wood growth could be directed into making wood products (with economic and social benefits); producing bioenergy (substituting fossil fuels); and/or enhancing the growing stock (piling up forest biomass in forest ecosystems at an accelerated rate). While bolstering the increment would be difficult within a 2–5 year time period, it may be feasible by 2035.[3]

Strong laws and regulations preventing the misuse of forests are essential for sustainably building the gross national increment. When it comes to silvicultural actions, the relevant decisions are made by the forest owners. As such, effective enforcement mechanisms are key to ensuring the law is adhered to.

Allocating resources to management and restoration projects offers another means of facilitating the sustainable management of forests, with financial support provided by public funding or private sector investments. In Finland, timber sales have acted as the main source of financing for silviculture and forest management. Thus, engaging forest owners, local communities and stakeholders regarding the importance of forests and how to care for them can empower individuals to contribute to more effective, sustainable forest management practices.

Monitoring and controlling pests and diseases is also critical to maintaining healthy forests. This can be achieved through biological control methods and resistant tree varieties. Alongside this, maintaining soil health and ensuring adequate water supply are crucial for forest growth. In some cases, applying the right type and amount of fertiliser is a useful approach, especially in degraded soils. Doing so must, however, be balanced with the risk of environmental pollution.

Implementing sustainable logging practices that minimise damage to the surrounding trees and forest floor can help maintain ecosystem integrity and promote regrowth. Finland's seasonal climate allows for a forest growing period of 100–180 days (Aalto et al. 2022). Here, avoiding spring harvests while favouring autumn harvests can help sustain growing stock during the critical summer weeks. Reducing the risk of fire by creating fire breaks and promoting less-flammable species offers

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[3] For a recent analysis from Sweden, see Paulsson et al. (2023).

another way of protecting forests and maintaining their health and productivity.

Finland's forest increment nearly doubled during 1970–2008, but has since stagnated (see also Table 2) (Henttonen et al. 2024). Whether there can be any return to the earlier trend is unclear. Theoretically, if the increment were raised to 110–120 Mm^3y^{r-1}, with the entirety of the extra increment incorporated into growing stock (and assuming the decrement remained unchanged), an additional sink of 9–23 million tonnes of CO_2 would be delivered annually.

Option 2: Reduce domestic harvests

Reduced harvesting allows forests to grow denser, thereby enhancing their carbon stocks and combat global warming, especially in the short term. If harvests were reduced (from 70–78 Mm^3y^{r-1}, Table 2), surplus biomass would accumulate in forests. Even if natural mortality were to increase, coarse woody debris would accumulate in forest ecosystems, contributing to the ecosystem carbon sink.

Forest owners decide how much to harvest. Balancing the pros and cons of reducing harvests requires careful management, as well as policies that take into consideration both environmental sustainability and the needs of local communities – forest owners in particular. In this respect, adaptive management strategies and investments in alternative livelihoods can help mitigate the negative impacts of reduced forest harvesting.

Lowering forest harvesting rates can help preserve biodiversity, protect species from habitat destruction, and maintain ecosystems that provide such crucial services as water purification and carbon sequestration. Given forests play a key role in preventing soil erosion and maintaining water cycles, reduced disruption through harvesting will help maintain soil structure and reduce sedimentation in rivers and lakes. Intact forest landscapes also offer greater recreational opportunities and aesthetic value, which can be beneficial for local communities, especially those reliant on eco-tourism.

On the negative side, reducing timber harvests may lead to wood product shortages, including construction materials and paper. This is likely to drive up prices and lead to increased imports from EU, potentially with higher environmental costs if sourced from less regulated countries. Forestry represents a significant economic activity in Finland, with reduced harvesting potentially causing job losses and economic downturns in areas dependent on logging. In some cases, strategic harvesting is necessary to maintain forest health, such as reducing the risk of wildfires by removing excess fuel or managing pests and diseases. Here, reduced harvesting might impede these essential management practices.

Hypothetically, reducing harvests is an attractive option in the context of a 2–5 year timeline as it would immediately impact the carbon balance of Finland's forests. On the negative side, this option contributes only marginally to the global carbon balance once leakage effects are accounted for. Moreover, reducing harvests would adversely impact the local economies of forest dependent municipalities.

To give a statistical example of this policy option, if harvests were lowered to 60 Mm^3y^{r-1}, this would provide an additional 14–25 million tonnes of CO_2 to

Finland's carbon sink (assuming the increment and natural decrements do not change).

Option 3: Improve the material efficiency of wood processing ('more from less')

The phrase 'more from less' – often employed in discussions about sustainability, business processes and technology – generally refers to a strategy aimed at increasing efficiency and productivity while using fewer resources, whether this be materials, energy or time (Beyeler & Jaeger-Erben 2022). Often, achieving more from less requires innovation, which may be achieved via new technologies, processes or practices that facilitate more effective use of resources.

In environmental contexts, 'more from less' encompasses reducing the consumption of limited or finite resources, minimising waste and shrinking the environmental footprint of activities. For businesses, 'more from less' can translate into cost savings. Through optimising processes and reducing resource use, companies can lower their expenditure while maintaining – or even increasing – productivity.

In a broader societal context, achieving more from less can also imply improving quality of life by making systems more efficient, thereby ensuring they require less work and generate less waste, contributing in turn to a healthier living environment. This concept of maximising value from available resources by minimising waste and redundancy is central to a number of modern practices and philosophies, including lean manufacturing, minimalism and the circular economy.

Improving the efficiency of industries and logistics can be seen as a constant, ongoing process driven by business interests. In the context of Finland's forest industries, for example, surplus electricity (bioenergy) is produced more efficiently in newer pulp mills than their more aged equivalents. In light of the 'more from less' approach, the economic returns provided by the forest industries could theoretically improve even as raw material use rates fall. In recent years, however, Finland's forest industries have not adapted well in this respect.

Until the end of the 1990s, high-quality printing paper used for offset printing was a key product coming out of the country's forest industries. Since then, the physical media forms making use of such paper (magazines and glossy journals) have been superseded by electronic modes of communication, such as social media. While the emergence of electronic media may contribute to the 'more from less' paradigm given the lean resources required to transmit information, from a Finnish perspective the economic earnings per harvested cubic metre of wood have been constrained, with the most rewarding product (high-quality printing paper) now phased out of the market. While new products may emerge over time, it will take many years to create industries capable of large-scale production.

'More from less' offers an attractive environmental management strategy due to the fact that it can contribute to the forest sector's economic performance. In contrast to options 1 and 2, forest owners cannot contribute much – instead, it is the role of private companies in re-organising industrial processes and logistics that is decisive. For decades, material efficiency has been a key strategic goal for the sector. In this respect, there are several opportunities for improvement, especially given a number of existing factories are so old as to be approaching obsolescence. For example, of the 17 major pulp mills currently in Finland, just two were constructed in the 21st century (Äänekoski in 2017 and Kemi in 2023). The recovery boiler is the heart of a pulp mill, with more modern models demonstrably more efficient when it comes to using wood, recovering chemicals and producing energy. Modernising pulp mills therefore offers a strategic opportunity for companies operating in Finland – while this may not be feasible within the next five years, it is certainly a possibility by 2035.

Option 4: Change the product palette

'Long-lived forest products' refers to materials derived from forests that have a long and useful life, while serving as carbon storage to help mitigate climate change. This includes wood used to construct buildings, bridges or other structures, as the timber used stores the carbon absorbed by its constituent trees for the entire duration of the building/structure's lifespan – which may be several decades or even centuries. High-quality wooden furniture that lasts for years and may be passed down through the generations also encapsulates carbon for a long period. Other examples include wooden flooring, which can last for decades with proper care, and utility poles and cross-arms, which are designed to last many years under harsh environmental conditions.

In sum, the concept underlying long-lived forest products is to extend the period that carbon is sequestered from the atmosphere. By harvesting wood and turning it into durable goods, the carbon captured by the trees is locked away in the products rather than quickly being released back into the atmosphere through decomposition or burning. As such, the strategy provides an additional tool for sustainable forestry and climate change mitigation efforts.

Finland's pulp and wood product industries consumed, respectively, 41.8 Mm^3 and 30.4 Mm^3 of wood in 2021 (Figure 1). While some adjusting of this ratio in favour of long-lived products is certainly possible, further research is needed on market demand and possible leakage. Assuming there is no change in harvest volumes, altering the product palette could improve the carbon sink provided by harvested wood products, but would not change the forest carbon sink.

In some instances, renewable, wood products may have to compete with non-renewable, products (see Braun et al. 2016). Here, one approach often adopted in climate change mitigation efforts is to develop and use those products that can most efficiently replace their fossil fuel-intensive equivalents. While science is inconclusive regarding the quantitative substitution effect of using harvested wood products instead of their non-renewable counterparts, it has the potential to be substantial, influencing economic patterns, technological development, and global environmental outcomes (Brunet-Navarro et al. 2021, Geng et al. 2017). As such, it should be seen as an integral part of achieving broader sustainability and climate goals.

The substitution effect revolves around how consumers and industries might best be induced – via changes in relative prices, technological advancements and policy incentives – to switch from goods and services with a high carbon footprint to alternatives that are more environmentally friendly. As renewable technologies become more cost-effective, so the economic incentives for switching to renewables increase. For example, falling prices for solar panels has meant more businesses and households are turning to solar energy for their electricity needs. The same holds true for wood-based products, provided their performance can meet required environmental and economic standards.

Governments can influence the substitution effect through policies that affect building standards, carbon pricing, subsidies for renewable materials and penalties for high-emission products. Through such policies, fossil fuel-intensive products can be made more expensive relative to their renewable counterparts, thereby encouraging substitution.

Advances in technology can lead to renewable products not only being cheaper, but more efficient and convenient – for instance, making wood-fibre packaging competitive with plastics made from natural gas or oil. Moreover, consumer preferences may be shifted by growing awareness of climate change and environmental issues, with people driven towards choosing greener, renewable alternatives.

Industries can adapt to increased demand for renewables by altering their supply chains, further reinforcing the substitution effect. On a global scale, the substitution effect has the potential to cause changes in market dynamics and international trade, with the countries and companies taking the lead in renewable technologies gaining competitive advantages.

Option 5: Import roundwood or pulp

The international forest sector has become increasingly globalised, with Bösch et al. (2023) observing: 'For example, roundwood is harvested in Laos and transported to Vietnam, where it is processed to sawnwood. Then, the sawnwood is transported to China, where it is processed to furniture. Finally, the furniture is shipped to Spain, where it is consumed'. This in turn has driven tropical deforestation, mainly through tropical forests being converted to agricultural use (Abman & Lundberg 2020). On top of this, illegal logging remains an unresolved problem (Piabuo et al. 2021). Teleconnected inter-country trade impacts are highly relevant to the global ecology and therefore subject to intensive scientific research (Henders et al. 2015).

While Finland's primary role in the forest sector from an international perspective is one of exporter, exchanges of raw materials and products occur both ways. In the past, roundwood imports have mainly been sourced from Russia, although wood-containing materials have also been imported from, among other countries, Sweden, Poland, the USA, France and Brazil (Bösch et al. 2023).

Imports from Russia declined gradually after 2006, then dramatically after 2022 (Table 2). The first reduction came in response to new customs fees imposed by the Russian government, effective from 1 June 2006, aimed at attracting forest industrial investments by penalising exports of unfinished wood. The processing of Russian wood in Finland then ceased completely in 2022 following Russia's full-scale invasion of Ukraine. These changes imply an increasing pressure within Finland to use domestic roundwood, with the consequent potential to relax domestic harvests if raw material can once again be sourced from abroad. Imported roundwood does not affect the carbon sink of forests in the country where the raw material is processed. Instead, harvest decrements occur in the forests of the exporting country (Mayer et al. 2005).

One feasible option is to import pulp to Finland. Unlike roundwood, pulp is a global commodity sufficiently valuable to justify shipping around the world. Finnish companies produce pulp in Uruguay and Brazil, from where production is directed, in particular, towards the Chinese market (Cheng et al. 2023).

Imports can replace domestic raw materials. If domestic harvests were to be reduced and imports increased, industrial production volumes would not be affected, meaning the adverse social and economic effects would be limited mainly to harvest operations and forestry. As such, the forest products industries could remain at full capacity, assuming imported raw materials are available at approximately at same cost as their domestic equivalents.

As an example, let us assume the 2006 ratio for imported wood/domestic wood could be reintroduced. That year, industries consumed 75.5 Mm^3 of wood: approximately 56.9 Mm^3 from Finland and 19.2 Mm^3 from abroad (Table 2).[4] If Finland purchased new imports equivalent to harvesting 10 $\mathrm{Mm}^3\mathrm{y}^{r-1}$, domestic harvests would fall, in theory lifting the carbon sink by about 14 million tonnes of CO_2.

While increasing imports of raw materials would be beneficial to Finland's carbon sink statistics, however, shifting harvests out of the country might not be helpful in advancing global climate mitigation goals.

Option 6: Implement BioCCS (carbon capture and storage from bioenergy)

Biomass combustion in Finland equates to 30–40 million tonnes of biogenic CO_2 returned to the atmosphere each year. Figure 1 depicts the pathways of this flux, from photosynthesis and forest increment to being partly contained within products. Solid and liquid fuels derived from harvest and wood residues are burned in large quantities, with pulp mills – where black liquor is treated in recovery boilers – hotspots for these biogenic CO_2 emissions.

In a modern pulp mill, more than half the inserted wood material is combusted for energy. Thus, if a plant consumes 5–7 Mm^3 wood annually, it releases 4–5 million tonnes of CO_2 in flue gases. The concentration of such large emissions in a single place has drawn attention to capturing and storing the CO_2 from flue gases, thereby preventing it from returning to the atmosphere and generating negative CO_2 emissions (Hu et al. 2023). Currently, no such facilities exist in Finland, and efforts elsewhere also remain in the pilot phase. A large-scale project is advancing in Stockholm that promises to be an important Nordic test case for the new technology (Löfstedt 2024).

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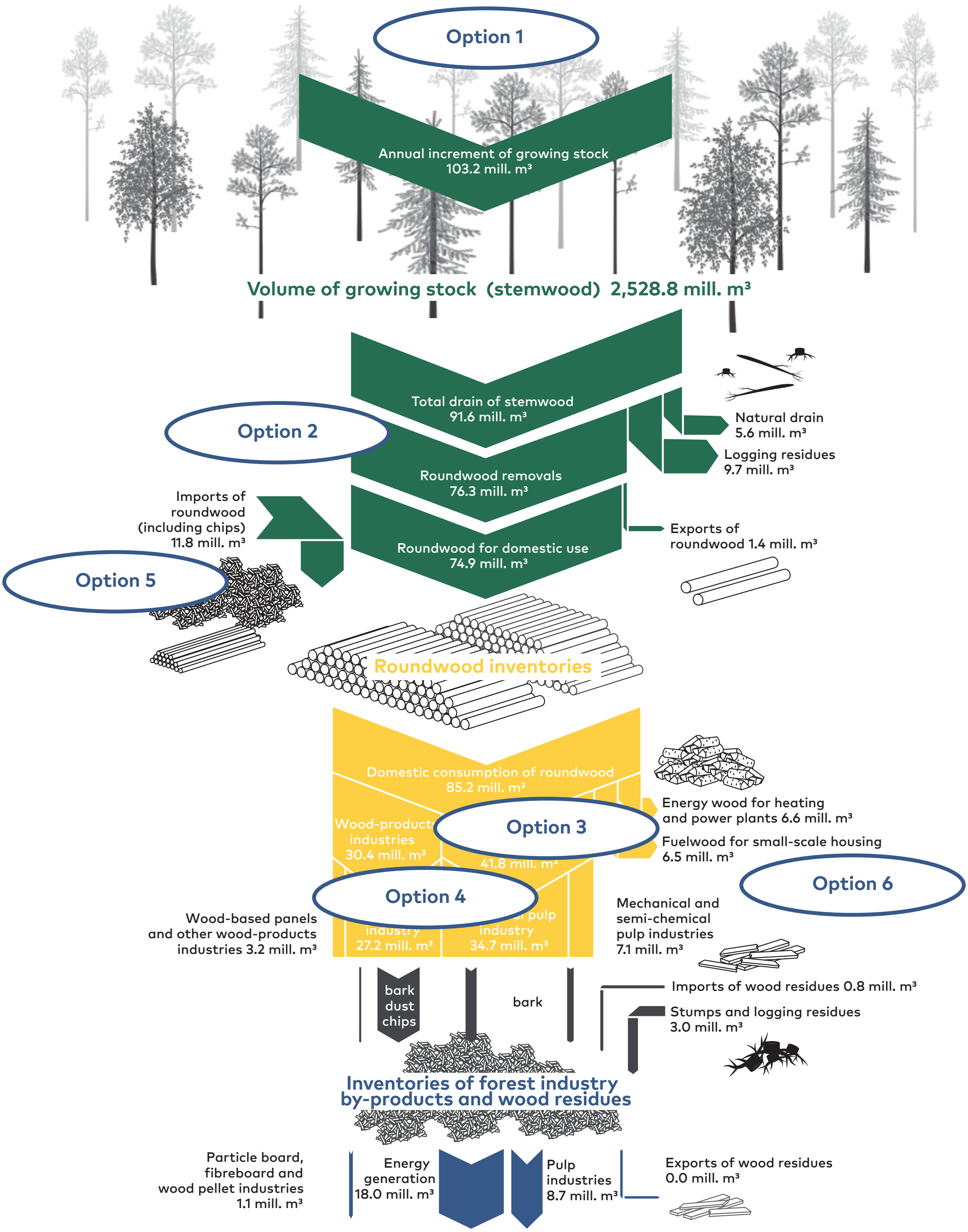
[4] The total figure for wood consumption does not correspond exactly with the combined domestic and imported wood figures as non-industrial users absorbed some domestic harvests.

Figure 6. Summary of options potentially changing the carbon sink of forest vegetation in relation to the wood flows of the forestry/forest industry system



Source: Natural Resources Institute Finland (Luke)(2023).

While the potential for BioCCS in Finland is in theory huge, the obstacles standing in the way of the required carbon capture and, especially, storage processes have yet to be fully surmounted. As such, it is unrealistic to expect this option to be implementable at an industrial scale in the near term (i.e. before the end of the 2020s). Theoretically, however, if 10% of Finland's biogenic CO_2 emissions were captured and stored, emissions would be reduced by 3–4 million tonnes.

5.4 National economy responses

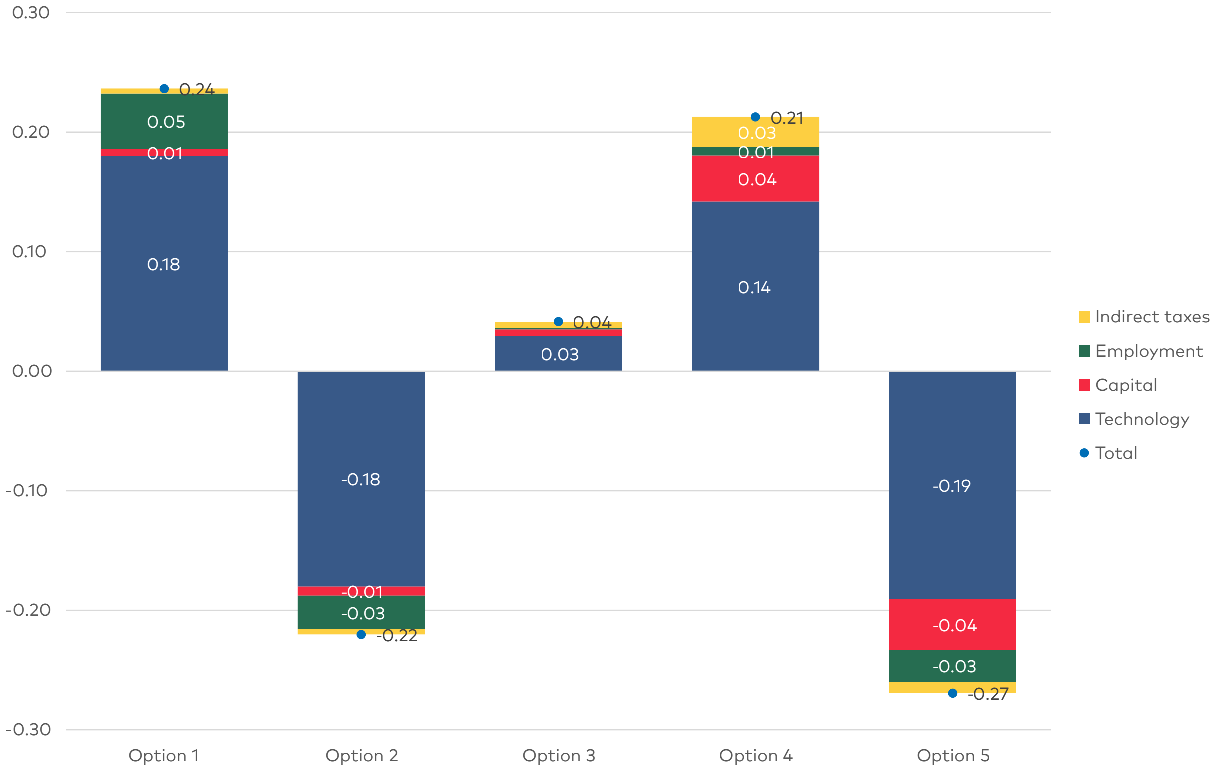
The six options discussed above can also be compared in terms of their economic impact. For this purpose, we make use of FINAGE – a computable general equilibrium model of the Finnish economy. While the effects of the policy options would by their nature be concentrated in the regions where the forest industries are located, the focus here is on the national level, as a more regional approach would require detailed, factory-level scenarios that are beyond the scope of this chapter. Moreover, option 6 is excluded from the economic analysis given that the implications of BioCCS technology are not yet fully understood. Options 1–5, however, can be simulated assuming changes in technology and/or the availability of roundwood.

The economic effects of these five options are summarised with the help of growth decompositions. Here, GDP can be evaluated in terms of supply (factors of production) or demand (final use of products and services), with growth decompositions splitting the overall change in GDP into its component contributions. Figure 7 below summarises the effects on supply-side GDP in terms of a growth decomposition displaying the supply-side components of GDP growth by 2030 (compared to the baseline). The dots show the overall change in GDP, which is then split into the contributions made by technological change, labour and capital. By definition, supply-side GDP also takes into account the effects of indirect taxes.

For option 1, we assume a yearly 1% improvement in forest growth. By 2030, this will amount to 5% growth in gross annual increments, which allows for more harvesting. GDP grows 0.24% more than in the baseline, with the majority of this growth (0.18%) due to (new silvicultural) technology. This productivity growth induces more investment and employment, which respectively contribute 0.01% and 0.05% to GDP. Turning to option 2, it can be seen that reducing harvests amounts to a negative technological shock to the economy, as it limits the use of a key factor of production. This also occurs in option 5, where harvesting is also reduced but the loss in lumber is offset by increased imports. To understand why GDP suffers a greater fall in option 5 compared to option 2, however, we must turn to demand-side effects. Meanwhile, options 3 and 4 increase factor productivity in the forest sectors – material efficiency production in the former case and also changes in the product palette in the latter case.

Figure 8, meanwhile, shows demand-side GDP decomposition, specifically private and public (government) consumption, investment and exports. Imports also contribute to demand-side GDP but tend to have a negative effect. In option 1, increased annual increments allow for the expansion of forest sector production and, hence, exports. Exports contribute 0.24%, which is also the net effect on GDP. The small negative con-

Figure 7. Supply-side contributions of policy options 1–5 to Finland's GDP growth (%) by 2030 compared to baseline

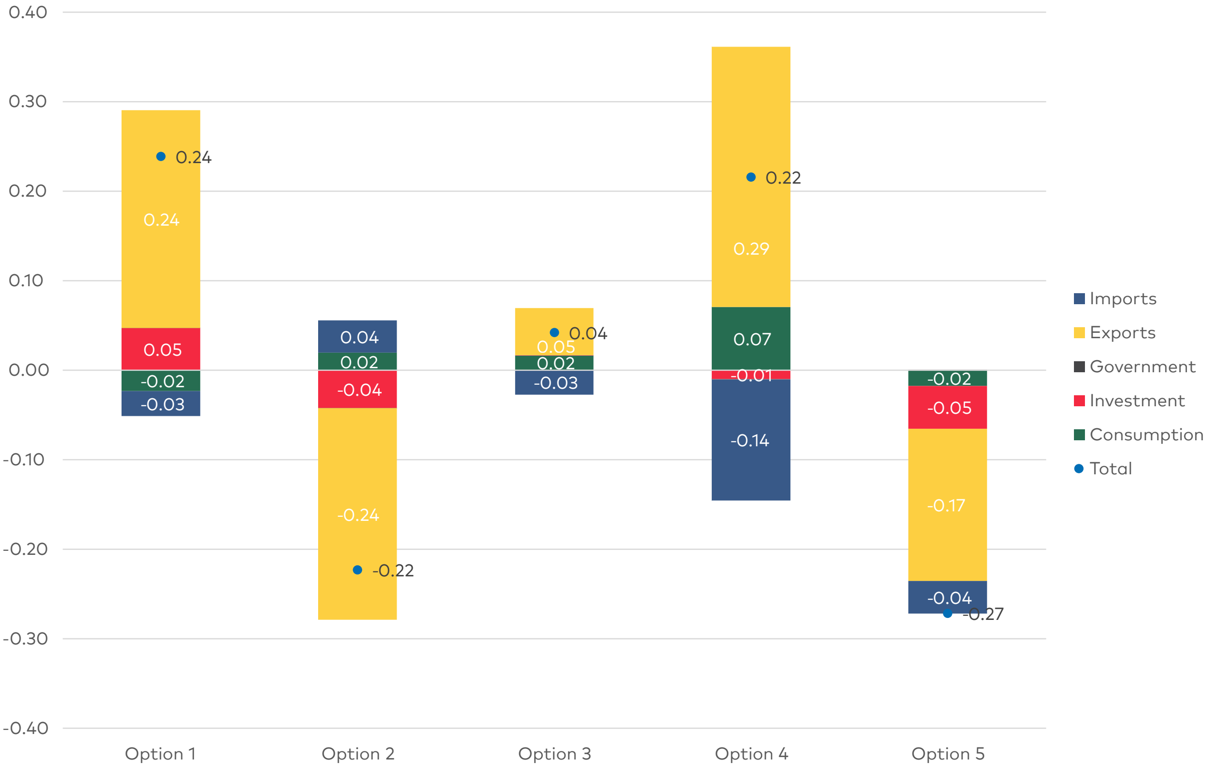


Source: Authors' own calculations.

tribution of -0.03% provided by imports implies they have only grown by a small amount. There is also a small negative contribution from consumption, as increased supply of lumber affects factor prices and therefore household income. In options 2 and 5, the main effect stems from falling forest sector exports due to reduced harvests. In option 5, this reduction is compensated for by an increase in roundwood imports and is therefore smaller. However, these increased imports have a negative impact on GDP, the magnitude of which depends on the price of roundwood imports, as well as the substitutability of imported roundwood and domestic lumber. In options 3 and 4, improved material efficiency in the forest sectors (option 3) and the introduction of new, higher-value products (option 4) boost exports and thus the economy.

In summary, while our analysis suggests that changes within the forest sector will have impacts on the forest carbon sink, breakthroughs in industrial processes when it comes to efficiency improvements and changes in the production palette are difficult to predict. New and novel industrial processes are, by definition, not fully known or understood. Nevertheless, if potential changes can be quantified in terms of changes in wood flows (as shown in Figures 1 and 6), they can also be quantified in terms of CO_2 emissions and sinks. With this in mind, the analysis adopts a 30-year timeframe in exploring the poten-

Figure 8. Demand-side contributions of policy options 1–5 to Finland's GDP growth (%) by 2030 compared to baseline



Source: Authors' own calculations.

Table 4. Estimated theoretical potential of emission reductions within a time range of 30 years

Intervention	Theoretical potential, $MtCO_2$	Decision maker
Increase gross annual increment (option 1)	9–23	Forest owner
Reduce harvests (option 2)	14–25	Forest owner
'More from less' (option 3)	n.a.	Industrialist
Change the product palette (option 4)	n.a.	Industrialist
Import more roundwood or pulp (option 5)	~14	Industrialist
Implement BioCCS (option 6)	3-4	Industrialist

tial of options 1–6 (Table 4). If a shorter timeframe (until 2035) is applied, two options in particular stand out as having the largest carbon sink potential: reducing harvests (option 2) and importing roundwood or pulp (option 5). These actions would assist Finland in most swiftly attaining carbon neutrality, notably at the cost of promoting forest harvests in other countries.

5.5 Regional economic effects of policy alternatives

The national and regional economic and social effects differ significantly between policy options. Here, we adopt a simple approach in which: 1) national economic impacts correlate with the volume and unit market price of (exported) products; 2) in the small- and mid-sized municipalities where industries are located, economic and social impacts correlate with the profitability of forest industrial companies; and 3) in rural Finland, economic effects correlate with the changes of income from timber sales experienced by forest owners.

The results of this approach indicate options 1 (increase annual increment) and 3 ('more from less') offer win–win strategies that promote the carbon sink while enabling economic and social development (Table 5). By contrast, options 2 (reducing harvests) and 5 (importing more roundwood or pulp) would not provide co-benefits for the national or regional economies. Nevertheless, given the comparatively difficult pathway of phasing out fossil fuels, they may offer a means of achieving national climate targets in the short term and at a reasonable cost.

None of the six policy options are under the national government's direct control, as they require the involvement of forest owners and forest industrial companies (Table 4). Nonetheless, economic instruments may have a role to play in terms of aligning economic interests with environmental sustainability, encouraging compliance through financial (dis)incentives rather than direct regulation. For example, environmental taxes and fees levied on forest-depleting activities not only generates revenue that can be put towards environmental projects, but makes polluting activities more expensive, thus discouraging them. Conversely, subsidies can encourage businesses and consumers to adopt environmentally friendly practices, with incentives such as tax rebates for promoting silviculture making sustainable choices more financially attractive. Another option is environmental performance bonds – used in Finland in the 1970s and 1980s to safeguard forest regeneration – which require companies to post a bond that may be forfeited if they fail to meet environmental standards or rehabilitate a site after use.

Lastly, environmental policies may seek to employ information campaigns and labelling to help reduce market friction. For example, sustainability labels on appliances could assist consumers and businesses in making more informed choices conducive to environmental quality.

5.6 Caveats, uncertainties and limitations

The evaluation provided by this chapter draws on the relevant forest sciences and economics literature, as well as empirical observations and statistics on CO_2 emissions, carbon sinks and timber resources. A more complete assessment of radiative forcing (the change in energy balance in the Earth's atmosphere) would require analysis of the trends associated with all the attributes compiled by the IPCC under the title 'short-lived climate forcers' (SLCFs).

Although the carbon sink of forest trees is an important component of land use, land use change and forestry (LULUCF) emissions and sinks, a number of important items fall outside the analysis provided by this chapter.

Table 5. Direction of policy option impacts on national and regional economies

Intervention	Impact on national economy	Economic impact on forest owners	Economic impact on forest industries
Increase gross annual increment (option 1)	+	+	+
Reduce harvests (option 2)	-	-	-
'More from less' (option 3)	+	?	++
Change the product palette (option 4)	+	?	+
Import more roundwood or pulp (option 5)	-	-	0
Implement BioCCS (option 6)	?	?	?

Firstly, while the carbon sink of forest vegetation is addressed in our analysis, changing stocks of soil carbon are not. Research indicates that soils can act as a carbon sink or source, with complex processes also affecting methane and nitrous oxide (Holmberg et al. 2021). Monitoring and verifying changes in soil carbon is, however, challenging, as soil carbon is spatially highly variable (Muukkonen et al. 2009). As such, managing soil carbon appears less feasible compared to managing timber resources.

Terrestrial ecosystems such as forests affect organic material flows in downstream rivers, lakes and coastal waters. In Finland, these impacts may be quantitatively significant to the national carbon budget given the humid climate, extensive freshwater systems and relatively long water retention times in watercourses, which leads to significant sedimentation (Syvitski & Kettner 2011).

Some uncertainties also remain in assessing the carbon stock and stock change of forest trees. As previously mentioned, a simple approach is to assume that one cubic metre of stem wood corresponds to 1.375 tonnes of sequestered CO_2 in whole-tree biomass (Kauppi et al. 2022). As trees grow taller, this coefficient decreases due to the fact that incremental biomass increasingly accumulates in stems (Kauppi et al. 2006). Conversions from volume to carbon units are approximations with temporal and spatial variations.

Unknown agents have affected forest growth, hampering in particular the growth rate of pine trees (Henttonen et al. 2024). Inter-annual variations in tree growth can therefore be significant, but do not show up in statistics such as those shown in Table 2, where increments are typically based on a five-year moving average. Given it is not possible to obtain precise forest statistics for any given year, however, a five- or ten-year horizon remains a more feasible and solid approach.

Finally, while stand-replacing forest disturbances have historically been rare in modern Finland – whether in association with storms, wildfires, tree pathogens or insect outbreaks – they may become more frequent and/or damaging over the coming years in response to the changing climate.

6. Conclusion: The forest sector's green transition in global perspective

Wood is a renewable resource that – when harvested sustainably – offers eco-friendly alternatives to plastics, concrete or steel, which require high energy inputs and produce more emissions during production. Moreover, wood products can store CO_2 over their lifespan, further contributing to carbon reduction. Wood and other forest biomass – including wood-based residues and waste – can be also used as renewable energy sources that, when managed sustainably, present a viable alternative to fossil fuels. In this chapter we addressed the potential of forest growing stock in carbon sequestration. The national government has set a goal of Finland becoming carbon neutral by 2035. While the emissions from the combustion of fossil fuels have been reduced significantly during 2003-2023, it is almost certain that a contribution of the forest carbon sink will be needed as a component of national climate policies to meet the goal of the national government.

This chapter attempted to address the following questions:

- Can the role of Finland's forest carbon sink be enhanced?
- What options exist to achieve this goal?
- What would the regional-level implications be for Finland's forest and energy sectors in terms of economic growth and employment?

We conclude that the carbon sink of Finland´s forests can indeed be enhanced and identify six potential options to achieve this goal. Two of the options are available in the short time frame, at least theoretically. The remaining four options are more sustainable, but difficult to put in place within the short time frame of 5-15 years.

It is important regarding successful implementation of any of these options to adopt policies and practises which are economically and socially viable. The forest sector provides jobs in forest management, restoration, and the sustainable production of forest goods such as timber, pulp and non-timber products. Importantly, forest related jobs are typically located in rural and semi-urban regions, where other economic opportunities are scarce.

Innovations in forest management, wood-processing and reforestation techniques can enhance both productivity and sustainability. Through educational programmes and sustainable practices, the forest sector can promote greater environmental awareness, encouraging responsible consumption and production patterns among consumers. Alongside this, the sector can take a proactive role in shaping environmental policies, advocating for global, national and local policies that prioritise conservation and sustainable forest management.

Forests act as significant carbon sinks, absorbing CO_2 from the atmosphere through photosynthesis (Pan et al. 2024). Managing forests sustainably ensures they can continue to sequester carbon effectively, which is vital for mitigating climate change. Through focusing on the various areas discussed in this chapter, the global forest sector – Finland included – can make a significant contribute to the green transition: reducing carbon footprints, conserving biodiversity and promoting sustainable development.

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Tourism in Iceland and the green transition

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ABSTRACT

The growth in Iceland's tourism industry marks the most significant economic shift seen in the country's regional economies over the past 50 years. Given that nature and wilderness are the country's main attractions, tourism-centric communities are disproportionately located outside the Capital Area. The green transition will likely negatively impact the tourism industry, at least initially, due to the costs associated with new technology, emissions licences and green taxes. These effects will inevitably be greater in regions heavily reliant on tourism. Tourism generates up to 50% of local labour income across the country's various municipalities – the average is 10%. Tourism seems to have the highest weight in the local economies of municipalities in the south and near the north coast. There are various options the Icelandic government could consider to mitigate these impacts, including subsidising domestic tourist transport; incentivising electric car usage for rentals; improving electric vehicle infrastructure; researching tourist behaviours with a view to tailoring policy; enhancing public transport; and supporting local food producers to reduce negative economic effects on tourism-centric communities.

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1. Introduction

This chapter focuses on emerging challenges to Iceland's tourism sector – a relatively new addition to the country's economy – arising from its commitments to increasingly ambitious climate and environmental goals. Most notably, the European Union's 'Fit for 55' package means requirements concerning the lowering of transport emissions will become more stringent. Given this sector is integral to tourism, especially for an island country with underdeveloped public transport, the implications for Iceland are significant.

Our analysis relies on a broad definition of tourism that is generally accepted by public bureaus of statistics (see Table 1). This definition incorporates transportation, as tourists travel to Iceland using planes or ships, and move around the country by car.

The key question underlying this chapter is: How will intensified climate goals affect growth, employment and labour income trends in Iceland's tourism industry? In answering this question, the chapter will explore the spatial varieties of these impacts – between Reykjavík and the country's rural areas – in order to identify which actions can minimise the green transition's rural economic costs and so prevent an increase in regional economic disparities.

More specifically, the questions posed by the research are as follows:

- What is the share of the tourism sector within Iceland's economy?
- How will European and national climate and environmental goals influence Iceland's tourism industry (e.g. in terms of economic growth, employment and labour income)?
- How will these impacts differ across regions?
- Which policy recommendations are best placed to minimise the rural economic costs arising from the green transition?

Following this introduction, Section 2 outlines the methods and data used in this chapter. Section 3 goes on to provide an overview of the Icelandic government's public policy concerning the green transition, as well as key international agreements, before Section 4 discusses the size of Iceland's tourism industry and its ecological footprint. The overall economic impacts of the green transition on the tourism industry are discussed in Section 5, with Section 6 then focusing in on the spatial disparities arising. Building on all of the above, Section 7 offers a set of proposals for minimising the negative local economic impacts of climate policies. Finally, Section 8 provides a brief summery and some concluding remarks.

2. Methods and data

This chapter is based mainly on data from Statistics Iceland, with the definition of tourism in line with section A.1 in Table 1 below (Frent 2015, p. 23).

Accommodation services, restaurants, bars, various leisure activities and passenger transportation are all classified as tourism, despite the fact that many of those industries also serve locals. For example, locals may require taxies and hotels for professional or private purposes and may eat at restaurants or avail themselves of leisure activities in their free time. As such, this classification is open to criticism.

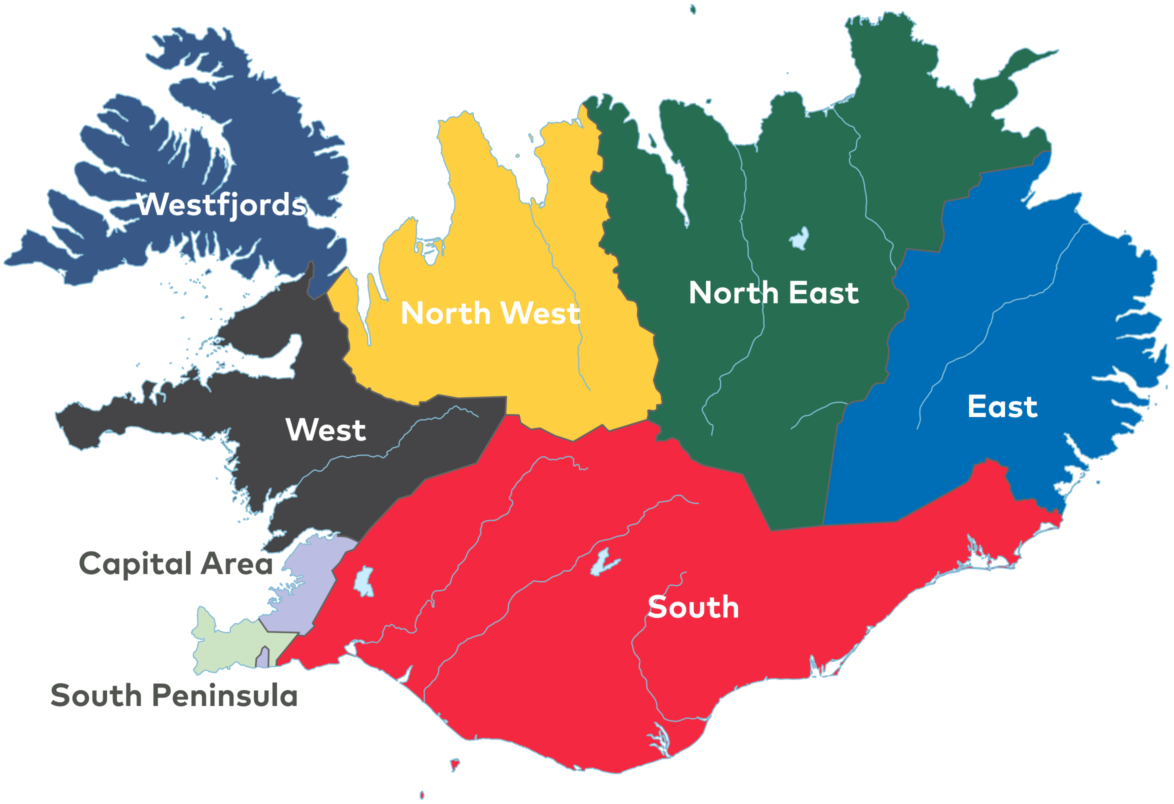
Table 1. Definition of tourism according to Statistics Iceland

No.	UNWTO categories	Icelandic categories	
		ISAT codes	Name
A.1. Tourism characteristic products/industries (for international comparability)			
1.	Accommodation services	55.10.1	Hotels and similar accommodation, without restaurants
		55.10.2	Hotels and similar accommodation, with restaurants
		55.20.0	Holiday and other short-stay accommodation
		55.30.0	Camping grounds, recreational vehicle parks and trailer parks
		55.90.0	Other accommodation
2.	Food-and bevarage-serving services	56.10.0	Restraurants and mobile food service activities
		56.29.0	Other food service activities
		56.30.0	Beverage serving activities
3.	Road passenger transportation	49.32.0	Taxi operation
		49.39.0	Other passenger land transport not elsewhere classified (n.e.c)
4.	Water passenger transportation	50.10.0	Sea and coastal passenger water transport
		50.30.0	Inland passenger water transport
5.	Air passenger transportation	51.10.1	Scheduled air transport
		51.10.2	Non-scheduled air transport
6.	Transport equipment rental	77.11.0	Renting and leasing of cars and light motos vehicles
		77.12.0	Renting and leasing of trucks
7.	Travel agencies and other reservation services	79.11.0	Travel agency activities
		79.12.0	Tour operator activities
		79.90.0	Other reservation service and related activities
8.	Cultural services	90.01.0	Performing arts
		90.02.0	Support activities to performing arts
		90.03.0	Artistic creation
		90.04.0	Operation of arts facilities
		91.02.0	Museums activities
		91.03.0	Operation of historical sites and buildings and similar visitor attractions
		91.04.0	Botanical and zoological gardens and nature reserves activities

9.	Sport and recreational services	77.21.0	Renting and leasing of recreational and sports goods
		92.00.0	Gambling and betting activities
		93.11.0	Operation of sports activities
		93.13.0	Fitness facilities
		93.19.0	Other sports activities
		93.21.0	Activities of amusement parks and theme parks
		93.29.0	Other amusement and recreation activities
A.2. Other consumption products			
10.	Goods purchased from trade activities	46.00	Wholesale trade
		47.00	Retail sale
11.	Other services		All the rest of industries providing services to tourists

Note: The Icelandic Classification of Economic Activities (ISAT) is based on the Statistical Classification of Economic Activities in the European Community (NACE).
Source: Statistics Iceland.

Figure 1. Regional classification by Statistics Iceland



Source: Statistics Iceland.

Bearing in mind such limitations, data on tourism was collected according to this classification wherever possible, with the approach based on three NACE classifications: 1) accommodations and food and beverages service activities (NACE 551–553, 561, 563); 2) transportation (NACE 491, 4932, 4939, 501, 503, 511); and 3) renting motor vehicles (NACE 771, 7711).

The data was classified either by municipalities (as in Figure 16) or regions (as in Figure 15). The traditional classification of regions is shown in Figure 1, although occasionally some regions were merged for the purposes of the study: for example, combining Nort West and North East into a single North region (Figure 15), or West and Westfjords into a single West region (Figure 14).

3. Domestic climate policies and international agreements

Iceland's first climate policy was approved in 2002 with the aim of curbing emissions, keeping Iceland's obligations under the Kyoto Protocol, and increasing carbon sequestration through afforestation and revegetation programmes. In 2007, the government adopted a new climate change strategy that set out a long-term vision for achieving a 50–75% reduction in net emissions by 2050 compared to 1990 levels. Although an action plan for climate change mitigation was adopted in 2010, it took until 2018 for the first Climate Action Plan containing specified actions and funding to be published, with a second version following two years later.

In July 2021, the European Commission presented the 'Fit for 55' package, which contains a set of legislative proposals designed to make the EU´s climate, energy, land use, transport and taxation policies fit for reaching the goal of a minimum 55% reduction in emissions by 2030. The package seeks to both amend existing EU climate and energy legislation and put forward new proposals that can contribute to the achievement of the EU's climate targets. In particular, the 'Fit for 55' action package proposes significant changes to the Emissions Trading System (ETS), the Effort Sharing Regulation (ESR) system and the land use, land use change and forestry (LULUCF) system. To implement new or updated measures to meet requirements in the Fit for 55 package, the Icelandic Climate Action Plan must be revised and updated. This chapter bases its analysis on the currently applicable second version of the Climate Action Plan, published in the year 2020.

3.1 Effort Sharing Regulation (ESR)

The EU's ESR sets out binding greenhouse gas emission targets for member states for the period 2021–2030. These annual targets concern emissions which are under the direct responsibility of each member state, from sectors not currently included in the EU Emissions Trading System (ETS), such as road transport, ships and ports, agriculture, small industrial installations and waste management.

The current aim of the ESR is to reduce emissions by 40% by 2030 compared to 2005; setting more ambitious, fair and cost-efficient national targets for member states; and contributing to the European Green Deal objective of EU-wide climate neutrality by 2050. The ETS operates in all EU countries, as well as the three EEA-EFTA (European Economic Area - European Free Trade Association) states (Iceland, Liechtenstein and Norway).

3.2 The Climate Action Plan

Iceland's 2018 Climate Action Plan was the country's first long-term, comprehensive plan concerning the green transition, and saw a substantial increase in government funding for key climate mitigation actions. Going further, the updated June 2020 version of the Action Plan presented new actions (a total of 48, up from 33 in the first edition) and increased funding. Moreover, it incorporated analyses estimating the individual and collective mitigation gains of the presented actions and took account of suggestions received through a consultation process with stakeholders and civil society.

The Action Plan is Iceland's main instrument for fulfilling its Paris Agreement commitments and to meet Iceland´s ESR commitments, in particular its 2030 emission reduction goals, as well as the country's stated goal of achieving carbon neutrality by 2040. It also takes into account the United Nations Sustainable Development Goals, which were universally adopted in September 2015 and require the participation and cooperation of diverse stakeholders.

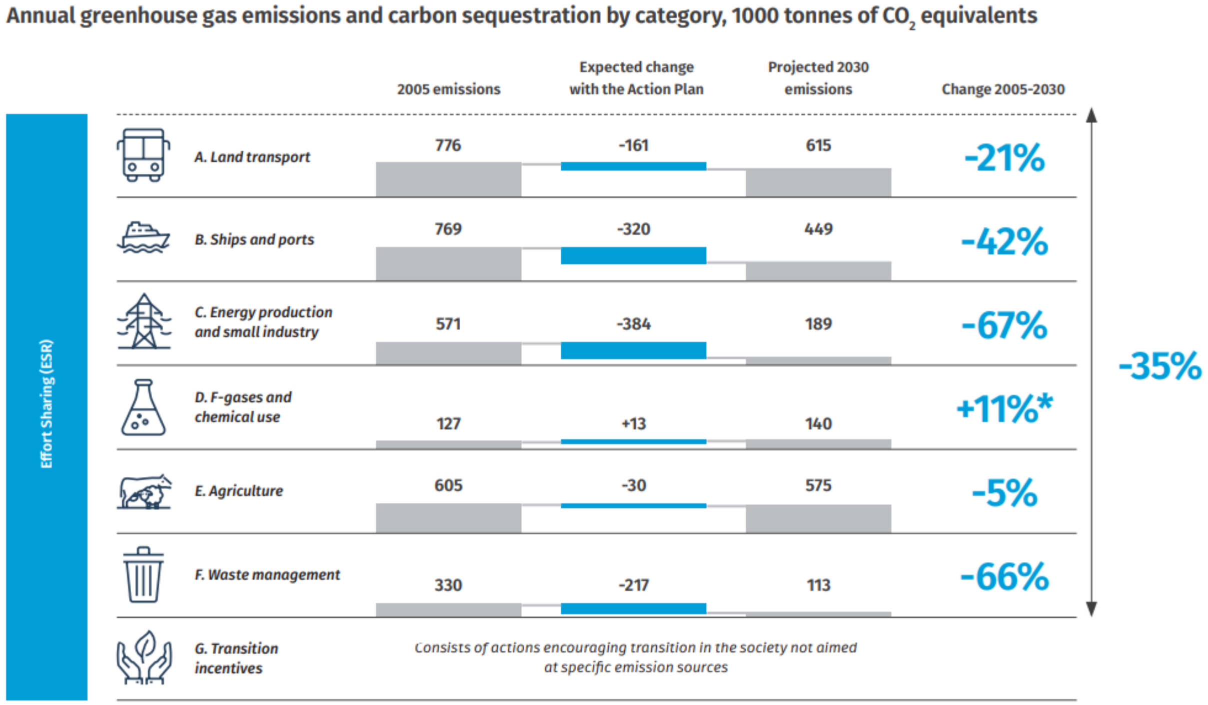
Analyses indicate that Iceland is on course to meet its ESR climate commitments. According to the Action plan the country should be able to reduce emissions in the relevant sectors by 35% through the confirmed measures. On top of this, it has been estimated that measures currently in preparation will lead to an additional 5–11% cut in ESR emissions, for a total decrease of 40–46%. Beyond this, the Icelandic government signalled in 2021 that it is willing to aim for an even greater reduction in emissions in ESR sectors by 55% by 2030 compared to 2005 (Helgadóttir et al. 2023).

The Action Plan will be assessed according to its impact on different income groups and analysed in terms of its costs and benefits, including the macroeconomic impacts of measures. As such, it will be important to ensure that climate mitigation measures support efforts to increase economic equality and equal rights. Here, consideration must be given to how the measures may affect particular jobs or societal groups, and how such impacts may be addressed or mitigated. As yet, no data has been published on the effects of the Action Plan measures on different income groups or geographical areas. For example, given electric cars are expensive, it may be assumed that changing from fossil fuel cars will be more challenging for those on lower incomes, meaning it is important to simultaneously focus on developing public transport infrastructure.

Overall, the ESR-related policies and measures presented in Iceland's 2020 Action Plan are set to lead to a decrease of more than a million tonnes of CO_2 equivalents in the relevant sectors by 2030 compared to 2005. To achieve these goals, emissions must be reduced in different sectors of the economy, amongst others tourism, especially regarding transport.

A minimum of EUR 300 million (ISK 46 billion) is expected to be spent on key climate actions in the period 2020–2024, with the goals and measures divided into different sectors depending

Figure 2. Estimated reduction (2005–2030) in Iceland's Effort Sharing Regulation emissions under the Climate Action Plan



Source: Government of Iceland (2020).

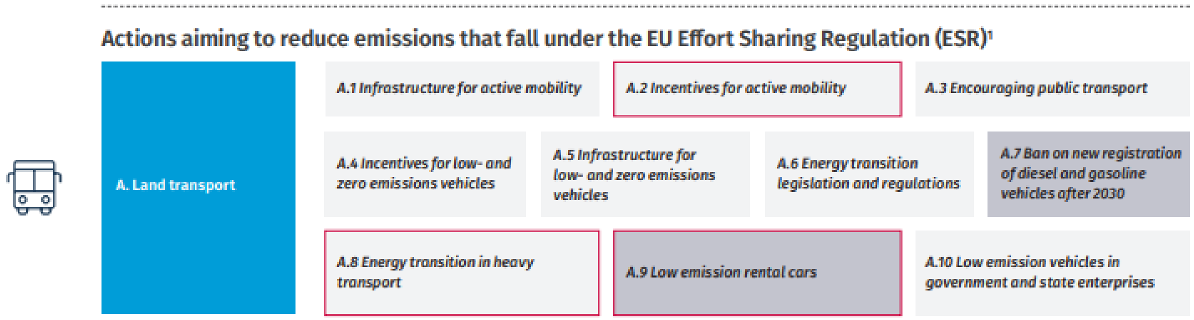
on the origin of emissions (Figure 2). An array of actions in various sectors aim to reduce emissions by up to 67% in individual sectors and 35% in total. Turning to land transport (Category A) specifically, ten distinct actions have been put in place with the ultimate aim of reducing emission by 21% (see also Figure 3) (Government of Iceland, Ministry of the Environment and Natural Resources 2021).

3.3 Land transport

Emissions from road transport constitute the single largest element of the ESR emissions in Iceland, amounting to 776,000 tonnes in 2005 and 979,000 tonnes in 2018. Assuming the measures defined in the Climate Action Plan are followed, it is estimated that by 2030 emissions will have fallen to 615,000 tonnes of CO_2-equivalents: a 21% decrease compared to 2005. It is worth emphasising that given road transport emissions have increased considerably – around 25% over the period 2005–2018 – this would represent a total decrease of 37% compared to 2018 emission levels. A considerable part of this increase is the consequence of tourist traffic. More generally, passenger cars (64%) are responsible for the largest proportion of road transport emissions, followed by transport vehicles (16%), vans (14%), group buses (6%) and other types of vehicles such as motorcycles and quad bikes (1%) (Ministry of the Environment, Energy and Climate n.d.).

The availability of electric cars and plug-in hybrids is growing rapidly,

Figure 3. Actions aimed at reducing land transport emissions according to the Climate Action Plan



Note: Actions in dark grey boxes are in preparation; actions in boxes with pink outlines are new to the 2020 edition of the Action Plan; all others actions have been implemented.
Source: Government of Iceland (2020).

as is the infrastructure for electric vehicles (i.e. charging stations). A record number of electric cars was registered in March 2020, equating to 41% of newly registered passenger cars. As of the end of May 2020, around 10% of the total number of passenger cars in circulation were eco-friendly. Even so, there remain around 200,000 petrol and diesel passenger cars in use in Iceland, as well as numerous transport vehicles, vans and other larger vehicles, which implies that reducing road transport emissions will take time. It is worth noting, however, that the emission rate of new fossil fuel cars is around 30% less than those which entered the market at the turn of the century.

The Land Transport section in the Climate Action Plan is divided into two parts: changing travel habits (actions A.1–A.3) and energy exchange (actions A.4–A.10) (Figure 3).[4]

Changing travel habits

Action A.1 focuses on infrastructure supporting active means of travel (e.g. cycling and walking), while A.2 covers tax subsidies designed to encourage people to use these modes of transport. The promotion of public transport (A.3) has gained importance due to the planned construction of new public transport in the Capital Area (the City Line), with a transport agreement between the state and Capital Area municipalities signed in autumn 2019. The first two actions are predicted to bring about an emissions reduction of 10,000 tonnes of CO_2-equivalents by 2030, while action A.3 is expected to reduce emissions by 16,000 tonnes of CO_2-equivalents by the same time.

Energy exchange

Action A.4 sets out financial incentives for ecological vehicles, some of which

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[4] An overview of the Climate Action's Land Transport (Sector A) policies and measures can be found in the appendix (A1).

were recently extended and some of which have been newly added. Under action A.5, infrastructure support for eco-friendly vehicles will be greatly increased, with various projects already launched towards this end, such as increasing the number of fast charging stations across the country. Even so, there remains a lack of infrastructure for other energy sources, such as methane and hydrogen, which are a prerequisite if trucks are to be powered by fossil fuel alternatives – this is also dealt with by A.5.

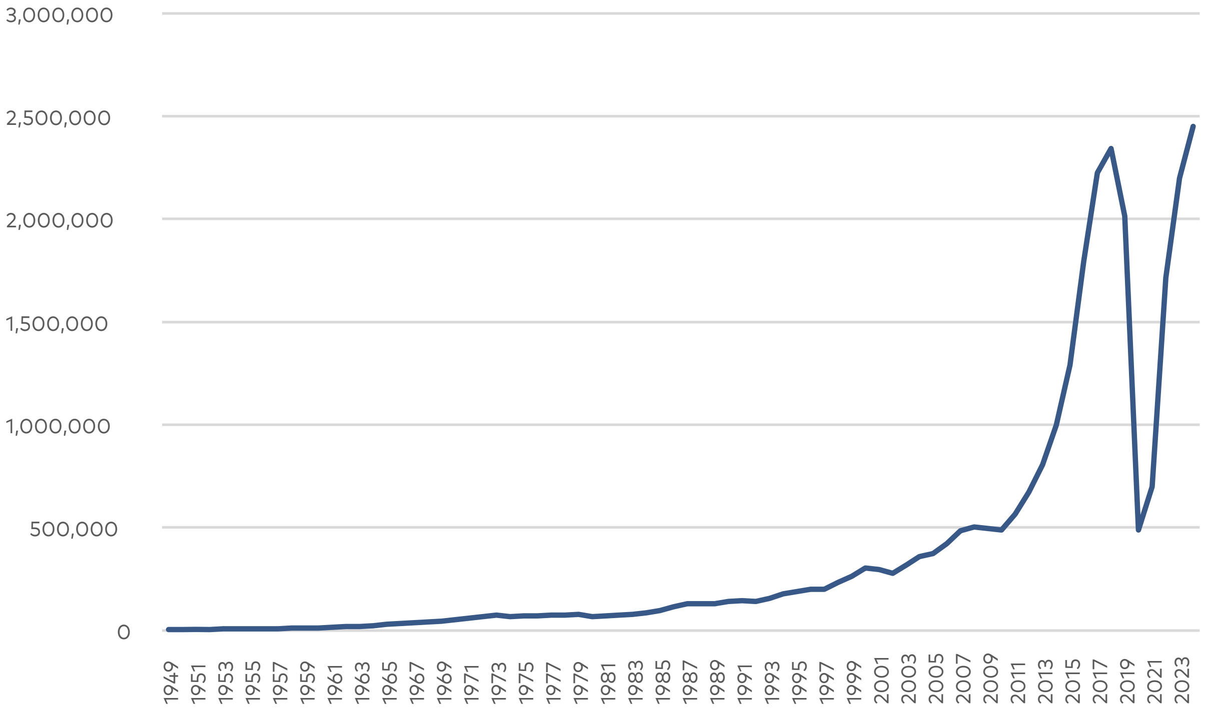
Action A.6 aims to ensure that all relevant laws and regulations support the energy conversion, while A.7 bans the registration of new petrol and diesel passenger cars after 2030. In addition, a special new action (A.8) will be taken to speed up energy exchange in heavy transport: emissions from a heavy vehicle are many times higher than from a passenger car, and such vehicles tend to be driven more. Another new feature of the Action Plan concerns eco-friendly rental cars (A.9), which represents a significant move given that rental cars make up almost half of Iceland's newly registered vehicles (Ministry of the Environment, Energy and Climate n.d.). The impact on greenhouse gas emissions is two-fold: firstly, tourist driving constitutes at least a quarter of all private driving in the country, and secondly, ex-rental cars end up being purchased as household cars for citizens. Finally, action A.10 imposes obligations on government entities to buy eco-friendly vehicles, a measure that has been implemented since the first edition of the Action Plan. Since 2020, government entities have, in principle, been prohibited from purchasing new gasoline and diesel vehicles.

Actions A.4–A.7 are evaluated together with action G.1 (carbon tax) from the category 'transition incentives' (see Figure 2). They are predicted to bring about a 51,000-tonne reduction in CO_2-equivalent emissions by 2030. Actions A.8 and A.9 have not been evaluated, while A.10 is estimated to reduce emissions by 1,000 tonnes of CO_2-equivalents.

For the most part, the impacts of the various transport activities on greenhouse gas emissions are not assessed separately for each policy or measure – rather, they are assessed collectively due to their mutual, synergistic effects. While a reduction caused by one action does not necessarily lead to a similar reduction elsewhere, the actions nevertheless mutually influence each other. Incentives for electric cars that lead to increased use of clean energy vehicles can, for example, lead to reduced emissions arising from public transport, as people wishing to avoid fossil fuels may choose to buy electric cars rather than use public transport.

Emissions from land transport is the single largest category in Iceland that falls under the ESR scheme and increased greatly in the years 2005 – 2018. In that same period, there was a high growth in tourism in the country. Individual measures in the Action Plan are therefore specifically focused at tourism e.g. infrastructure and incentives for ecological vehicles and low emission of rental cars, since rental cars are the most popular form of travel for foreign tourists in Iceland. This is discussed in more detail in the next chapter.

Figure 4. Number of foreign tourists in Iceland 1949–2024



Note: Tourists arriving via Akureyri are missing for the year 2022. The 2023 figure is preliminary and the 2024 figure is a forecast.
Source: Icelandic Tourist Board.

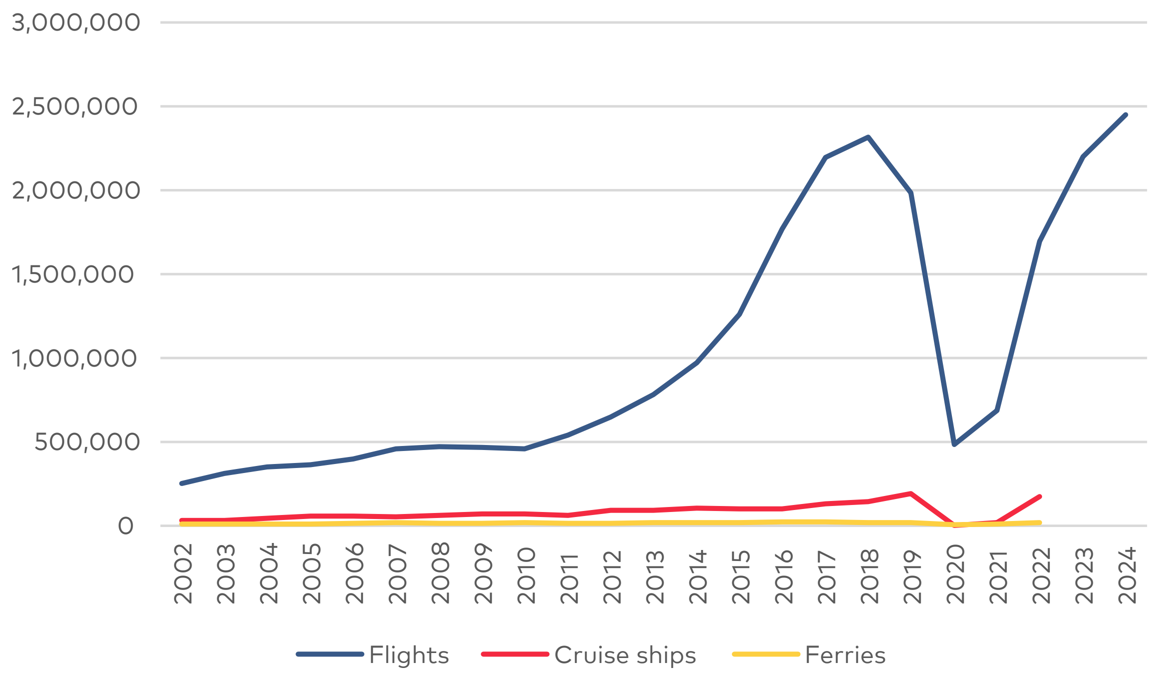
4. Tourism in Iceland

4.1 The economic importance of tourism

Iceland is a geographically isolated island in the far North Atlantic. With its cool, wet climate, the country has historically not been attractive to Europeans or North Americans seeking warmer destinations for their relatively short summer vacations. More recently, however, Iceland has been attracting increasing numbers of overseas tourists due to cheaper flights, successful marketing, rising wealth worldwide, and greater demand for different types of leisure and travel experiences. Repeated surveys have shown that foreign tourists visit Iceland because of its exceptional natural features (Ferðamálastofa 2023, Óladóttir 2020). The country is sparsely populated and can boast a variety of glaciers, geysers, varied waterfalls and black beaches, as well as the northern lights at winter times, all of which have proven popular among foreign guests and promoted a positive national image.

Tourism in Iceland did not take off until the 21st century, in particular, after the bank crisis of 2008 (Figure 4). The devaluation of the Icelandic Krona (IKR) by approximately 50% played a significant role in this, reinforced by several others factors, such as the eruption of Eyjafjallajökull in 2010, which was followed by a successful marketing strategy ('Inspired by Iceland') and the foundation of the low-cost Icelandic airline WOW air. Around 300,000 tour-

Figure 5. Foreign passengers arriving in Iceland 2002–2023, by mode of transport



Note: The 2023 figure is preliminary and the 2024 figure is a forecast.
Source: Statistics Iceland.

ists came to Iceland in 2000, rising to 500,000 in 2009 and reaching 2.3 million in 2018, two years prior to Covid-19 pandemic. The increase in tourism, however, slowed down several months prior to the pandemic due to the appreciation of the Icelandic Krona and the subsequent bankruptcy of WOW air on 28 March 2019 (V. Karlsson 2022).

Most foreign tourists travel to Iceland by air, with a much smaller number arriving by ships (Figure 5). There is only a single ferry running scheduled tours between Iceland, Denmark and the Faroe islands. While the ferry port at Seyðisfjörður – a small village on the east coast – is geographically one of the closest places to mainland Europe, it is far from the Capital Area on the southwest coast. A growing number of cruise ships also visit Iceland. The size of the cruise ships has become a problem for many small villages and towns, which struggle to provide services for large (albeit brief) influxes of tourists. The Capital Area and Akureyri on the north coast are better able to accommodate cruise ships.

Tourists arriving by air mostly travel around the island in smaller groups in rented cars, meaning their demands are better suited to the local supply of services compared to cruise ship passengers. Icelandair has been the largest, most resilient and very often only operating Icelandic international airline. They have several times had Icelandic competitors but almost always only one at every given time. WOW-air, founded in 2011, was one of the most successful

Table 2. Share of tourism in export income, employment and GDP

Industries	Export income 2023	Employment 2022	GDP 2022
Tourism	31%	12.5%	8.8%
Fisheries	19%	3.8%	6.4%
Industrial products*	28%	7.8%	8.3%
Others	22%	75.9%	76.5%
* Industrial products equated to manufacturing in terms of employment and GDP			

Source: Statistics Iceland.

competitors during the years it operated (Mbl 2014) and had a strong impact on the growth in tourism as mentioned earlier. In addition, a number of foreign airlines offer scheduled flights to Iceland. In 2022, it was 27 airlines (Isavia 2022).

According to Statistics Iceland, tourism accounted for 31% of the country's total exports of goods and services (the current account in macroeconomic terms) in 2023 – or more precisely, the last quarter of 2022 and the first three quarters of 2023 (Table 2).[5] This figure is less than it was prior to the Covid-19 crisis, when an all-time high of 41% was reached in 2017, falling to 36% in 2019. Here, it should be noted that fisheries had only a 19% share in Iceland's goods and services exports in 2023, compared to approximately 53% in the first half of the 1980s when they were central to the Icelandic economy (Statistics Iceland 1992, p. 204). The transportation sector – which accounted for 17% of goods and services exports over the period 1981–1985 – was serving the fisheries more than tourism but was not included in the figure of 53%. By contrast, it has been included in the more recent numbers for tourism (2017, 2019, 2023).

The share of tourism in Iceland's gross domestic product (GDP) was 8.2% in 2016–2019, reaching its highest point since 2009. It was 3.5% in 2009 and 2.9% in 2020, although it now seems to be rising back to its high-water mark, hitting 8.8% in 2022 (Statistics Iceland n.d.a).

Tourism accounted for just under 15% of total employment in Iceland in 2017 and 2018, when it reached its highest point of the period 2008–2022 (Figure 6). Recent figures indicate that the current proportion has risen again to around 15%, or possibly higher. Both fisheries and manufacturing contribute considerably lower employment percentages compared to tourism, despite each generating a substantial proportion of Iceland's export income. Combined, fisheries, tourism and manufacturing have been very significant for the local economy outside the Capital Area, contributing proportionately more in terms of employment than is the case for the Capital Area's economy.

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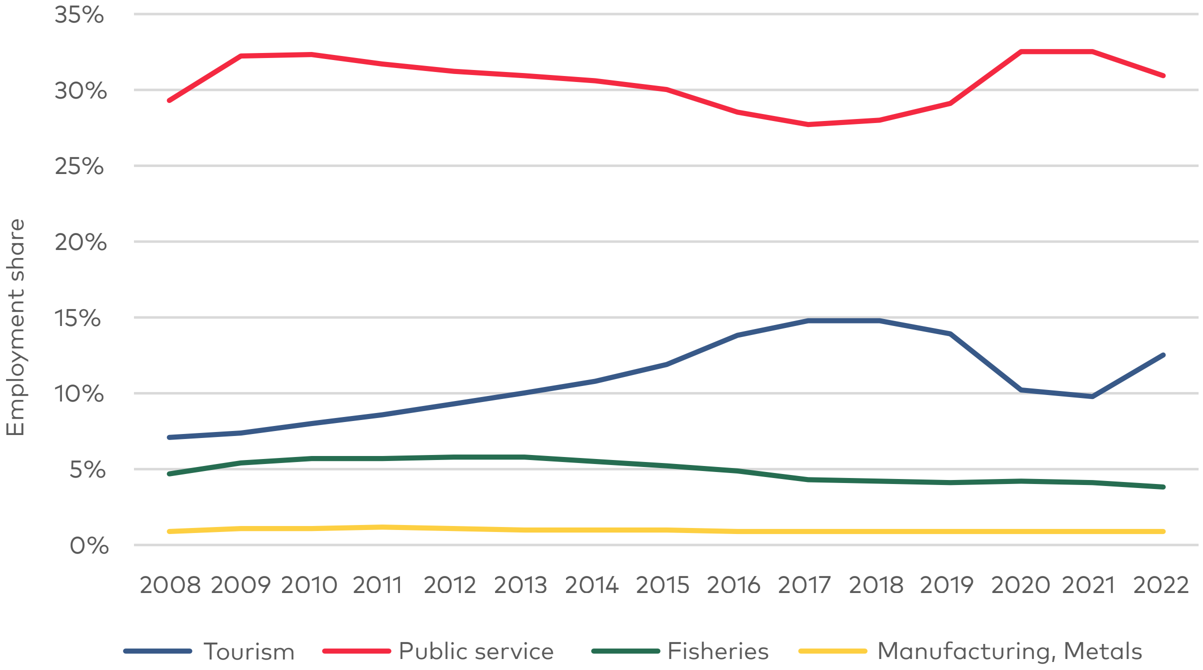
[5] The 2023 figures are preliminary. See Statistics Iceland webpage: www.hagstofa.is (accessed 8 January 2024).

Figure 6. Share of tourism in Iceland's total employment compared to selected other branches, 2008–2022

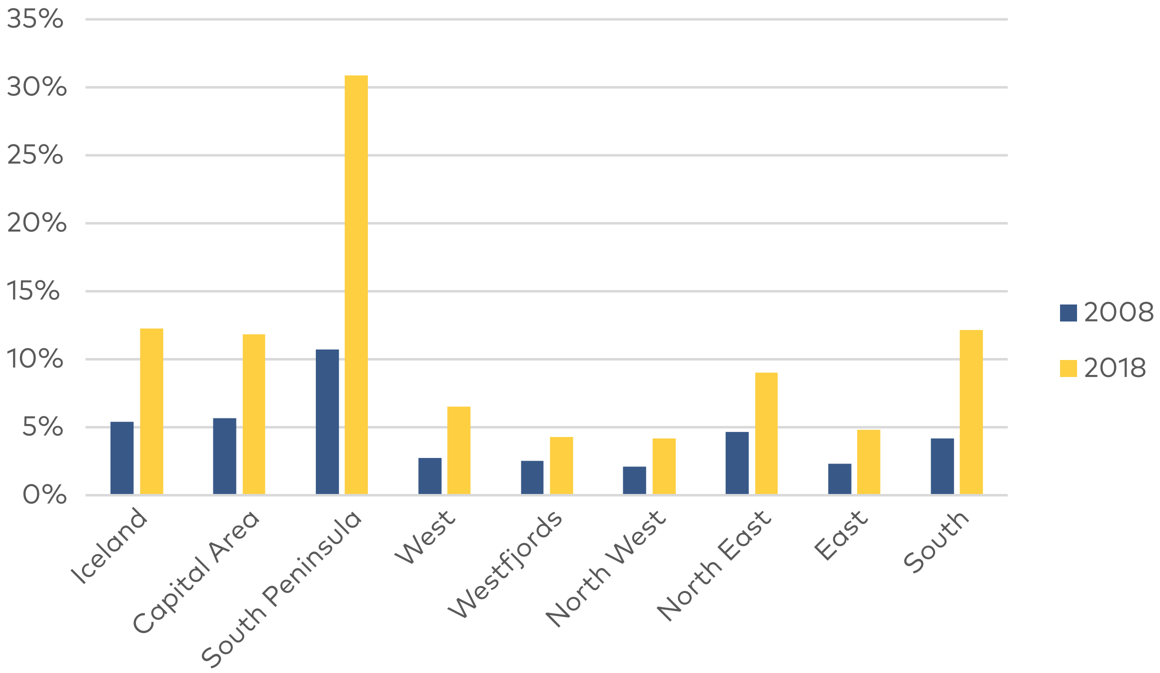


Source: Statistics Iceland.

In 2008, tourism accounted for 5.4% of total labour income in Iceland (Figure 7). By 2018, this had risen to 12.3% – an increase of 127% – while tourism's share of employment increased from 7.1% to 14.8% over the same period (a 108% increase) (Figure 6). The regional disparity underlying the 2018 figures for total labour income is notable: in the South Peninsula, the figure was a lofty 30.9%, compared to 4.1% in North West – 7.5-fold difference (Figure 7). Accordingly, the South Peninsula, South, Capital Area and North East have the largest tourism industries, while the West, East, Westfjords and North West have relatively smaller tourism industries.

Interestingly, one could think that tourism would have a relatively larger economic impact outside the Capital Area, given one of the main reasons tourists come to Iceland is to see its natural and ecological attractions. This does not, however, appear to be borne out by the figures for share of tourism in labour income by region, which is the closest available indicator. According to the 2018 figures, only the South Peninsula has a larger share than the Capital Area, while the South is on a par. However, when the country was classified according to municipalities, Reykjavíkurborg, the capital city, only came out as having the 21st largest share of tourism (Table A2 in the Appendix), with Skútustaðahreppur, Mýrdalshreppur and Skaftárhreppur claiming the top three spots.

Figure 7. Tourism share of local labour income in Iceland's total labour income and by regions, 2008–2018



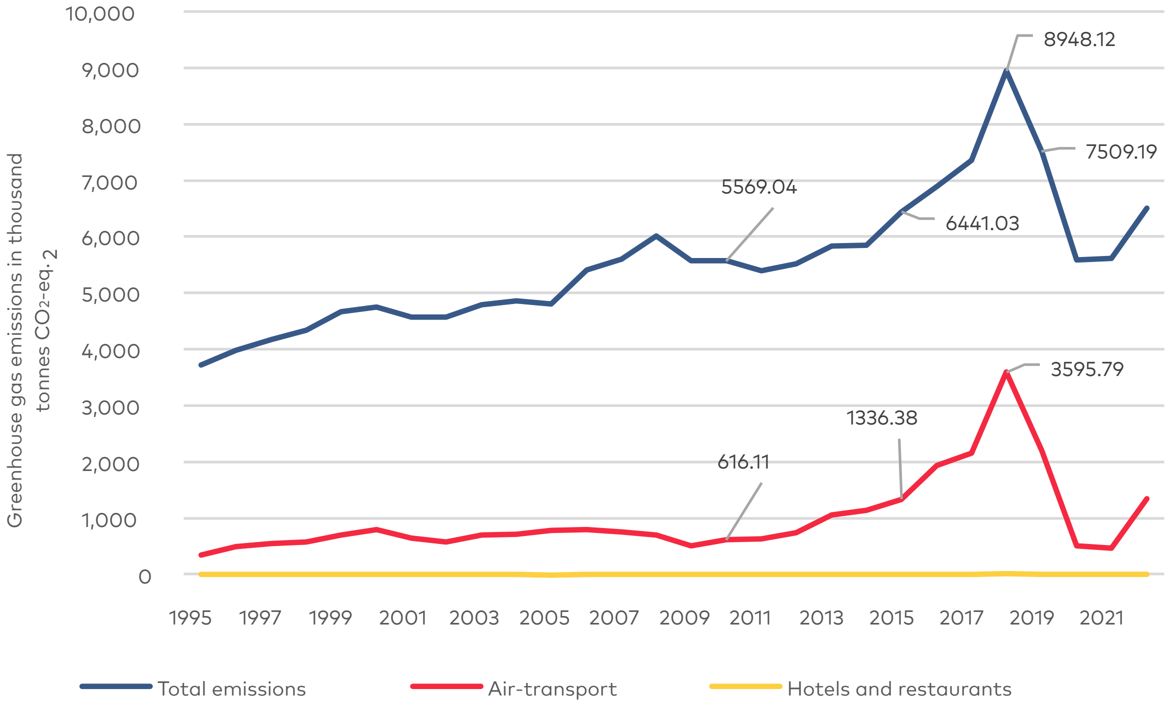
Source: Statistics Iceland.

4.2 The ecological footprint of tourism

In 2021, a report was published comparing and classifying Iceland's greenhouse gas emissions across various industries for the years 2005 and 2019 (Loftslagsvegvísir atvinnulífsins 2021). Although tourism is not well represented in the standard classification of businesses or industries used in the report, air transport, rental cars and land transport did feature: this does not cover the entirely of tourism greenhouse gas emissions (other possible sources include accommodation, sea transport, consumption, waste disposal and electricity), but nevertheless represents its largest share. Another caveat is that not all air and land transport and rented cars are for tourists – fisheries, for example, also make considerable use of land transport and cargo flights to transport fresh fish exports. Three cargo airlines operate in Iceland, compared to 27 airlines geared towards passenger transport (Isavia 2022).

The report puts Iceland's total emissions in 2019 at 6,210,000 tonnes of CO_2-equivelents, an increase of 28% compared to 2005. Tourism-related branches were responsible for 22% of total emissions in 2005 and 32% in 2019, reflecting an 83% increase in tourism-related emissions over this period. Meanwhile, Statistics Iceland – which has been reporting on greenhouse gas emissions since 1995 – estimates a somewhat higher level of total emissions for 2019: 7,509,190 tonnes (Figure

Figure 8. Tourism-related sources of greenhouse gas emissions



Source: Statistics Iceland.

8). The organisation's figures show that the share of flight transport alone in the Icelandic economy's total emissions fell from a high of 40% in 2018 to 29% in 2019. As noted earlier, this was mainly due to the bankruptcy of WOW air, before Covid-19 drove it down further to 8% in 2021– the lowest level seen in the period 1995–2022. By 2022, it had risen again to 22% of total emissions, equating to 1,342,050 tonnes of CO_2-equivelents. It should be noted that, thanks to hydroelectricity and geothermal heating, hotels and restaurants produce near-zero emissions. Overall, however, the tourism sector's high share of total emission means it is unavoidable that the industry must make efforts to reduce its emissions.

A study by Sharp et al. (2016) suggests that tourism-related activities in Iceland were responsible for 1.8 million tonnes of CO_2 equivalents in 2015, compared to 600,000 in 2010. This equates to 28% of Iceland's total emissions in 2015 and 11% in 2010: an almost threefold increase. Aviation is responsible for 50–82% of a tourist's emissions footprint, depending on the flight distance travelled to get to the country.

Breaking the ecological footprint down into its constituent parts is instructive. Such an analysis was conducted for the year 2013, although no comparable figures are available for more recent years (Table 3) (Sharp et al. 2016). Even so, it is unlikely that the respective shares of the various emissions sources have changed much in the past decade, even if the total volume has risen (Figure 8).

Table 3. Sources of carbon footprint within Icelandic tourism, 2013

Sources of ecological footprint of tourism	Kg CO_2-eq. per tourist	Share of the total
Flight	800	59%
Local transport	330	24%
Accommodation and restaurant services	100	7%
Retail goods	70	5%
Recreation and leisure services	50	4%
Sum	*1,350*	*100%*

Source: Sharp et al. (2016).

As can be seen in Table 3, the average total carbon footprint per foreign tourist amounted to 1,350 kg of CO_2-equivalents, with flights accounting for 59% of this and local transport 24%. The three other categories listed ranged from 4% to 7% of the total – substantially lower than the two transport categories.

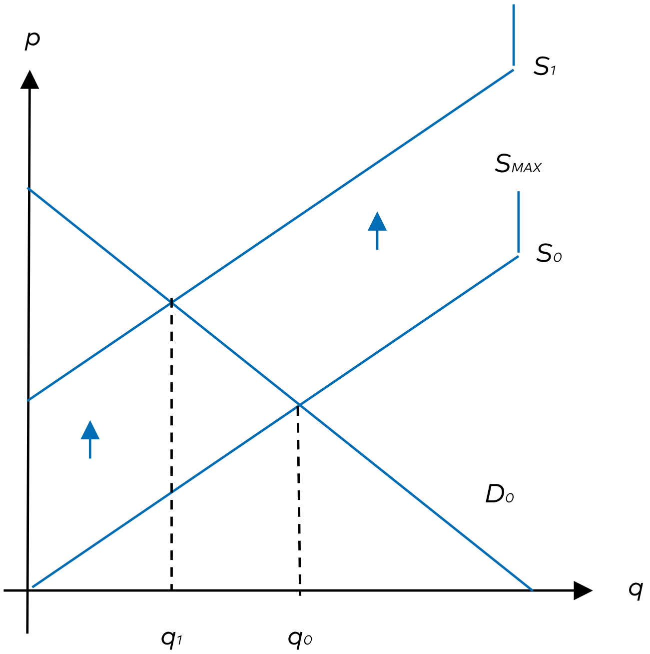
The reasons behind the large carbon footprints caused by flight and local transport appear straightforward. In the case of the three other sources (accommodation and restaurant services; retail goods; and recreations and leisure services), it seems likely the recorded emissions arise from the transportation of raw materials and goods necessary for the provision of these services, as well as the transportation of the clients making use of such services.

5. Economic impacts of climate policies on Iceland's tourism industry

The international agreements and other commitments signed up to by the Icelandic government will, in all likelihood, have a number of negative impacts on the country's tourism industry in the short run. The necessity of investing in environmentally friendly technology will increase fixed costs, as those operating in the tourist industry will have to buy more expensive equipment, such as new airplanes and e-fuel vehicles. On top of this, having to buy more expensive products on an ongoing basis, such as e-fuel, will increase marginal costs (Martin et al. 2023). Marginal costs will also be affected if the tourism industry is required to purchase quota permits for increased emissions. At the same time, and for similar reasons, tourists, will have to pay more for food while travelling around Iceland. As Figure 9 demonstrates, full activation of the agreements will lead to an upward shift in the supply curve, with consumers and tourists facing higher prices, the level of which is partly determined by elasticity of demand.

If fixed costs rise, so too will travel costs (price), while the corresponding number of tourists will decrease (q_0 to q_1). Although this means a fall in the tourist surplus, this will not translate into a fall in the social surplus, provid-

Figure 9. Supply and demand in Iceland's tourist market



Note: Figure expresses prices (p), quantity (q), supply curves (S) and a demand curve (D).

ed the increase in travel costs reflects the true social costs of pollution damage (Rosen & Gayer 2008). Instead, it would lead to increased social surplus, if $q_1 < q^*$, since the harmful climate effect (the area between the supply curves, a rectanguloid) exceeds the consumer and producer surplus (the triangle between the old supply curve and the demand curve) on the amount of tourism given by $q_0 - q_1$.

The climate issue is one type of externality that could explain the difference in the supply curve (S_0, S_1). It should be mentioned that externalities could be of other origin as well, as has been discussed in Iceland in relation to the country's capacity in tourism. Discussion of Iceland's maximum tourism capacity (S_{MAX}) has led to the formulation of a number of estimations aimed at addressing the issue. S_{MAX} encompasses three aspects: 1) social capacity; 2) natural capacity; and 3) infrastructure. Social capacity refers to the number of tourists that locals are able and willing to tolerate and serve. Natural capacity, meanwhile, reflects the natural landscape's vulnerability to tourist traffic, with some vegetation or natural phenomena more at risk than others. There are, for example, very sensitive Icelandic cave formations that can easily be damaged or ruined. Regarding infrastructure, Iceland faces limitations in light of the fact it only has around 400,000 inhabitants, spread across a relatively large geographical area. As such, the road network, telecommunications, and hiking, cycling and riding tracks struggle to meet the demands of 3 million or so tourists each year.

Building on the above, it is necessary to look separately at, firstly, international travel to Iceland and, secondly, tourist travel within Iceland. The price elasticity of international flights to and from Iceland can be different than the price elasticity of domestic transport to and from tourist destinations, with the latter mainly dependent on the demand for rental cars and a willingness to drive around the country.

5.1 International travel to Iceland

When it comes to international flights, hydrogen appears to be the way forward (Krein 2022, Lawson 2023). Icelandair, the largest local airline company in Iceland, has already begun taking steps – albeit small – in this regard. E-fuel is more expensive than fossil fuels, and according to a recently published paper was estimated to increase fuel costs by between 104% to 159% (depending on electricity source) in the year 2020, falling to 24%–67% by 2050 (Martin et al. 2023). Here, it should be borne in mind that fuel costs constitute 30–40% of operating expenses (Swidan & Merkert 2019), or, according to another source, close to 40% (Ryerson & Hansen 2013). That means the price of plane tickets to/from Iceland is likely to rise 31–64% in the short run, and 7–27% in the long run (assuming high competition in the market).

The level of reduction in tourist numbers depends on the elasticity of demand and supply. According to recent research, the price elasticity of airplane tickets is low: -0.03 to -0.005, depending to the day of the week and length of time to the flight's departure (Meyer et al. 2022). Based on the expected rise in flight tickets and elasticity of demand, the number of tourists would decrease by 0.5–1.1% in the short run and 0.1–0.5% in the long run.[6] Another research paper focused on demand for outbound tourists in Australia also indicated very low ticket-price elasticity (Seetaram 2012), although not all studies on the topic reach this conclusion, with another paper looking at flights from the UK suggesting the contrary (Seetaram et al. 2014). If price is very inelastic, the demand curve is relatively steep. Assuming this is the case for overseas tourists to Iceland, the reduction in tourist numbers will be relatively small. Thus, increases in travel price (for whatever reason) will harm tourists more than producers (the flight companies) and those working in tourism-related industries.

Price elasticity may, however, differ between people going about their daily routine (workers) and those engaging in leisure activities (tourists) (Divisekera 2010). In this context, Heffer-Flaata et al. (2021) conducted an interesting study on how sensitive demand for international flight tickets or outbound travel is against accommodation taxes in Europe. The results suggest that the level of sensitivity varies depending on the chosen destination and peak/off-peak seasons. It is more elastic than the previous studies suggested. Accordingly, one would expect higher plane tickets prices arising from the green transition to decrease demand as well, although not as dramatically as the rise in price might suggest.

5.2 Tourist travel within Iceland

Information about rental car prices was provided by Höldur ehf., one of the largest car rental companies in Iceland. The average fixed one-week fee charged by Höldur for a rented car is approximately €636 if it runs on fossil fuels or €700

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[6] The average number for price elasticity was used.

(based on exchange rates at the time of writing) if it runs on electricity. According to the company, the fee for an e-car should in fact be considerably higher in order to cover their costs, but they needed to decrease it due to low demand.[7] Furthermore, the government had stipulated that no value added tax (VAT) was to be applied to purchases of e-cars in Iceland, equating to a government subsidy of about 20%, but this was rescinded at the beginning of 2024. As such, it would be reasonable to increase the fixed fee for e-cars by about 35% in order to accurately reflect the cost difference.[8] It is, however, cheaper to drive an e-car in Iceland, costing approximately €0.03 per km on average compared to €0.15 per km for a fossil fuel car.[9] If this is true, a simple breakeven analysis suggests that tourists would have to drive 2,517 km per week to be better off in an e-car than a fossil fuel car.[10] Given this equates to almost two times the length of Iceland's ring-road, it is unlikely in the extreme that a foreign tourist will drive this distance over the course of a week's holiday, which is roughly the average duration an overseas visitor stays (Ferðamálastofa 2023). A foreign study supports this notion as well (Bęben et al. 2022).[11] Thus, any prohibition of fossil fuel cars will almost certainly have a negative effect on tourists' budgets, potentially reducing their overall demand for activities while on holiday.

To what extent is a tourist's willingness to drive a rental car in Iceland sensitive to fuel prices? A 2010 Australian study offers some guidance in this regard: like Iceland, Australia is an island that for most tourists requires a plane journey to visit, while its geographical size and low population density outside urban areas means travellers are often dependent on rental cars (Divisekera 2010). As such, the price elasticity of tourists concerning domestic transport is low: -0.36, therefore price inelastic. In other words, in the event of a 10% rise in the marginal cost of domestic travel – encompassing domestic flights, rental cars and buses – demand for such travel would fall by 3.6%.

5.3 Steps already taken

Small but significant steps have been taken towards lowering Iceland's tourism-related emissions: airlines are using e-fuel supplements (A.P. Karlsson 2023), e-cars have become more prevalent in car rentals, and new, greener passenger ships are entering Icelandic waters (Claesen & Einarsson 2023). Regarding car rentals in particular, figures from Statistics Iceland indicate the use of e-cars has increased rapidly in recent years, shooting up from 1.2% of total numbers of cars in use in 2019 to 15.9% in 2022 (Figure 10).[12]

Information provided by Höldur suggests that, given it cannot charge

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[7] Email from Höldur; Reynir Hallgrímsson, 1 November 2023.

[8] Emails from Höldur; Sigurður Guðmundsson, 30 October 2023 to 1 November 2023.

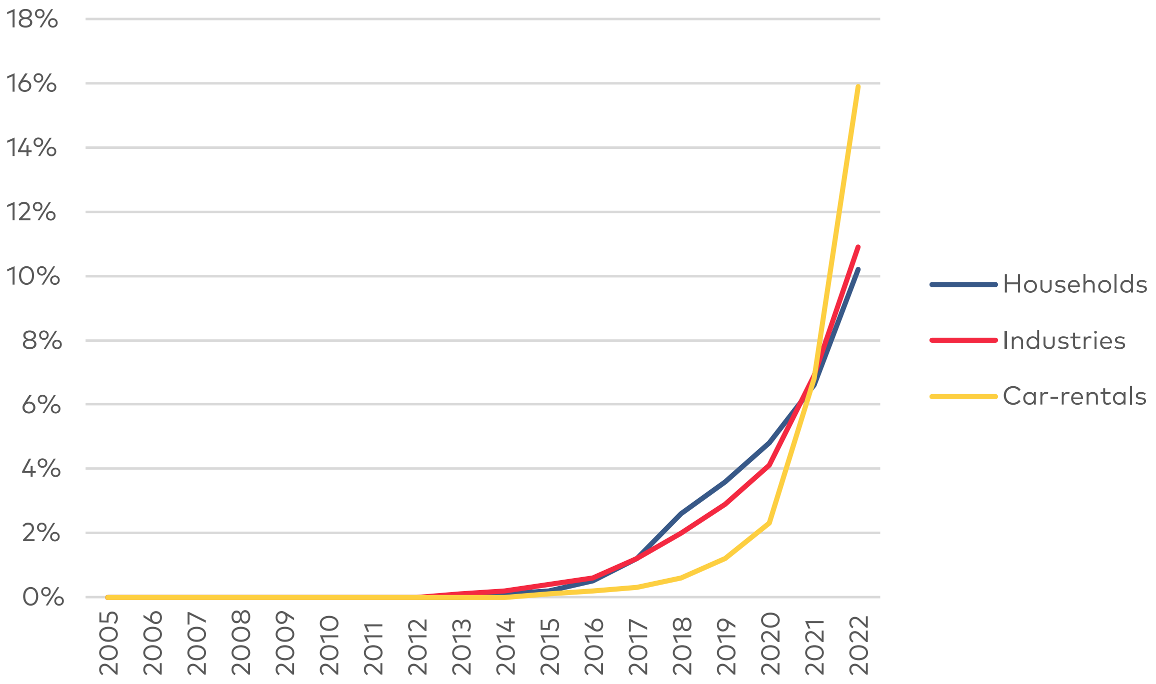
[9] See Orkusetur webpage: https://calc.orkusetur.is/ElectricCar (accessed 31 October 2023).

[10] I use Icelandic krónur in this calculation: $95{,}147+23x=140{,}451+5x \Longrightarrow 18x=45{,}304 \Longrightarrow x=2{,}517$.

[11] The ring-road is 1,321 km long and road passes through every region of the country apart from the Westfjords, which can be accessed by a detour. See the Icelandic Road and Coastal Administration webpage: https://www.vegagerdin.is/vegakerfid/vegalengdir/ (accessed 8 November 2023).

[12] This is based on numbers for the industry in the NACE code 'Administrative and support service activities' (The N-category), where car rentals are included and are the largest owner of cars within that industry: NACE no 7711 called 'Renting and leasing of cars and light motor vehicles' (ÍSAT númer 77.11).

Figure 10. Share of electric and hybrid car use in Iceland, 2005–2022



Source: Statistics Iceland.

the prices needed to cover its costs, the number of e-cars in its fleet will not continue to increase as fast as was the case over the 2019–2022 period. Moreover, until recently, no VAT was applied to e-cars purchased in Iceland. Going forward, the purchase of e-cars will be subsidised post hoc, but capped at approximately €6,000 per car (based on exchange rates at the time of writing).[13]

6. The rural economic impacts of tourism-related climate policies

As has been set out above, Iceland's attempts to address climate policies will likely increase the costs of overseas tourists flying into the country, as well as domestic travel costs for both local and foreign tourists. This will in turn reduce the number of tourists coming to and travelling around Iceland. What remains to be determined, however, is how the impacts of this might differ spatially.

6.1 Spatial impacts of increased travel costs to and from Iceland

While it would be natural to assume that more expensive plane tickets to Iceland would harm tourism to the capital area and the rest of the country evenly, this is not necessarily true. Iceland is host to a variety of attractions, some of which may be categorised as 'must see' destinations and others of which are vis-

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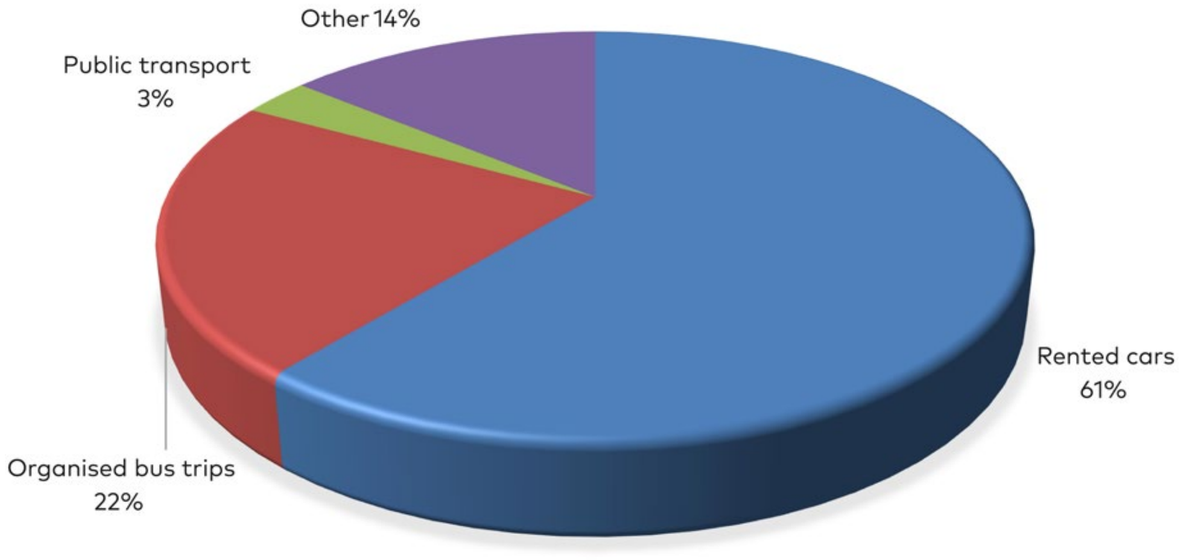
[13] Emails from Höldur; Sigurður Guðmundsson, 30 October 2023 to 1 November 2023.

Figure 11. Modes of transport used by tourists in Iceland in 2022



Source: Icelandic Tourist Board (2023).

ited more 'out of curiosity'. Iceland's two most prominent 'must see' destinations – the Golden Circle and the Blue Lagoon – are both within the vicinity of the capital. Given that those flying into to Iceland are more likely to give priority to the country's 'must see' destinations, the number of tourists visiting destinations 'out of curiosity' will likely fall if travel budgets become more constrained due to higher plane ticket costs.

Moreover, the capital area is closer to the international airport than most other parts of the country, making it more accessible in terms of travel time and cost. Accordingly, Iceland's other districts are more at risk from the impacts of air travel price rises.

6.2 Spatial impacts of increased travel costs within Iceland

Rented cars are the most common means of travel used by foreign tourists in Iceland (Figure 11). Given that – as touched on above – Iceland's 'must see' destinations are for the most part relatively close to the capital area, increased travel costs will likely reduce the number of tourists travelling to the country's more distant regions. Here, the perceived value of a destination has a direct effect on tourist behaviour: if a destination is regarded as a 'must see', the number of tourists visiting it will not decline much relative to other ('want to see' or 'perhaps see') destinations.[14]

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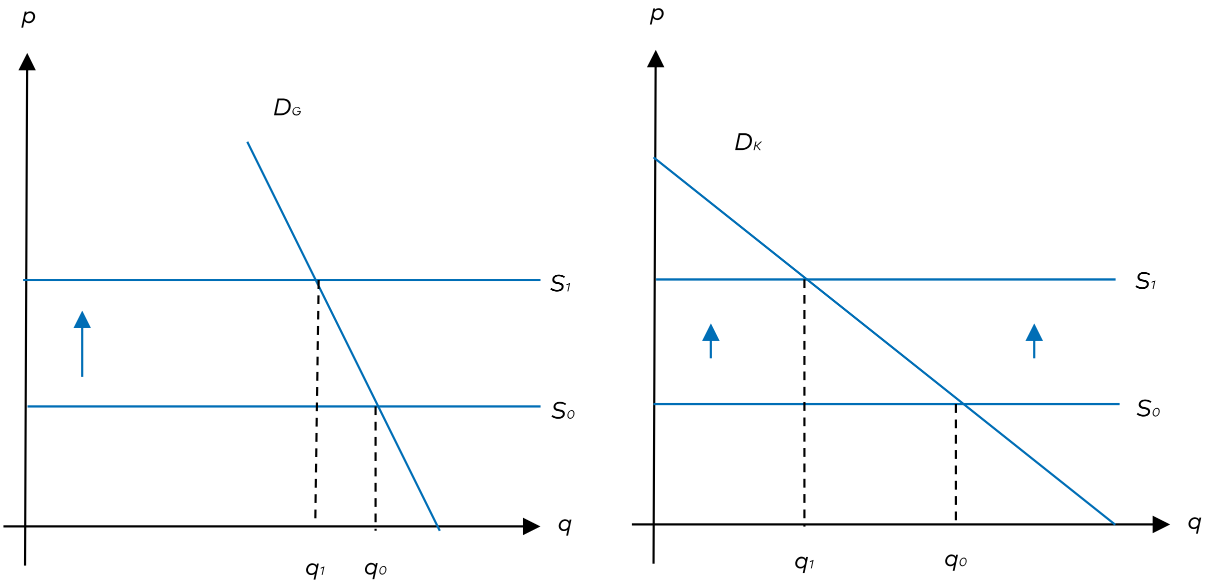
[14] The demand curve is close to vertical and so almost perfectly price inelastic.

Figure 12. Two different tourist destinations located within a one-day range from Reykjavík



A: Golden Triangle

B: Kirkjufell

Take the Golden Circle – Iceland's best-known tourist attraction – as an example. The Golden Circle consists of Thingvellir, Geysir, Gullfoss and the Blue Lagoon. Of these, Gullfoss is the furthest from the capital area (around 88.5 km), while the Blue Lagoon is approximately 50 km away. Compare this with Kirkjufell mountain, which is around 183 km from the capital area and not as highly appreciated ('must see' vs. 'see out of curiosity'). As demonstrated by Figure 12, the two attractions' different elasticities of demand (demand for Golden Triangle is more inelastic as shown by a steeper demand curve) mean that if travel costs rise identically per km and all else remains equal, the number of tourists visiting Kirkjufell will decrease more than is the case for the Golden Circle.[15]

As discussed in Section 5.2, choosing to rent an e-car over a fossil fuel car would only be advantageous cost-wise if the visitor would end up driving more than 2,517 km over the course of a week, which is a very unlikely prospect. Given this, it would be logical to assume that the higher fixed cost attached to the e-car would render it uneconomical and therefore unattractive to tourists looking to rent a car. This outcome is, of course, dependent on both fossil and e-fuel cars being available, which is currently the case. However, many countries around the world are imposing prohibitions on selling new fossil fuel cars that will become active over the coming years: in Iceland, it is scheduled to take effect in 2030. After this time, although the total number of tourists coming to Iceland will likely fall due to increased travel costs, the disparity between the capital area and the rest of the country will be narrowed due to the lower mar-

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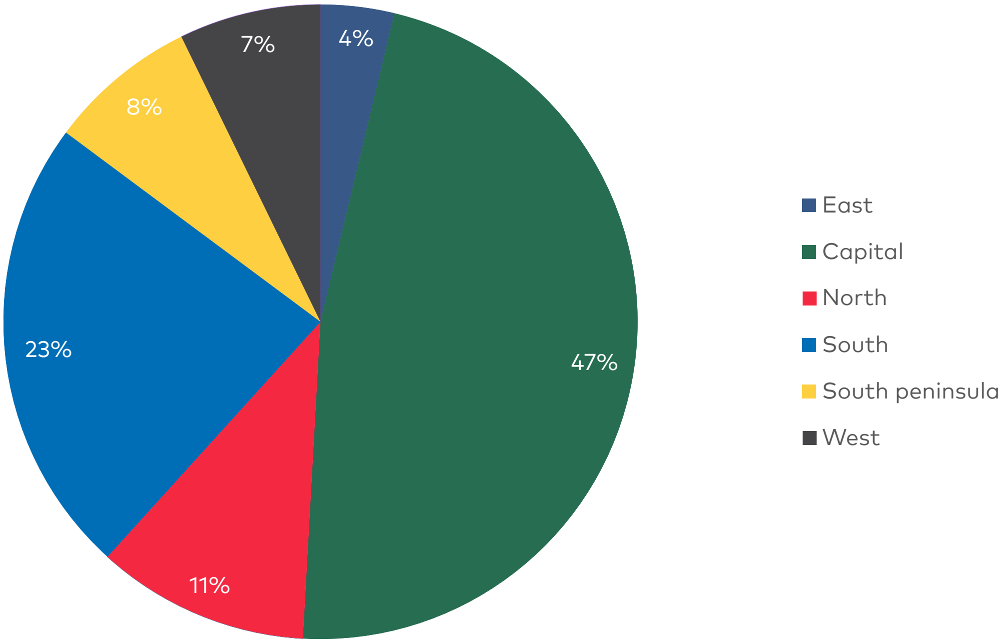
[15] The supply curve shifts up, with the magnitude of the shift comparable to the changes in travel cost.

Figure 13. Proportion of tourist overnight stays by region in 2019



Source: Statistics Iceland.

ginal costs of travelling further distances.[16] That could result in a net gain for Iceland's rural areas because, as argued, demand is more sensitive to the costs of travelling within the country than the cost of travelling to it. Here, it should be borne in mind that such a scenario requires adequate infrastructure for electric cars, especially charging stations.

The vast majority of foreign tourists arrive by plane at Keflavík airport at the South peninsula, following which many will drive for half-an-hour to the capital, Reykjavík. Almost all foreign visitors visit the Capital Area (Figure 15 A), and this is where half of all overnight stays take place (Figure 13). As such, the capital area represents the main hub from which tourists can embark on day trips to adjacent regions – such as the South, West and South Peninsula – where they might spend the night if they need to travel any further. The South is the second most popular region for overnight tourist stays, followed by the North, the South Peninsula and the West. The least popular region for overnight stays is the East, which is farthest from the Capital Area and so accords with the argument put forward above. Although the North is the second furthest region from the capital area, its strong performance can be ascribed to both strong infrastructure and the beauty of the regional capital, Akureyri, which is the second largest urban community in the country (assumed the greater capital area is counted as a single conurbation). Akureyri also serves as a hub for visiting the Diamond Circle, which

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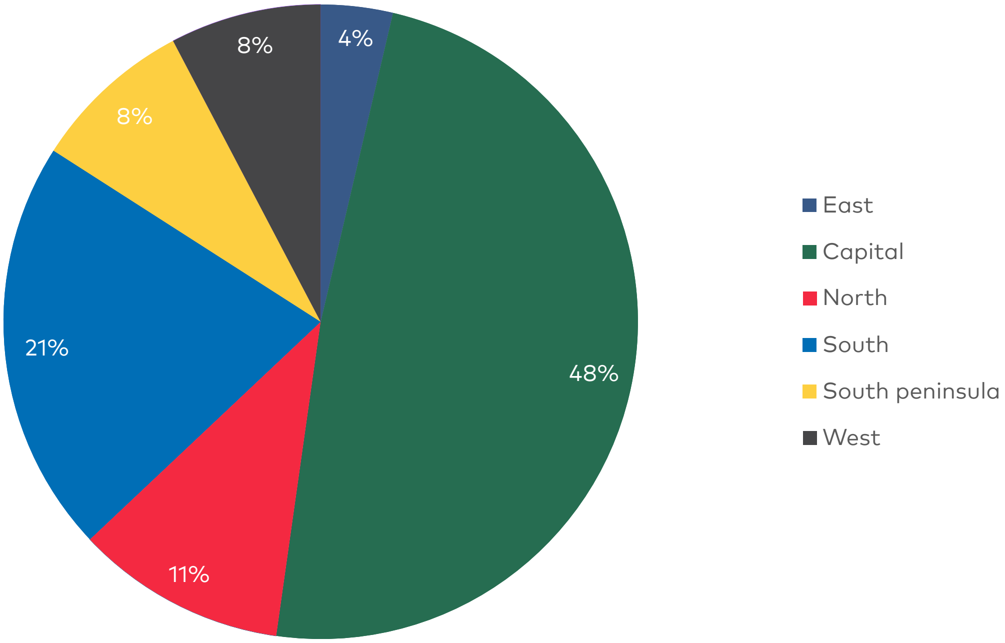
[16] Here the income and substitutional effect of the demand is needed to decide the net impact of the change (Eaton & Eaton 1991).

Figure 14. Proportion of rooms available to tourists by region in 2019



Source: Statistics Iceland.

consists of five highly attractive tourist destinations (Goðafoss waterfall, Lake Mývatn, Dettifoss waterfall, Ásbyrgi canyon and Húsavík). A new travel circle – the Silver Circle – is currently being established in the West.

It should be noted that there are no significant regional disparities when it comes to the number of overnight stays relative to the number of available rooms for tourists (Figure 13 and Figure 14), which indicates that accommodation capacity is either too low or close to its equilibrium.

On the other hand, a considerable disparity becomes apparent when overnight stays are compared with visits by region (Figure 15). The numbers for overnight stays are based on accommodation registrations reported by hotels, hostels and other accommodation providers, while those for visits are based on a survey conducted among foreign tourists in which the following question was asked: 'Did you visit any of the following regions (for a longer or shorter period)? Please indicate all the regions you visited'.[17] According to the results of the survey, the vast majority of tourists visited the South region (79%), despite the fact it only accounts for 23% of overnight stays (Figure 13).

Tourists were also asked whether they would like to visit Iceland again, and if so, were presented with the question: 'Which region(s) would you like to visit on your next trip to Iceland? Please select all that apply'.[18] The Westfjords and the North were both named by 30% of those answering the question, with the

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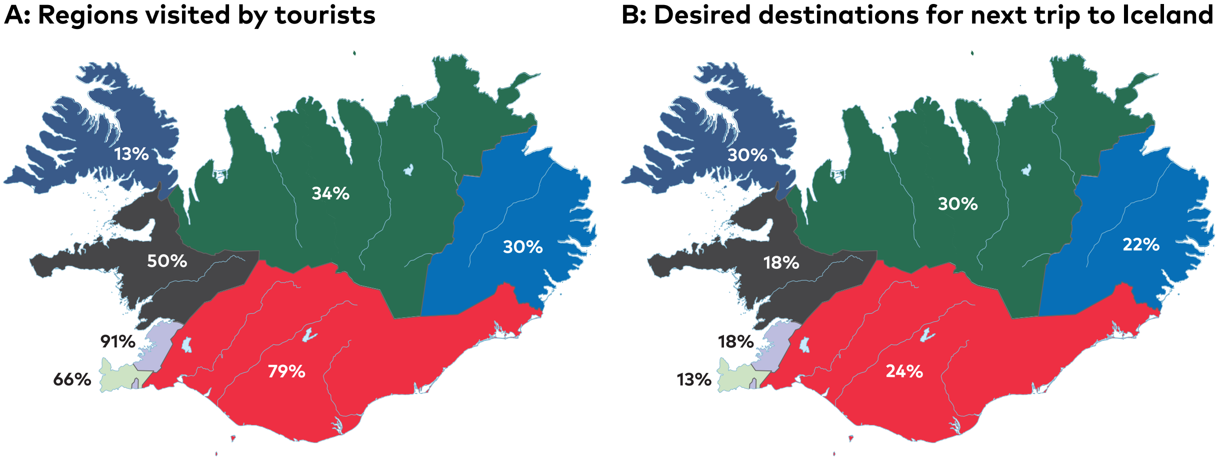
[17] Email from Icelandic Tourist Board; Oddný Þóra Óladóttir, 29 November 2023.

[18] Email from Icelandic Tourist Board; Oddný Þóra Óladóttir, 11 December 2023.

Figure 15. Popularity of Icelandic regions among tourists in 2022 (actual and desired visits)



A: Regions visited by tourists

B: Desired destinations for next trip to Iceland

Source: Icelandic Tourist Board (2023).

other regions all lagging behind (Figure 15 B). Only 18% wanted to visit the Capital Area again, and 13% the South Peninsula. According to an Icelandic Tourist Board survey, 17.3% of foreign tourists in 2022 had visited Iceland previously, and 16.5% in 2023.[19]

Here, it is worth highlighting that an earlier 2017 study suggests municipality (or local authority) revenue attributable to tourism is higher if tourists stay overnight rather than just pass through or visit for a few hours (Karlsson et al. 2017). The study even indicated that if a municipality receives a large number of tourists but almost none stay overnight in accommodation, then the cost to the municipality will exceed the income generated. Accordingly, municipalities gain more by getting tourists to stay for one or more nights, thereby ensuring a positive impact on their income.

An additional way of assessing the local economic impacts of climate policies is by looking at tourism's share of local labour income within each region. Towards this end, data down to the municipality level is presented in Figure 16 and Table A2 in the Appendix, with the distance from Reykjavík – the largest hub for foreign tourists – added in the latter source in order to indicate the likelihood of visitors travelling there for an overnight stay. According to the data, Skútustaðahreppur, Mýrdalshreppur and Skaftárhreppur are in the most vulnerable economic position should levels of tourism fall, since the local labour income is to large extent dependent on tourism. Skútustaðahreppur is part of the North, while the other two municipalities are in the South. Skútustaðahreppur is in a far more vulnerable state than the other two when distance to Reykjavík is kept in mind as well as the observation that the South is the most popular tourist destination. Overall, there may be considerable spatial disparities when it comes to green transition policy impacts, similar to those experienced during the Covid pandemic (Árnason & Skúladóttir 2020).

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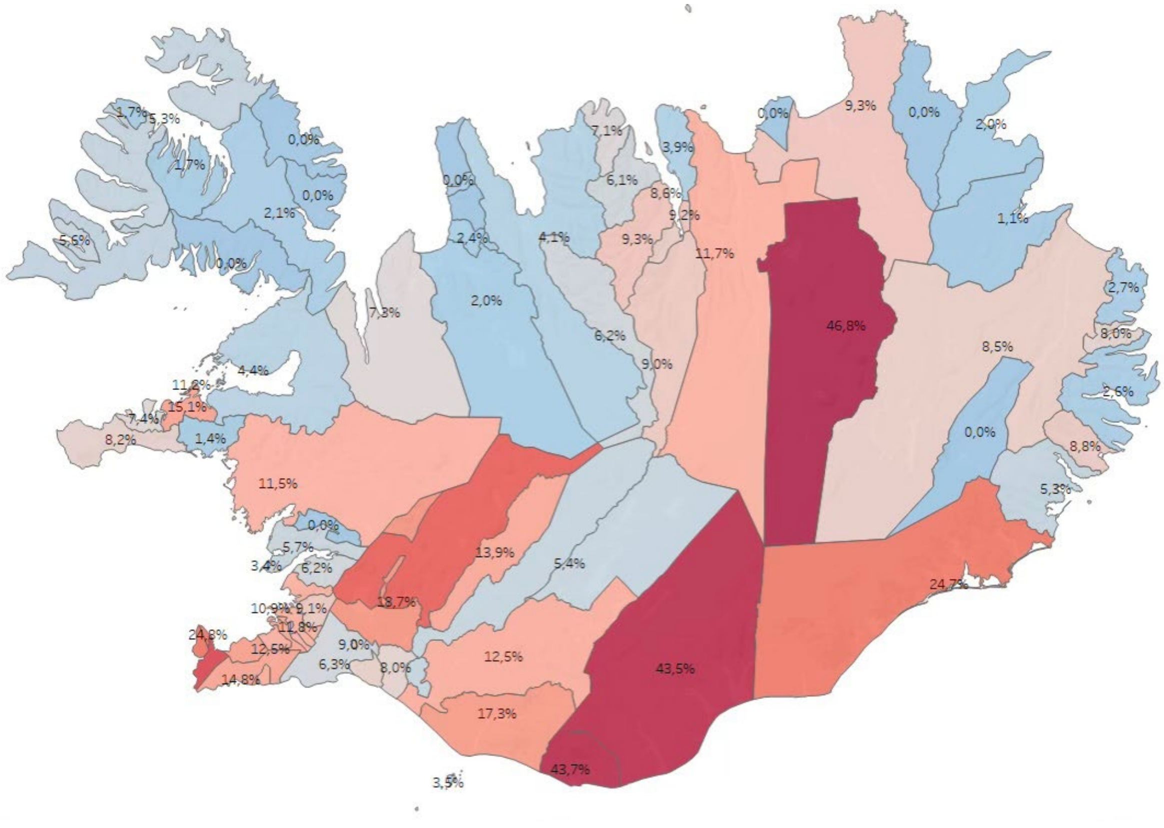
[19] Email from Icelandic Tourist Board; Oddný Þóra Óladóttir, 7 March 2024.

Figure 16. Tourism share of local labour income in Icelandic municipalities, 2018



Note: Shades of red indicate percentages of 7.5% and above and shades of blue percentages below 7.5%.
Source: Figure by Þorkell Stefánsson, specialist at the Icelandic Regional Institute based on Statistics Iceland (see also Table A2 in the Appendix).

Across all the municipalities, tourism generates between 0% and 50% of local labour income: the average is 10% and the standard deviation 0.1. As this suggests, some Icelandic municipalities are economically highly dependent on tourism, while others are not. Moreover, some of the highly dependent municipalities are far away from the Capital Area as well and the level of attractiveness of tourists destinations in some cases magnify the blow marginally, as argued earlier. When presented graphically (Figure 16), the distribution becomes clearer, with the municipalities displaying the highest tourism shares of local labour income located in the South, North East, Capital Area and South Peninsula. By contrast, the East and West lag behind, and Westfjords and North West have the lowest shares. Accordingly, one could expect some kind of polarization where the municipalities farthest away from the capital area would experience relatively greatest loss following green transition policy, especially those who already have the highest share of their labour income in tourism, while loss will be relatively lower in the proximity of the capital area.

7. Actions to minimise the rural economic costs of climate policies

A number of potential actions could be undertaken to minimise the impact of tourism-related climate policies:

1. Provide subsidies for domestic transport (buses and airplanes) to mitigate impacts arising from more expensive international travel due to the green transition.
2. Increase use of electric buses and rental cars by strengthening subsidy policies and facilitating the construction of appropriate infrastructure (e.g. charging stations).
3. Improve public transport coverage and links across the country.
4. Provide support for producers of local food and other potential local tourist goods.
5. Conduct more research on tourist behaviour in relation to demand for flights, rental cars and other transportation modes, as well as food.

7.1 Subsidies for domestic transport

Air travel is responsible for the greatest portion of tourism's ecological footprint (Table 3). Plane ticket prices will likely increase once the authorities put their green transition policies in action because e-fuel is more expensive. As set out above, some regions will probably be harder hit than others by this, in particular those further away from Reykjavík.

The rise in plane ticket prices arising from the green transition could potentially be mitigated by increasing the subsidies already given to scheduled domestic flights or any other passengers' transport (or even all transport), although this may not be deemed wise from an environmental perspective. Such measures may, however, prove not as necessary in light of developments in the field of electric airplanes (driven by electric motors and fuelled by charged batteries), which could be conducive to the shorter distances involved in domestic flights. According to a report produced by Kackus (2023), flights on these electric planes may even prove to be cheaper than the flight services offered today – at least in Iceland.

If that suggestion is not feasible, the authorities could as well subsidise e-fuel consumption of international flights. This would however be more complicated without international agreements since the vast majority of flight companies offering scheduled flights to and from Iceland are of foreign origin.

7.2 Subsidy policies and infrastructure facilitating increased use of electric buses and rental e-cars

As described previously, the main obstacle standing in the path of increased use of rental e-cars in Iceland is the fact that they are more expensive to rent than fossil fuel cars unless the person renting the car is willing to drive over 2,517 km in a week (the 'breakeven point'). As such, the average tourist will choose a fossil fuel car. If, however, the breakeven point could be reduced by 50% or more, then this situation will be reversed. There are two ways of achieving this (aside from prohibiting the use of fossil fuel cars): increasing taxes on fossil fuels cars and/or subsidising electric vehicles. This inevitably leads to the question of how much taxes should be raised by or alternatively what level of subsidy is required.

Recall that the fixed fee charged by the car rental company is highly dependent on the price the company must pay for its cars, while also taking into account factors such as operational costs and anticipated profits/dividends within a very competitive market (there were 145 car rental companies in Iceland authorised to operate in Iceland in November 2023) (Jónsdóttir 2017).[20] With this in mind, we use the rental fee as a proxy number for the price the rental company must pay to purchase a car. An electric car (priced at €936) is 48% (€302) more expensive than a fossil fuel car (€634), which gives us the aforementioned 2,517 km breakeven point. Accordingly, this difference in price between the two types of vehicles must be reduced by 50% (to €151) in order to reduce the corresponding breakeven point by 50%. This can be done either by reducing the price of an e-car from €936 to €785 (a 16% reduction) or increasing the price of a fossil fuels car from €634 to €785 (a 24% increase) – in other words, providing a 16% subsidy on electric vehicles or imposing a 24% tax on fossil fuel cars (or a mixture of the two).

Despite what might be suggested by these calculations, however, the experience thus far has been that tourists are not choosing e-cars over fossil fuel cars despite there being almost no difference in rental price. As mentioned earlier, a manager at Höldur explained that the company had been forced to reduce its rental fee for e-cars due to low demand. Given that it has not been possible for the company to gain the higher income on electric cars it needs in order to counter-balance the higher purchase costs involved while achieving sufficient turnover, the incentive is to keep only a limited number of e-cars in its fleet. This translates into a lower supply of electric cars for rent in Iceland.

The fact that the e-cars purchased by Höldur were seldom hired despite the low price of electricity (which translates to a calculated breakeven point of 493 km driven per week)[21] and the presumed appeal to tourists' consciences regarding fossil fuel emissions begs the question: Why are so few electric cars rented in Iceland? Is it the infrastructure? If so, would increased investment in electric vehicle infrastructure be a more effective policy in steering tourists towards e-cars? However, how would a foreigner know prior to renting a car that Iceland's infrastructure is insufficient for electric vehicles? Is it a reputational issue? Or is it simply that people tend to use goods and services they are already used to, particularly when faced by having to drive in an unfamiliar country?

As mentioned, until recently VAT (19.35%) was not applied to purchases of new e-cars. However, car rental companies are obliged to pay VAT should they choose to resell the car on the second-hand market – a rule that does not apply to ordinary households in Iceland (Arnarson 2023). This reduces the gain provided to the car rental companies by the subsidy: for example, the effective subsidy would fall from 19.35% to just under 10%, if the market value of the second-hand car is half of what the company initially paid for it. Given this, the government would be well advised to rethink how a subsidy designed to address

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[20] See Icelandic Transport Authority webpage: https://island.is/listi-bilaleigur (accessed 17 November 2023).

[21] 95,147 + 23x = 104,038 + 5x = > x = 493.

this problem might be applied. There are two ways: 1) higher share of the VAT to be cancelled when for car rental companies sell e-cars; and 2) a subsidy for every rented car. Here, better knowledge of tourist behaviour in response to price changes is needed. If demand for rental cars is sensitive to the prices charged – as one local research article suggests is the case (Jónsdóttir 2017) – it could be wise to use subsidies to stimulate e-car turnover. However, subsidizing e-cars is not warranted unless they have some positive climate effects not accounted for in the price.

7.3 Improve public transport coverage and links

While public transport outside the Capital Area has improved in recent years, coverage remains poor compared to most other comparable countries. That is due to a number of reasons, including relatively high investment and operational costs, the sparsely populated countryside, and the low density of urban areas. Scheduled domestic flights use small planes, tickets are very expensive, and Reykjavík – despite acting as the hub for such flights – is only connected to four regions (now 11 destinations points – i.e. airports) out of seven.[22] Buses run to all regions but are poorly connected to international flights. In addition, four ferries operate along domestic routes in Iceland. Unlike most other countries, there is no central station in Reykjavík to connect all travel modes domestically and internationally.

All means of public transport must be considered from the perspective of finding cost-efficient ways of reducing emissions. This may mean directing attention towards e-fuel planes, as previously discussed, which appear to present small-scale advantages in that they are becoming cheaper for short-distance flights and can operate with fewer passengers than present airplanes (Kackus 2023).

While an express train between the international airport and Reykjavík has been discussed and a cost–benefit analysis implemented, a final decision has not been made by the authorities, as there remains political contention regarding the matter.

Public transport is poor in the Capital Area as well, consisting solely of a bus network that only 5% of the area's population use (Hrafnsson & Árnason 2023a, p. 16). A new public transport system is being prepared but remains the subject of heated political debate. Money had already been spent on the first stages of the project by both the municipalities and the central government before the latter paused proceedings in the wake of a revised investment plan issued in autumn 2023.

Interestingly, local public transport is good and free of charge in Akureyri, an urban community of close to 20,000 inhabitants – it was even rated better than in the Capital Area in a 2020 survey (Karlsson & Pétursdóttir 2021). Moreover, the local administration has shown no indication that it intends to start charging for bus tickets in Akureyri in the near future.[23] Official data on municipality operating costs suggests that Akureyri's bus network is in fact

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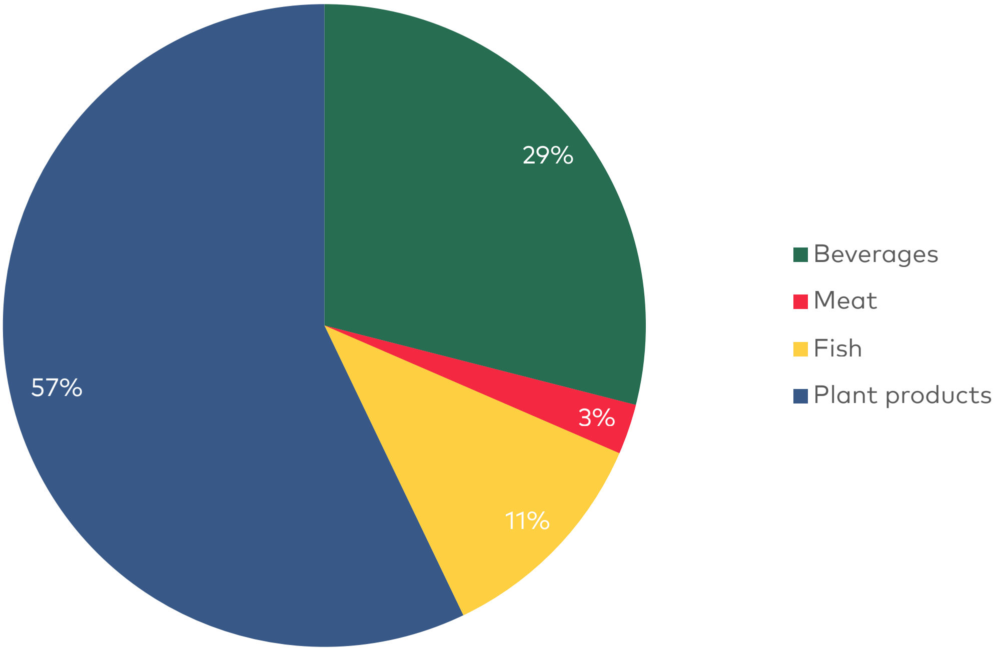
[22] See Isavia webpage: www.isavia.is/reykjavikurflugvollur/flugupplysingar/afangastadir (accessed 27 November 2023).

[23] Ásthildur Sturludóttir; communications on 22 November 2023.

Figure 17. Imported food in Iceland in the period 2017–2021



Source: Statistics Iceland.

cheaper to operate per inhabitant than in Reykjavík (Snævarr & Jóhannesson 2023), despite the fact that Akureyri is a much smaller urban community than the Capital Area, which is also 42% more densely populated.[24] At the same time, traffic congestion is greater in the Capital Area than Akureyri (Karlsson & Pétursdóttir 2021): only around 4% of Akureyri's population make use of the bus network (Hrafnsson & Árnason 2023b, p. 10), compared to the previously mentioned 5% figure for Reykjavík. In conclusion, it is hard to run a public transport in Iceland. Not only because the country is large in size and population density is low but also because relatively few people use it, even when it is available for free.

7.4 Increase availability of local food and other tourist necessities

By increasing the supply of local foods, one could potentially reduce tourism's ecological footprint by shortening the distance between the producer and consumer. This would also have a positive economic impact on rural areas, offsetting the increased costs arising from the green transition. According to Statistics Iceland (Statistics Iceland n.d.b), 750,000 tonnes of food was produced in the country in 2021, of which 550,000 tonnes was exported. At the same time, close to 200,000 tonnes of food was imported. 400,000 tonnes of food is left when the export has been subtracted. Taken together, the net food supply for 2021 amounted to almost two times the

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[24] Based on numbers from Statistics Iceland and National Land Survey of Iceland.

total annual need for Iceland's recorded population, which, as of January 2023, stands at 387,758 (Directorate of Health n.d.).[25] This discrepancy cannot be explained by the number of tourists: although 2.2 million foreign visitors came to Iceland in 2023, they only stayed for an average of seven days, which equates to 42,192 'permanent inhabitants'. Given half of Iceland's net supply of food is imported, what possibilities are there for reducing the quantity of imported food?

In order to answer this question, it is necessary to determine which foodstuffs Iceland is importing and whether it is possible or realistic from the point of view of competitiveness to produce domestic substitutes. The numbers reveal that more than half (57%) of Iceland's imported foodstuffs for the period 2017–2021 consisted of plant products (fruits, vegetables, cereals, grain etc.) (Figure 17). Although it is difficult and unprofitable to grow many things in Iceland, there are opportunities presented by greenhouse production, while developments in the growing of vegetables and grain have opened the door to outdoor harvests. The numbers indicate that domestic production of plant products equated to 18.4% of total imports of such foodstuffs over the five-year period. In 2017, there were approximately 200 Icelandic producers operating in this sectorial branch – a decline compared to 2008, although total income increased over this time in real terms, as did returns, possibly due to increased economies of scale (V. Karlsson 2019). While there may still be opportunities for scaling up, it should be borne in mind that the market share of domestic vegetables fell from 48% in 2010 to 27% in 2018 (V. Karlsson 2019, p. 82).

Drinks and beverages were the second largest sectorial branch in terms of import share, at 29%. It seems likely, however, that the recorded figures are misleading, as no domestic production was registered for beverages and drinks, and approximately 80% of these imports were subsequently exported. Here, the (lack of) numbers recorded for domestic production are the problem, rather than the import figures.

Interestingly, fish accounts for 11% of Iceland's food imports, compared to 88% of its food exports. On average, Icelanders only eat around 315 grams of fish per week, so it does not loom overly large in local consumption (Gunnarsdóttir et al. 2022). It is possible, however, that greater quantities are consumed by tourists given Icelandic fish is reputed to be of high quality and is the country's most popular food export. Increased fish consumption by tourists could provide opportunities to local districts both during holiday visits and after travellers return home, through increased international demand. The same principle also applies to for other Icelandic products.

The share of meat in Iceland's food import is very small, at just 3%. Traditionally, lamb has enjoyed a relatively large market share among Islandic meat producers, although more recently it has lost ground to pork and chicken (Karlsson et al. 2015, Statistics Iceland n.d.c). However, some have suggested that it would be better to import lamb meat to Iceland due to the ecological footprint caused by domestic production (Matthíasson 2019a). To what ex-

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[25] The Directorate of Health (i. Embætti landlæknis) estimates the per capita consumption of food in Iceland 1956-2020 kg/person/year. It turned out to be approximately 580 kg.

tent is this argument valid, and might it also apply to other domestic products (Matthíasson 2019b)? Here, it should be noted that while red meat production in Iceland is largely based on domestic input factors (aside from fossil fuels and fertilisers), pork and chicken production relies mainly on imported animal food. Given this complex situation, care must be taken when it comes to public policies aimed at stimulating domestic food production, with consideration given to what is most cost efficient in terms of emission reductions.

Overall, it seems that Iceland has an opportunity to increase domestic plant-based food and possibly drink production, while the situation regarding meat is more questionable. Lamb is produced across the island and so supports a geographically broader cross-section of residents but is not especially popular among tourists. Conversely, although tourist demand for chicken and pork is greater, most production takes place in and around the Capital Area, with animals fed on imported grain. Given these complications, pork and poultry might offer the best means of serving tourists a domestic meat they wish to eat, while also lowering the sector's ecological footprint.

On the other hand, seeking to increase pork and poultry production may be seen to run contrary to the key objective of encouraging cultural tourism through the promotion of local food. Most of Iceland's traditional food is based on lamb meat and ocean products (e.g. fish, shellfish, seaweed), rather than pork, poultry or beef. From this point of view, it could be wise to keep supporting sheep farming, both for the production of lamb meat and due to the fact that handmade sheep's wool sweaters are one of Iceland's most cherished tourist souvenirs. Furthermore, Iceland's food and wool processing are both based on traditional work practices, using technology that can be traced back many years.

7.5 Conduct more research on tourist behaviour

When determining the most efficient policy approaches for dealing with environmental challenges and their regional economic impacts, it is necessary to gather accurate, in-depth information concerning, among other things, social costs and deadweight loss. How accurate can a public policy using green taxes be if policy-makers are not fully aware of the tourism-related social and consumer benefits, or the relevant costs and price elasticity of demand of relevant goods (Baumol & Oates 1988)? How might such policy affect local economies? And how effective is it likely to be if policy-makers cannot rely on strong models to forecast its effects? As these questions imply, there is a need for studies addressing issues of this kind. In particular, it would be useful to explore: 1) demand for plane tickets to Iceland; and 2) tourist demand for various transport modes within Iceland. Doing so would provide much-needed knowledge regarding how the supplied quantity and price of a transport mode affects demand both for the transport mode in question and for other possible transport modes. Such data could feed into discussions around whether, for example, it would be worth investing in another international airport located in the vicinity of Akureyri, or whether an access fee or tourist tax should be applied to those entering the country. Another possible avenue of enquiry would be to look into tourists' consumer behaviour regarding Icelandic food products.

8. Summary and concluding remarks

The tourism industry plays a significant role in the Icelandic economy, especially when considered in terms of export income (the current account), where it generated 31% of Iceland's exported goods and services in 2023. Put another way, tourism was Iceland's largest export industry. Moreover, the tourist industry accounted for 8.8% of Iceland's GDP and 15% of the country's labour force prior to the Covid-19 crisis, with levels returning close to these levels in 2022.

Tourism's ecological footprint accounted for 32% of Iceland's greenhouse gas emissions in 2019 and it is the fastest growing branch in that regard. Air flights alone were responsible for 29% of the country's emissions that year, although this was a fall from the high of 40% seen the previous year. Given these figures, it is crucial that Iceland addresses tourism's ecological footprint if the country is to achieve its green transition goals.

While tourism is important for Iceland as a nation, it means more to some regions than others. When the share of labour income is used as an indicator, the South Peninsula benefits most from tourism, with the South and the Capital Area in second and third place. Alternatively, if we divide the country into municipalities, two out of the top three (out of 74) are located in the South, and one in the North.

The green transition will most likely affect the tourism industry negatively, at least in the short run, given that more expensive technology, the need for emission licences and/or the imposition of green taxes all inevitably lead to higher prices when travelling to and within Iceland. This may prompt fewer tourists to visit Iceland while impacting the spending budgets of those who do choose to come. There is also the issue of spatial disparities, with higher travel costs more likely to affect tourist areas located further away from the Capital Area than those within the region.

The government has a number of options when it comes to minimising the impact on communities that are highly dependent on tourism. First, it could provide subsidies aimed at increasing the number of domestic flights using e-fuel. Second, in order to encourage the use of rented e-cars among tourists, it could increase subsidies on electric cars and/or increase taxation on fossil fuel cars, while at the same time improving the national infrastructure for electric vehicles. Third, it could improve public transport coverage and links across the country. Fourth, it could provide support to local food producers (and other local tourism-related businesses). And fifth, it could facilitate further research on, among other things, how tourist behaviour is affected by increased travel costs.

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Navigating carbon neutrality in a petro-rich state: Challenges for Norway

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ABSTRACT
Despite being a sustainability pioneer, Norway's quest for environmental leadership contrasts sharply with its reliance on a petroleum-based economy. This chapter explores the two main strategies that have been proposed as a means of mitigating this petro-climate paradox: firstly, the Green Party's and environmental activists' repeated, if unsuccessful, demands that the country move towards pulling out of petroleum altogether; and, secondly, the currently pursued 'clean petroleum' approach, which involves integrating renewable energy from hydro and wind sources. This transition has, however, sparked political and regional debates over conservation and energy pricing, complicating the shift to renewables and slowing progress towards Norway's 2030 climate goals. Consequently, there is increased momentum for offshore wind, which does not provoke as serious regional reactions, but which lags behind onshore wind in industrial maturity and hence requires more substantial innovation support. At present, Norway risks missing its 2030 targets and may need to invest in foreign green initiatives, as during the Kyoto Protocol era. The chapter also highlights promising green transition initiatives involving carbon capture and sequestration and blue hydrogen, building industrial collaboration in the larger North-sea region while repurposing de-commissioned oil and gas fields benefitting Norwegian coastal regions in a low-carbon future.

Keywords: climate, petroleum, oil, gas, regional issues, industrial policy

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1. Introduction

Norway's pursuit of environmental leadership in the 21st century presents a profound paradox, reflecting its dual role as a country that is both a sustainability pioneer and deeply reliant on a petroleum-based economy. This apparent contradiction has evolved over time – Norway was once in a prime position to lead the way towards a sustainable future, thanks to its abundant hydroelectric power resources developed in the 19th and 20th centuries. Thus, when the climate challenge emerged in the early 1990s, Norway's renewables-based electricity sector stood out in marked contrast to many other nations struggling to move away from coal-powered energy sources.

The rise of offshore petroleum activities in the late 20th century and early 2000s, however, posed a substantial challenge to Norway's green aspirations. The country's pursuit of petroleum development, primarily aimed at catering to a broader North European market, triggered a surge in CO_2 emissions that have tarnished Norway's standing in international climate rankings, engendering a complex petro-climate conundrum.

This chapter delves into how Norway might navigate this conundrum, in particular whether the country's climate leadership ambitions can be reconciled with its substantial petroleum production. In doing so, the chapter sets out the challenges this presents to both the business sector and the political landscape and explores possible solutions through reform or innovation. The analysis is framed against the backdrop of the Paris Agreement and the European Union (EU)'s climate commitments, which Norway has pledged to uphold. Furthermore, the chapter considers what role regional divides play in addressing the petro-climate dilemma.

The remainder of the chapter is structured as follows. Following this introduction, Section 2 delineates the petroleum industry's significance for Norway, encompassing macroeconomic, industrial and regional perspectives. Section 3 then examines Norway's climate commitments, detailing national, industry-specific and regional climate emissions, before outlining strategies for their reduction. Section 4 explores potential solutions to the petro-climate dilemma, showcasing industrial strategies and public policies aimed at achieving climate neutrality. This includes both the transformation of the petro-industrial complex and the emergence of new industrial approaches across the country's regions. Next, Section 5 investigates the divergent political views and initiatives that have become apparent across various political arenas, including territorial disputes with traditional herding communities. Finally, Section 6 serves as an epilogue, assessing whether and how Norway can fulfil its climate objectives in the face of its commercial, political and regional divides.

The analysis is based primarily on existing open sources – including policy documents, industrial studies, press articles and civil society communiques – supplemented by interviews conducted with a view to gaining background information. Among those who participated in the interviews are representatives from the Norwegian Forum for Development and Environment (Lillian Bredal Eriksen), the Norwegian Environmental

Agency (Hans Kolshus and Hanne Birgitte Laird) and Offshore Norge (Hildegunn T. Blindheim). While we are grateful for the openness shown in sharing their perspectives and factual insights, responsibility for the report and its analysis rests entirely with the authors.

2. Norway's petroleum dependency

Although Norway does not feature among the world's leading petroleum producers, it has assumed a crucial role in Europe. As highlighted in Table 1, the country supplies 25% of the continent's gas and 13% of its oil – an increasingly significant position against a European policy agenda backdrop of growing energy security concerns. As will be discussed, Norway's and Europe's paths towards reducing petroleum dependency are deeply interconnected.

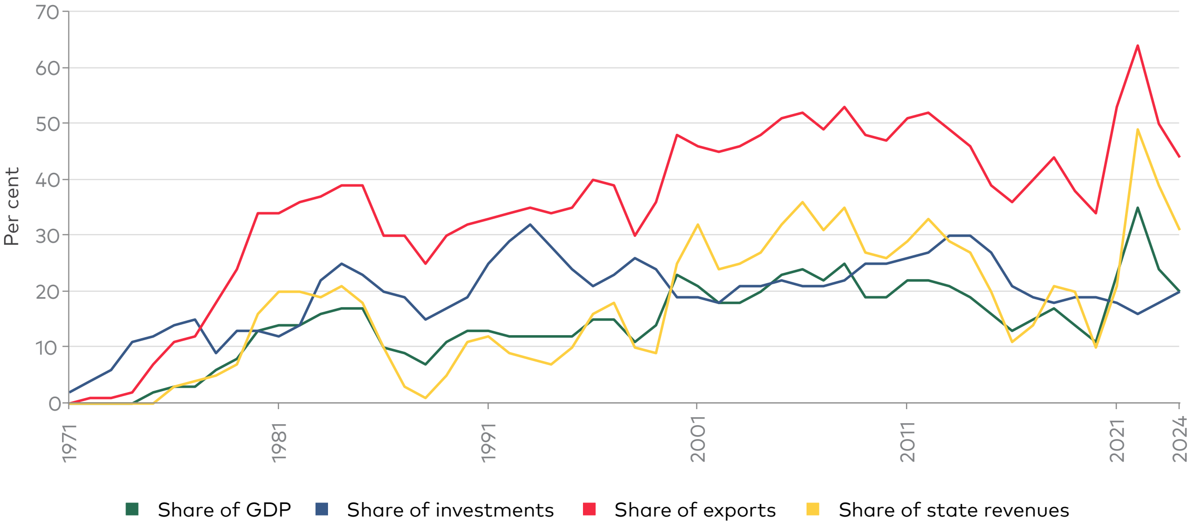
Petroleum's importance to Norway's domestic economy cannot be overstated. As detailed in Table 1, Norway ranks just behind Kuwait and the United Arab Emirates in oil production per capita, and leads the world in per capita natural gas output. Norway's more than 50 years of experience in petroleum-related activities has seen it develop an inextricable bond with a sector that has become pivotal to the country's macroeconomic stability, as well as the industrial growth enjoyed by various regions. This profound dependence underlies Norway's reluctance to heed environmentalists' calls to cut back on oil and gas production in order to curb the sector's significant CO_2 emissions. Such hesitancy stands in stark contrast to the country's commitment to ambitious climate goals, illustrating the complex challenges Norway faces in aligning its environmental aspirations with its economic dependencies.

Table 1. Norway's position as a petroleum economy in 2022

	Norway's world ranking as an oil and gas nation	Norway's share of world production	Norway's production as a share of EU consumption
Oil production	12	2%	13%
Oil export	8		
Oil production per capita	3*		
Gas production	8	3%	25%
Gas export	5		
Gas production per capita	1		

**After Kuwait and UAE.*
Source: Kearney et al. (2022).

Figure 1. Macroeconomic indicators for the petroleum sector, 1971–2024



Source: Norwegian Petroleum (2024), based on Statistics Norway (National Accounts), Ministry of Finance (National Budget 2024).

2.1 Macroeconomic benefits

Today, the petroleum sector is by some distance Norway's largest industry in terms of value added, export value, investments and state revenues. Furthermore, the prosocial organisation of the petroleum economy – based in part on ground rent taxation and extensive public ownership – means that large business profits are combined with extensive transfers to society. These transfers reached over 30% of state revenues in the first decade of the 21st century and have since increased to over 40% following the energy price hikes seen in the wake of Russia's invasion of Ukraine. Oil and gas has constituted over 40% of Norwegian exports and 20% of gross domestic product (GDP) for several years, reaching 60% and 30% respectively in 2022 under the Russian embargo (Figure 1).

Since production started on the Norwegian continental shelf in the early 1970s, petroleum activities have – at the time of writing – contributed over NOK 24,000 billion (€2,136 billion)[3] to Norway's GDP[4] (Norwegian Petroleum 2024). Despite this, only about half the estimated recoverable resources on the Norwegian shelf have so far been produced and sold.

In part motivated by fear of the so-called 'Dutch disease' – in which revenues from abundant natural resources heat up the domestic economy but subsequently cause abrupt contraction when reserves are depleted – government revenues from petroleum activities are transferred to the Government

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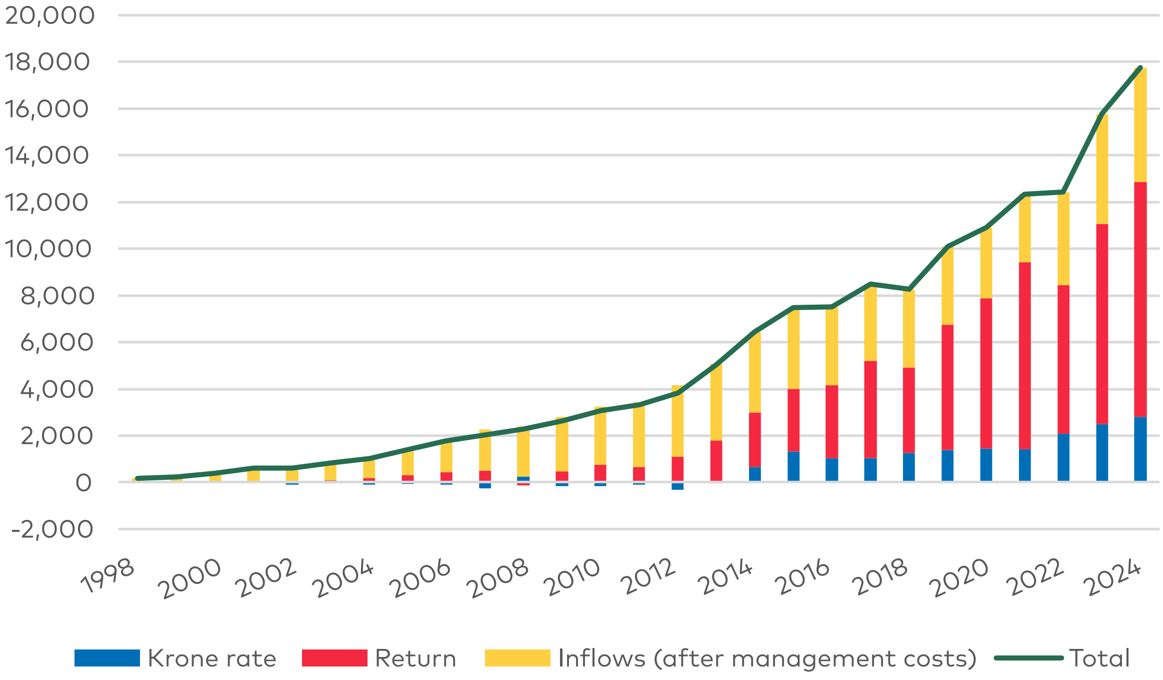
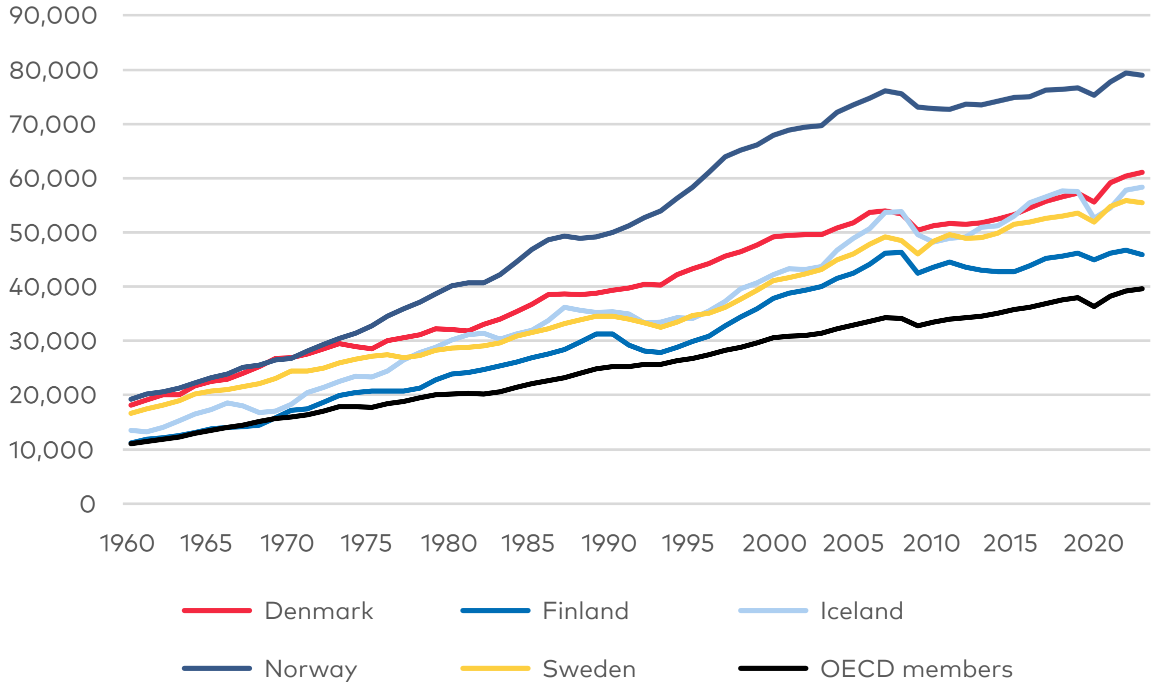
[3] Based on exchange rates in July 2024.
[4] This does not include related service and supply industries.

Figure 2. The Oil Fund: Market value development (in billion NOK)



Source: NBIM (n.d.).

Figure 3. GDP per capita (constant 2015 US$): Denmark, Finland, Iceland, Norway, Sweden and the OECD members



Source: World Bank (n.d.).

Pension Fund Global, nicknamed the 'Oil Fund' (Norwegian Petroleum n.d.a). Government spending from the fund is then restricted to its expected real return: currently estimated at 3% (Norwegian Petroleum 2024).

Concerns about macroeconomic stabilisation are accompanied by a desire to ensure financial sustainability for future generations – hence the 'Pension Fund' labelling. The Oil Fund is currently valued at more than NOK 15,000 billion, making it is now one of the world's largest funds (Figure 2). This is exemplified by the fact that it owns almost 1.5% of all shares in the world's listed companies.

Despite the measures taken to prevent an overheated economy, Norway's GDP per capita has surged ahead of its Nordic counterparts since the onset of the petroleum boom in the 1970s (see Figure 3). As of 2022, Norway's GDP per capita was more than 30% higher than that of Denmark when adjusted for constant 2015 US dollars.

2.2 Industrial impacts

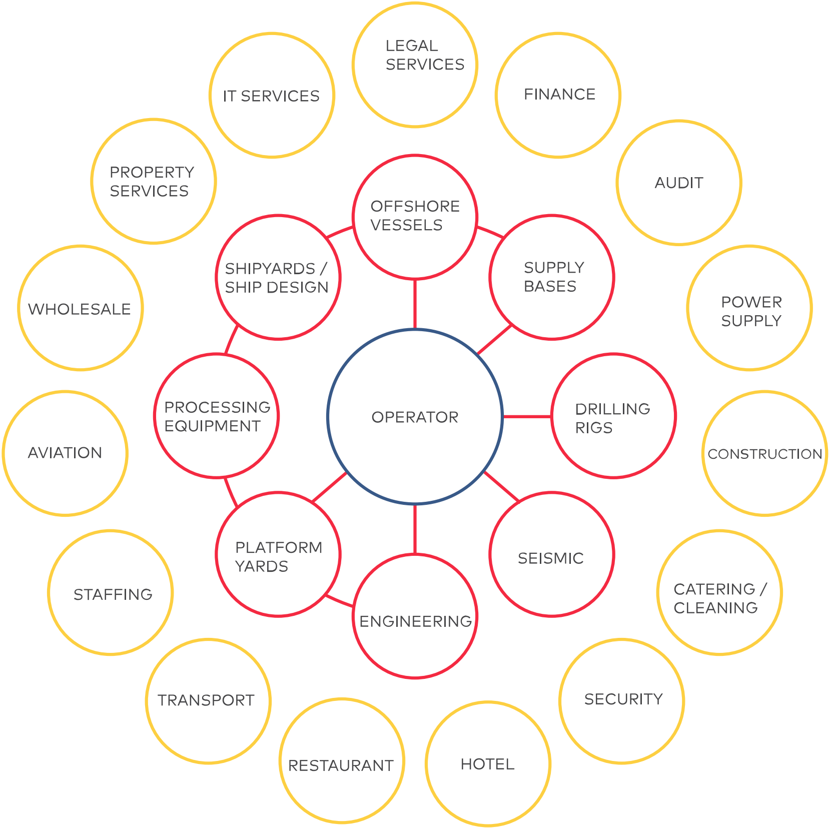
Beyond its significant macroeconomic contributions, the oil and gas sector serves as a cornerstone of Norway's industrial strategy. The nation's abundant petroleum resources have attracted some of the world's most sophisticated petroleum companies, which have proceeded to engage in pioneering deep sea oil and gas extraction activities. The sector's growth has been strategically supported by Norwegian government policies focused on national competency development, with robust participation from the state. Initiatives have led to the establishment of Statoil (now Equinor) and other Norwegian 'industrial champions', which serve as foundational pillars of this strategy.

The oil industry has been instrumental in rejuvenating Norway's maritime sectors, as well as the country's shipbuilding and advanced engineering industries, demonstrating its extensive influence beyond direct operations. The Norwegian-based service and supply industry, encompassing approximately 2,000 companies, generated a total turnover of NOK 374 billion in 2020, about 30% of which came from international markets. This sector's expansive impact highlights Norway's strategic positioning and its outsize contribution to global energy and engineering markets (Menon Economics 2021).

Supply and service companies play a crucial role across all stages of the petroleum value chain. During the exploration phase, specialised firms offer seismic surveys, data processing, and geological and geophysical services, in addition to drilling and well services. Engineering services, platform solutions, and a diverse range of equipment requiring production and installation are provided by various yards. Meanwhile, supply companies focus on developing and installing production equipment for seabed placement.

In the operational phase, the industry offers shipping, maintenance and a suite of other services. Given the production phase's potentially lengthy duration – which may span several decades – there is often demand for substantial upgrades, including integrating new processing equipment and drilling additional wells. Moreover, when maintaining a field eventually becomes economically unfeasible, work is required to decommission its infrastructure.

Figure 4. Direct and indirect petroleum-related activity



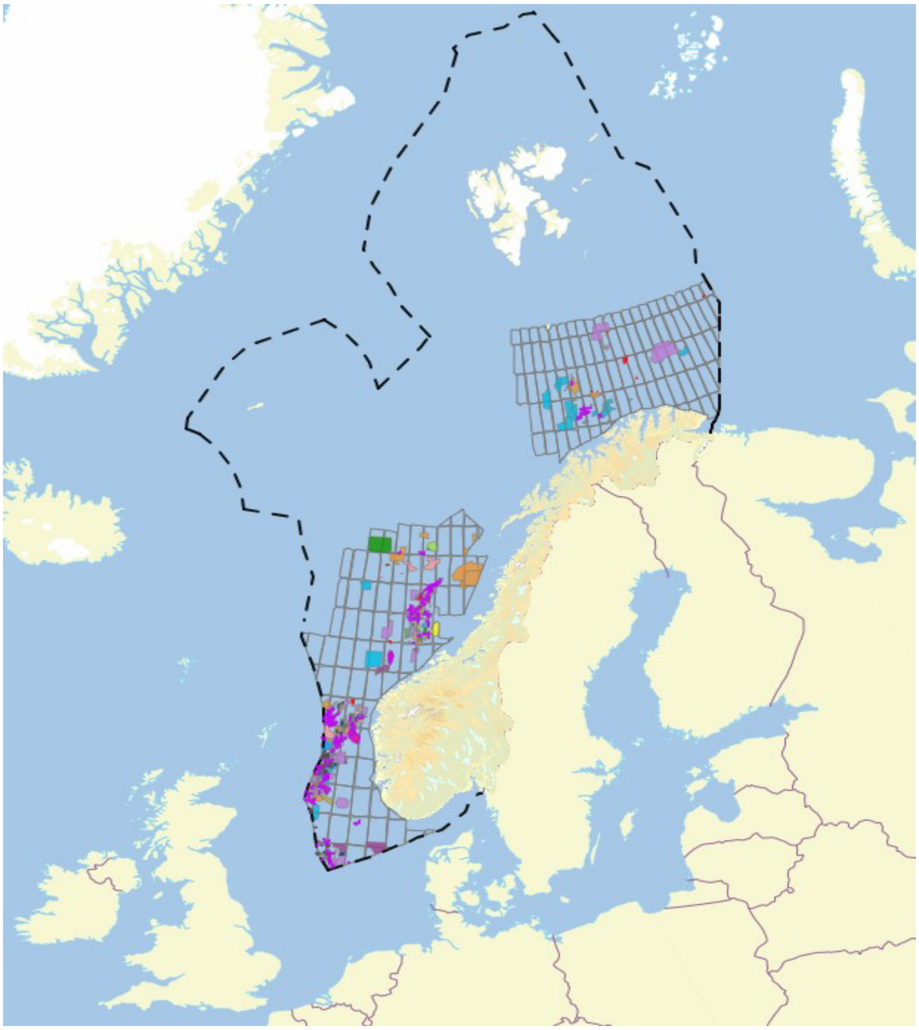
Source: International Research Institute of Stavanger (IRIS), referenced by Norwegian Petroleum (n.d.b).

Figure 4 delineates the interactions between oil companies/operators (represented in dark blue) and the various service and supply segments (shown in light blue). The industry also encompasses a variety of other services (depicted in orange), as identified by Menon Economics (2021), although activities within these segments prompted by the petroleum sector are not classified under the service and supply industry.

2.3 Regional impacts

Petroleum has played a pivotal role in Norway's economy, contributing significantly to wealth generation and job creation across various regions. As depicted in Figure 5, the country has progressively extended its petroleum extraction activities from the North Sea in the south, moving across the Norwegian Sea and into the Barents Sea in the north. This expansion along Norway's rugged coastline has sparked debate due to the escalating ecological and technological challenges associated with advancing petroleum production into the Arctic. Despite these concerns, numerous counties and local communities have sought to secure an equitable portion of the petroleum-derived wealth. Regional employment opportunities, particularly

Figure 5. Petroleum fields in the Norwegian economic zone



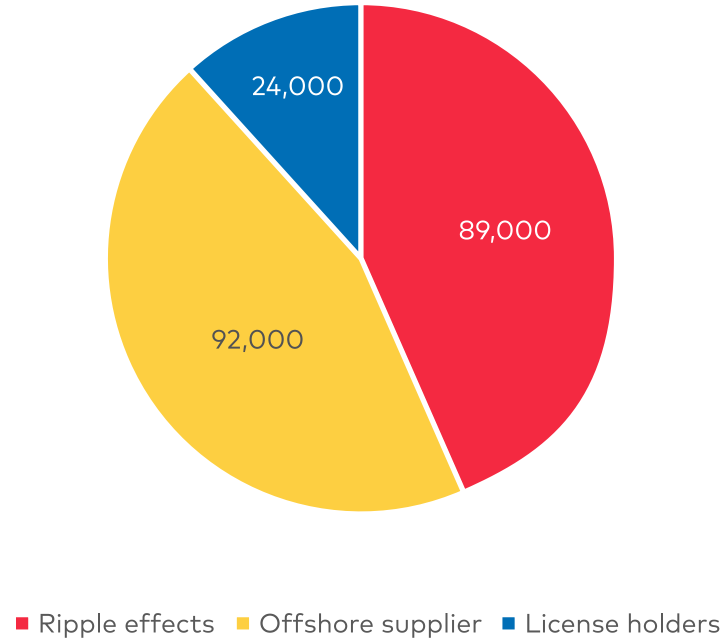
Source: Norwegian Petroleum (n.d.c).

in under-developed costal districts, has been one of the key benefits of the petroleum economy and a basis for securing its social legitimacy. Such opportunities are also expected to be central to the green transition.

The influence of petroleum activities on employment in Norway was meticulously analysed by the Menon Economics group in a 2021 study. The research reveals that the petroleum sector sustained 180,000 full-time positions in 2019, equivalent to 205,000 individuals being employed and accounting for approximately 10% of Norway's private sector employment (Figure 6). The scope of this impact encompasses the full extent of the petroleum industry's value chain.

A significant portion of these employment benefits stem from the offshore supply industry's contributions to both the domestic and international petroleum sectors, supporting around 92,000 jobs. Similarly, some 89,000 positions are attributed to 'ripple effects' –

Figure 6. Employment generated by the petroleum activity (2019)



Source: Menon Economics (2021).

the economic activities generated when concession holders and their suppliers procure goods and services from enterprises outside the petroleum sector. By contrast, direct employment within concession holding companies only amounts to approximately 24,000 individuals.[5]

Given its offshore character, it is no surprise that a large part of the Norwegian petroleum industry is located in Western Norway. As highlighted in Figure 7, Rogaland, in southwestern Norway, has felt the most pronounced impact, with over 30% of the county's total employment stemming from the petroleum sector. Vestland and Møre og Romsdal, in Western Norway, also benefit notably from the industry, with 11% and 8% of their total employment linked to petroleum-related activities. This is fuelled by the presence of suppliers and the headquarters of several leading concession holders. The petroleum sector also accounts for more than 5% of total employment in Agder, Trøndelag, Vestfold, Telemark and Oslo, underscoring its significance across various Norwegian locales.

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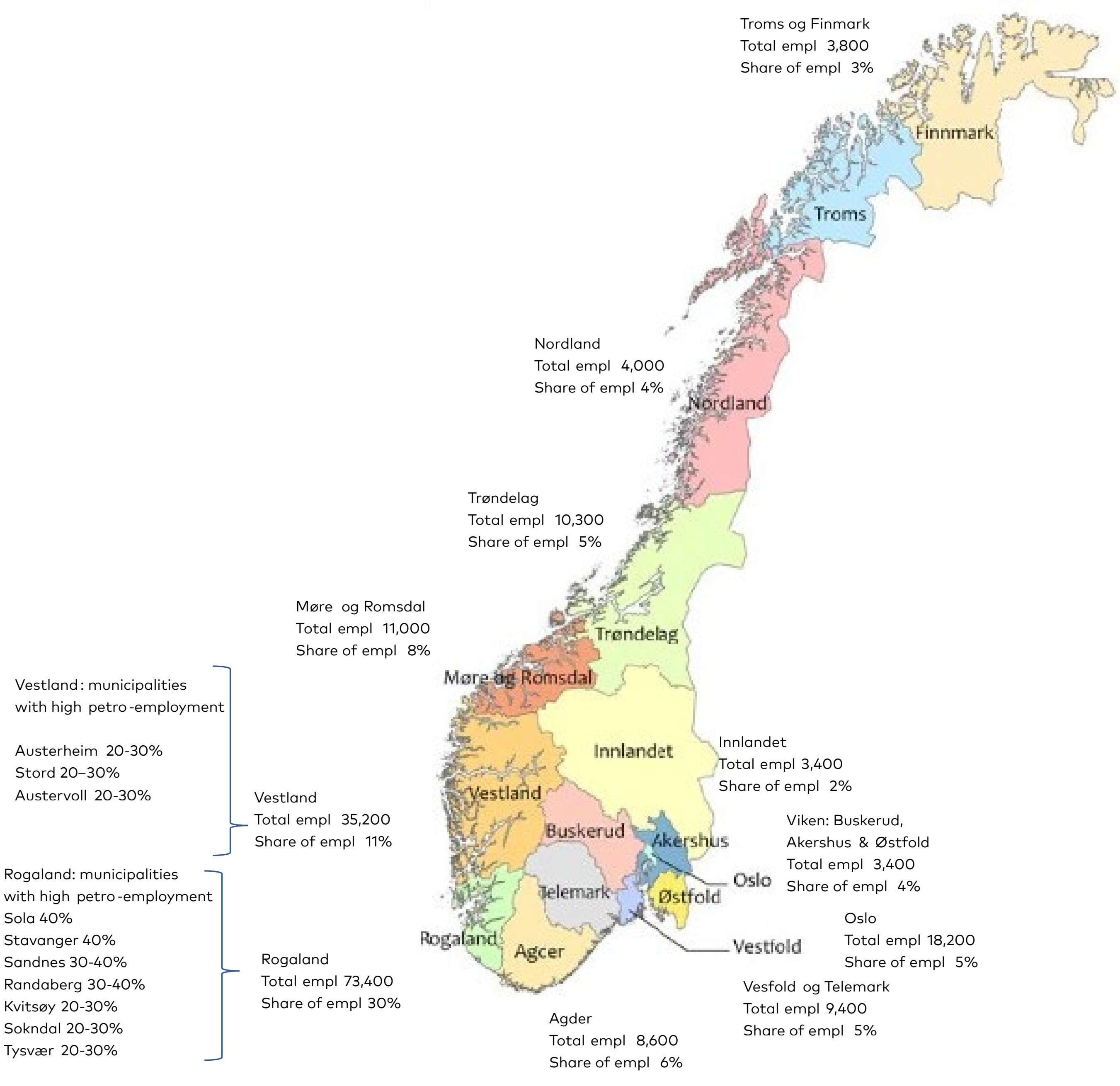
[5] It should be emphasised that the indirect effects are distributed based on a model calculation by Menon (2021) and thus are subject to significant uncertainty. It is also worth noting that Menon has not included consumption effects (i.e. the effects of employment that support consumption), which in turn supports further economic activity. If they had done so, the effects would likely have been about 20% higher. The reason why consumption effects are not included is that a significant proportion of those who today have a job supported by petroleum industry demand would likely, in the event of lower demand from the industry, have found employment regardless.

Figure 7. Regional employment effects of the oil and gas-based economy, with ramifications in 2019



Troms og Finmark
Total empl 3,800
Share of empl 3%

Nordland
Total empl 4,000
Share of empl 4%

Trøndelag
Total empl 10,300
Share of empl 5%

Møre og Romsdal
Total empl 11,000
Share of empl 8%

Vestland: municipalities
with high petro-employment

Austerheim 20-30%
Stord 20–30%
Austervoll 20-30%

Vestland
Total empl 35,200
Share of empl 11%

Innlandet
Total empl 3,400
Share of empl 2%

Viken: Buskerud,
Akershus & Østfold
Total empl 3,400
Share of empl 4%

Rogaland: municipalities
with high petro-employment
Sola 40%
Stavanger 40%
Sandnes 30-40%
Randaberg 30-40%
Kvitsøy 20-30%
Sokndal 20-30%
Tysvær 20-30%

Rogaland
Total empl 73,400
Share of empl 30%

Oslo
Total empl 18,200
Share of empl 5%

Vesfold og Telemark
Total empl 9,400
Share of empl 5%

Agder
Total empl 8,600
Share of empl 6%

Source: Menon Economics (2021), integrated into a regional map of Norway.

The Menon study reveals that in Rogaland county up to 40% of the workforce in Stavanger and Sola municipalities are engaged in petroleum-related roles. When it comes to Sola, this figure can be attributed to the presence of major industry players such as Halliburton, ConocoPhillips and Schlumberger, while Stavanger – known as the country's oil capital – is home to Equinor's headquarters, as well as offices for Aker Solutions and Archer.

In Sandnes, another municipality in Rogaland, employment in the petroleum sector ranges between 30% and 40%, buoyed by major establishments such as Vår Energi's headquarters and numerous oil company offices. Similarly, Randaberg, which as has a 30–40% petroleum job ratio, benefits from the Risavika harbour, a key logistics centre for the oil industry that hosts several prominent national and international oil companies.

In Vestland county, municipalities such as Austrheim, where Veltec is located in the Mongstad industrial park, and Stord, where Kværner operates a significant shipyard, also have a substantial portion of jobs tied to the petroleum sector.

Conversely, smaller communities – such as Kvitsøy and Sokndal in Rogaland – experience minimal direct involvement in the oil and gas industry, with their employment impact largely down to residents commuting to other areas hosting major petroleum businesses. In this respect, Tysvær – which has a Kårstø gas processing and condensate plant owned by Equinor – stands out as an employment destination. As all of the above illustrates, the employment impacts of the petroleum industry vary widely between municipalities.

The influence of the petroleum industry is not limited to the petro-industrial strongholds of Rogaland and Vestland (Menon Economics 2021). In Oslo and Akershus, engineering firms, seismic companies and knowledge-based service providers cater to the petroleum sector. Trondheim has distinguished itself with robust petroleum-oriented research and educational institutions, while the Bergen area has emerged as a centre for maintaining offshore platforms and subsea equipment.

In Buskerud – particularly the municipality of Kongsberg – a specialised environment has evolved in subsea technology, automation and dynamic positioning systems. This has in part been facilitated by defence industry expertise. Southern Norway is home to world leaders in drilling technology, while a comprehensive maritime cluster has sprung up in the northwest of the country. This cluster encompasses the entire shipbuilding and ship equipment spectrum, including advanced offshore vessels.

As exploration and production activities have extended into the Barents Sea, the petroleum industry's reach has expanded into Northern Norway, further illustrating its widespread impact across the country.

2.4 An industry with global reach

The Norwegian petroleum sector extends far beyond national borders, with the country's oil service and supply industry having established a significant presence in offshore markets worldwide. According to the Norwegian Offshore Directorate, exports to international markets generated NOK 374 billion (€38.07 billion) in 2020 (accounting for approximately 30% of the industry's revenue (Norwegian Petroleum n.d.b). The subsea equipment and installation sector led the way in international turnover, closely followed by operations and professional services, alongside topside and processing equipment. The United Kingdom, the United States and Brazil were the top three markets by revenue in 2020. Additionally, shipping hubs such as Singapore and South Korea have served as significant markets for well packages and various platform and drilling equipment.

The petroleum economy's substantial contributions to Norway's macroeconomic stability, state finances and regional industrial development mean the country has become heavily reliant on the sector. This dependency underscores how important it is to strategically balance economic benefits with environmental responsibilities in the nation's transition towards more sustainable energy practices.

3. The climate footprint

In the years since climate change emerged as a major issue in the early 1990s, Norway has fallen from climate front runner to laggard in terms of CO_2 per capita emissions. This period coincides with the country's move beyond its 20th century hydropower-based industrialisation into its late-20th and early 21st century petroleum-based growth.

Having previously engaged in friendly competition with Sweden over who was foremost in the climate leadership arena, Norway had by 2022 fallen far behind its Scandinavian rival. While Sweden had managed to halve its emissions down to less than 3.2 tonnes per capita by this time (Table 2), Norway's emissions remained largely stable around 6.5. This is also larger than Denmark's 4.4 tonnes and the EU's 5.7 tonnes and is also beaten by Finland's 6.15 tonnes (all in 2022 numbers).

Despite its petro-industrial transition, Norway has kept up its sustainability leadership ambitions, leaving the country with a challenging discrepancy between ideals and practice once it aligned its climate strategy with the Paris Agreement. Highlighting the country's dedication to climate action, Norway revised its nationally determined contribution in 2022, setting a target to cut emissions by at least 55% below 1990 levels by 2030 (Government of Norway 2023a). The formation of the EU–Norway Green Alliance in 2023, as part of the European Green Deal, further detailed Norway's commitment to being a climate frontrunner. The alliance underscores a mutual commitment between Norway and the EU to meet their 2030 climate targets and pursue climate neutrality by 2050. It also emphasises Norway's commitment to be a major producer of renewable energy by 2030 (Government of Norway 2023b).

Table 2. Greenhouse gas emissions (CO_2), tonnes per capita, 1990–2022

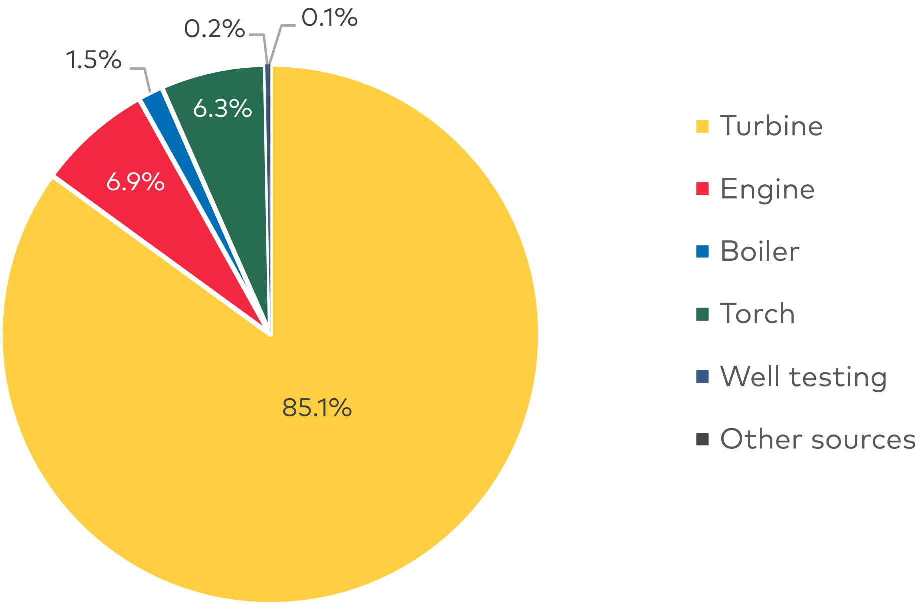
	1990	2022
Norway	6.48	6.52
Denmark	9.92	4.42
Finland	10.8	6.15
Sweden	6.00	3.16
EU28	8.44	5.74

Source: OECD (n.d.).

However, combining such aspirations with European-scale oil and gas production remains a major test, which has only gained increased urgency as Norway faces mounting pressure to put its climate strategy into operational practice towards the 2030 deadline. The main approach is 'clean petroleum', which involves Norway promoting sustainable development through the efficient, low-emission production of oil and gas, while playing a part in developing and deploying new green technology (Government of Norway 2020). Although the idea of clean production and the potential environmental benefits derived from petroleum technology are valid, petroleum extraction's most significant climate impacts occur during its end use: for example, in vehicles and heating. Nonetheless, this downstream use, often referred to as 'Scope 3', is primarily the responsibility of consuming countries.

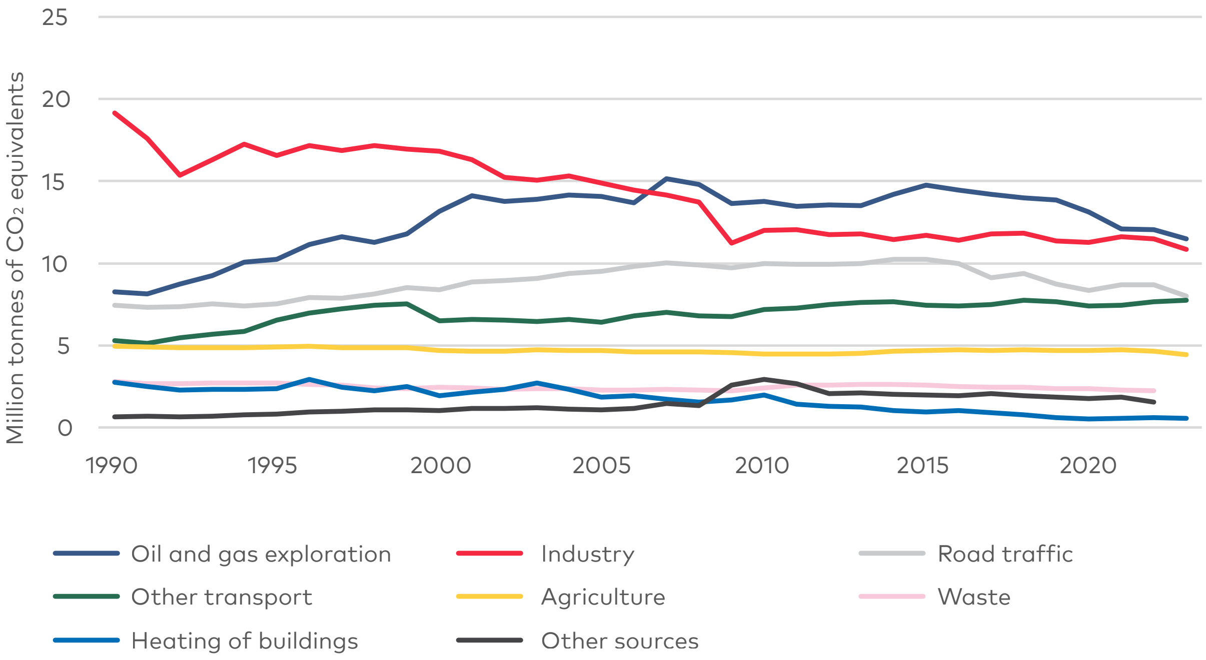
While Norway has gradually fallen behind its Nordic and European counterparts in terms of reducing climate emissions, managing to stabilise emissions amidst a significant expansion of its petroleum economy is no small achievement. Between 1990 and 2020, energy consumption in petroleum production doubled from 34.3 terawatt-hours (TWh) to 68.3 TWh. Since 2005, annual energy use has fluctuated between 63 and 73 TWh, predominantly reliant on fossil fuels (NVE n.d.). As illustrated in Figure 8, the primary sources of CO_2 emissions include natural gas and diesel combustion in turbines, engines and boilers. Further emissions are contributed by the flaring of natural gas, which is permitted only for safety purposes. Other sources include direct releases of hydrocarbon gases into the atmosphere through cold venting and leaks, as well as emissions associated with oil loading and well testing (Norwegian Offshore Directorate n.d.)

Figure 8. Sources of CO_2 emissions in petroleum production



Source: Norwegian Offshore Directorate (n.d.).

Figure 9. Greenhouse gas emissions in Norway by sources



Source: Norwegian Environment Agency (n.d.a), based on Statistics Norway (SSB) and the Norwegian Ministry for Climate and Environment.

3.1 Emissions by sectors of the economy

A systematic overview of CO_2 emissions in various sectors of the Norwegian economy has been provided by the Norwegian Environment Agency (n.d.a). As indicated in Figure 9, the broad picture is that emissions from oil and gas extraction have risen by 40% since 1990, with most of this increase occurring before 2000. Since then, emissions have stabilized around 14 million tons of CO_2 equivalents, with notable reductions in 2020 and 2021 due to a fire and shutdown at Hammerfest LNG. Historically the largest source of emissions in Norway, the industry has reduced emissions by 43% since 1990, mainly through technical and operational improvements, especially before 2010.

In road traffic the Agency points out that emissions have increased by 8% from 1990 to 2023, driven largely by a rise in freight transport. Passenger car emissions remained stable until 2015, thanks to improved fuel efficiency and a higher proportion of diesel vehicles. Since 2015, emissions have declined due to the growing use of electric and hybrid cars and biofuels. From 2022 to 2023, road traffic emissions dropped by 7.8%.

Emissions from other transport sectors—including shipping, aviation, and railways—rose by 46% from 1990 to 2023, with domestic shipping and motorized equipment contributing significantly to this increase. Meanwhile, agricultural emissions, accounting for 9.5% of the total, have remained stable since 1990, predominantly consisting of methane and nitrous oxide from livestock and manure.

Emissions from heating of buildings, representing 1.2% of the total, have, according to the Agency, significantly decreased since 1990, largely due to a ban on fossil heating oil in 2020. Waste-related emissions, constituting 4.6% of the total, are primarily from methane at closed landfills and CO_2 from waste incineration. Other sources contribute 3.1% of emissions, with fluorinated gases from products being the largest single contributor. Emissions from these gases increased until 2013 but have since stabilized due to regulatory controls.

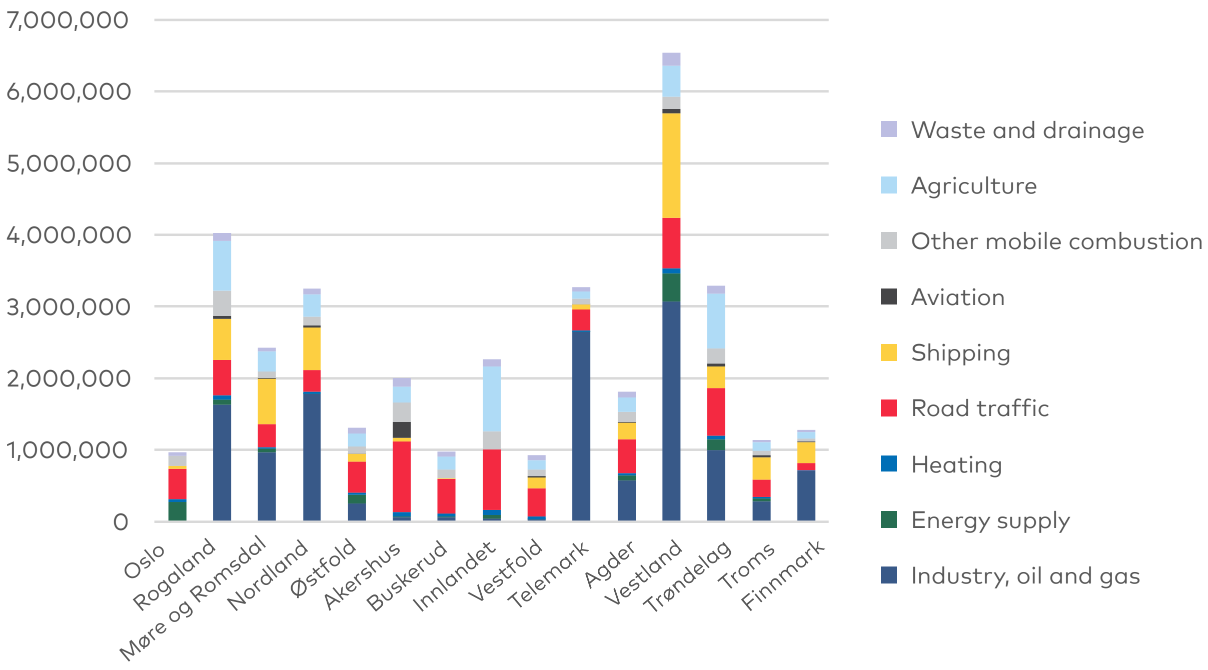
3.2 Regional variation[6]

Norway's petro-industrial challenge is unevenly distributed across the country's regions, with some facing very different CO_2 emission obstacles to others (Figure 10).

The location of industries plays a major role, as demonstrated by the fact that the highest emissions are found in the industrial, oil-rich counties of Vestland, Vestfold, Telemark and Rogaland. In Vestfold and Telemark, nearly 70% of emissions come from the industrial sector. Porsgrunn, with a heavily industrialised economy (housing companies such as Norcem Brevik and Yara), is the municipality with the highest emissions registered in the official climate accounts. In Vestland and Rogaland, industrial emissions accounted for 40–45% of total emissions.

In Viken, Oslo and Innlandet, by contrast, road traffic accounts for the majority of emissions. Furthermore, agriculture contributes a relatively large

Figure 10. Greenhouse gas emissions by county and activity (2022), CO_2 equivalents



Source: Government of Norway (n.d.b).

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[6] This section is largely based on data and descriptions from the Norwegian Environment Agency and Government of Norway (n.d.a).

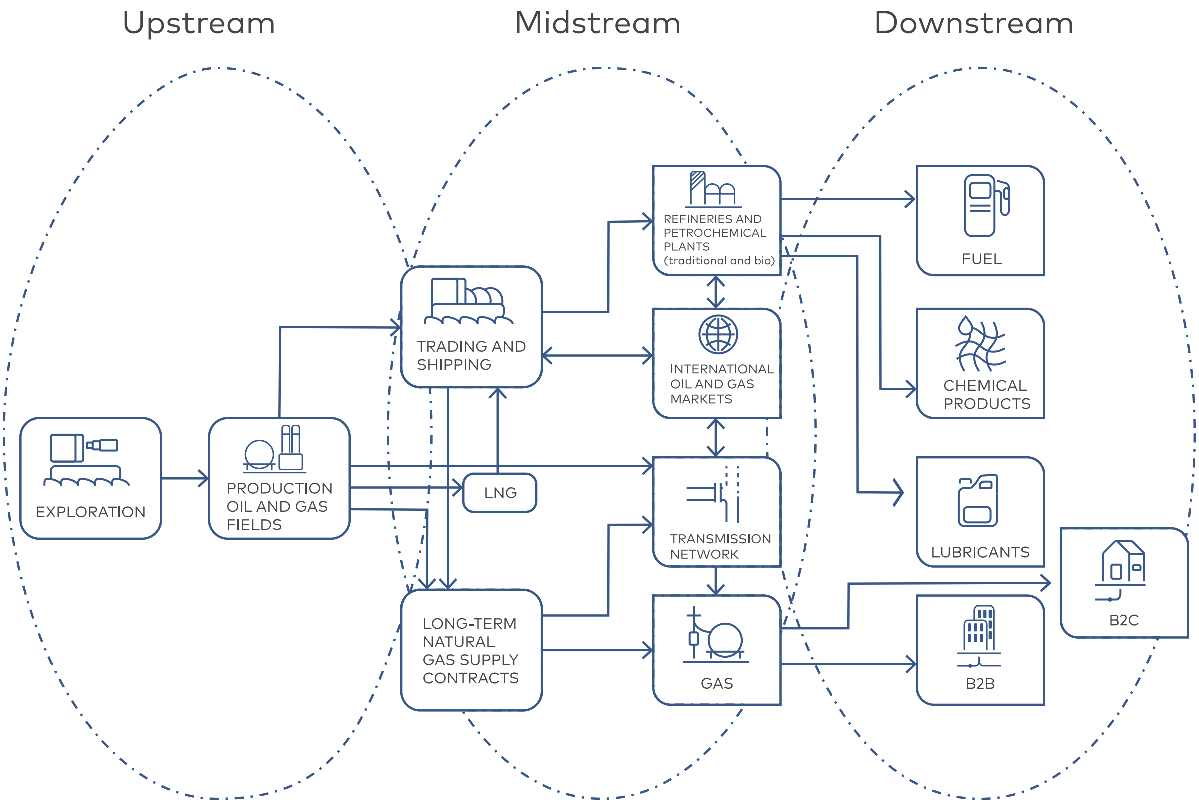
proportion of emissions in key agricultural counties such as Innlandet, Trøndelag and Rogaland. Finally, maritime transport is responsible for relatively significant emissions in coastal counties in Vestlandet and Northern Norway.

4. Strategies for addressing the petro-climate dilemma

With much of the low-hanging industrial CO_2 reduction potential already tapped, Norway faces significant challenges when it comes to meeting the European Economic Agreement targets of halving total CO_2 emissions by 2030 and achieving net-zero emissions by 2050. Maintaining the status quo in the petroleum industry is no longer viable.

Consequently, the petroleum sector is being compelled to undergo a substantial green transformation, which is being pursued through two main strategies: firstly, promoting 'clean petroleum' to adapt the industry to increasingly stringent climate constraints, and, secondly, advocating for a more profound shift towards petroleum alternatives ('beyond petroleum'). Both strategies leverage the extensive resources and expertise available within the petroleum value chain, which extends from upstream production through midstream transportation and refining to downstream retailing (see Figure 11). While the clean petroleum strategy focuses on industry reform, the beyond petroleum strategy emphasises complete transition and substitution.

Figure 11. The petroleum industry value chain



Source: Midttun et al. (2022).

In order to coax the petroleum industry into pursuing greening strategies, Norway is exposing the sector to increasing CO_2 costs. Towards this end, the government has not only joined the European emissions trading system (ETS) but added on a carbon tax that is set to be increased up to NOK 2,000 (€176)[7] per tonne (Government of Norway 2020). This combination of carbon tax and ETS means that companies on the Norwegian shelf in 2023 paid approximately NOK 1,500 (€132)[8] per tonne for their CO_2 emissions – significantly higher than the amount paid by most other businesses in Norway and much higher than in other countries with petroleum activities (Norwegian Petroleum n.d.d). As pointed out by environmental NGO Bellona, the Norwegian government's ambition to increase the sum of the ETS and petroleum carbon tax to €200 (NOK 2,272)[9] per tonne in 2030 is probably the most ambitious carbon tax in the world (Bellona 2021).

After incorporating the petroleum industry into the ETS, Norway could theoretically rely solely on this carbon market mechanism to address the sector's emission challenges. However, the high profitability of petroleum production suggests that the carbon price set by the ETS only exerts limited influence, even with the special Norwegian carbon tax added on. Consequently, emission reductions are only likely to occur in countries where industrial production is less profitable, rather than in countries such as Norway. As such, relying on the ETS would not be sufficient for Norway to meet its commitments under the Paris Agreement.

The Norwegian government is therefore attempting – on top of financial incentives – to stimulate the green transition through Enova, a state-owned enterprise owned by the Ministry of Climate and Environment. Enova's activities are focused around late-phase technology development and early market introduction. The aim has been to increase the pace and scale of pilot and demonstration projects, as well as full-scale testing, allowing new technologies and solutions to reach the market more rapidly (Government of Norway 2020).

4.1 Clean petroleum: Integrating climate strategies in the petroleum value chain

In line with global industry trends, Norway's petroleum sector has embraced a 'clean petroleum' strategy to mitigate its environmental impact. This approach includes reducing flaring and methane emissions, and transitioning energy portfolios towards natural gas in order. Moreover, the sector has initiated pilot projects for biofuels and invested in carbon capture and storage (CCS) technologies. There has also been targeted investment in renewable energy sources, such as wind and solar, as delineated in the green boxes and circles in Figure 12.

By integrating these green initiatives into its existing framework, the petroleum industry has started reducing CO_2 emissions while preserving the sector's core functions. This approach has enabled Norway to navigate its petro-climate dilemma, maintaining a presence in both the traditional fossil fuel market and the emerging renewable energy landscape. It delicately balances preservation of the fossil fuel value

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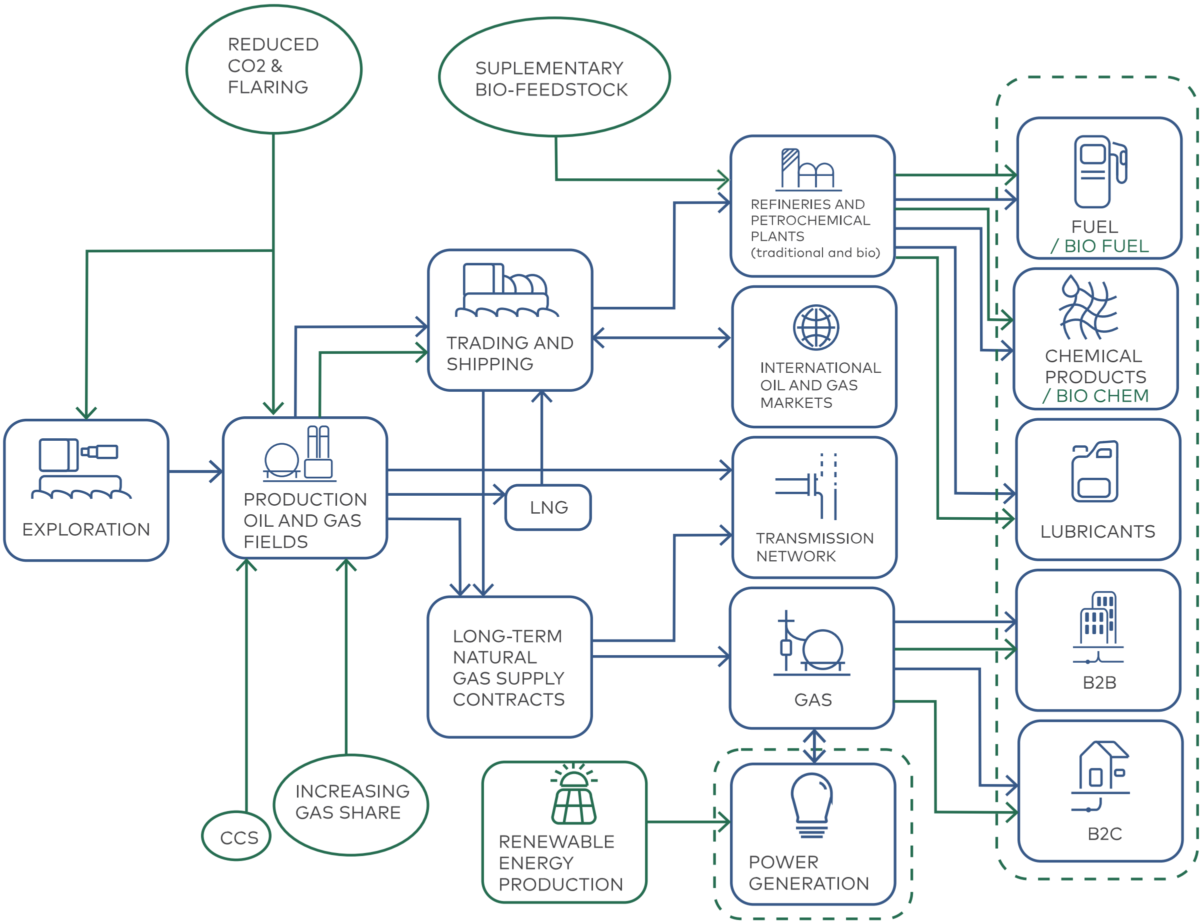
[7] Exchange rate 25 july 2024.
[8] Exchange rate 25 july 2024.
[9] Exchange rate 25 july 2024.

Figure 12. The clean petroleum perspective



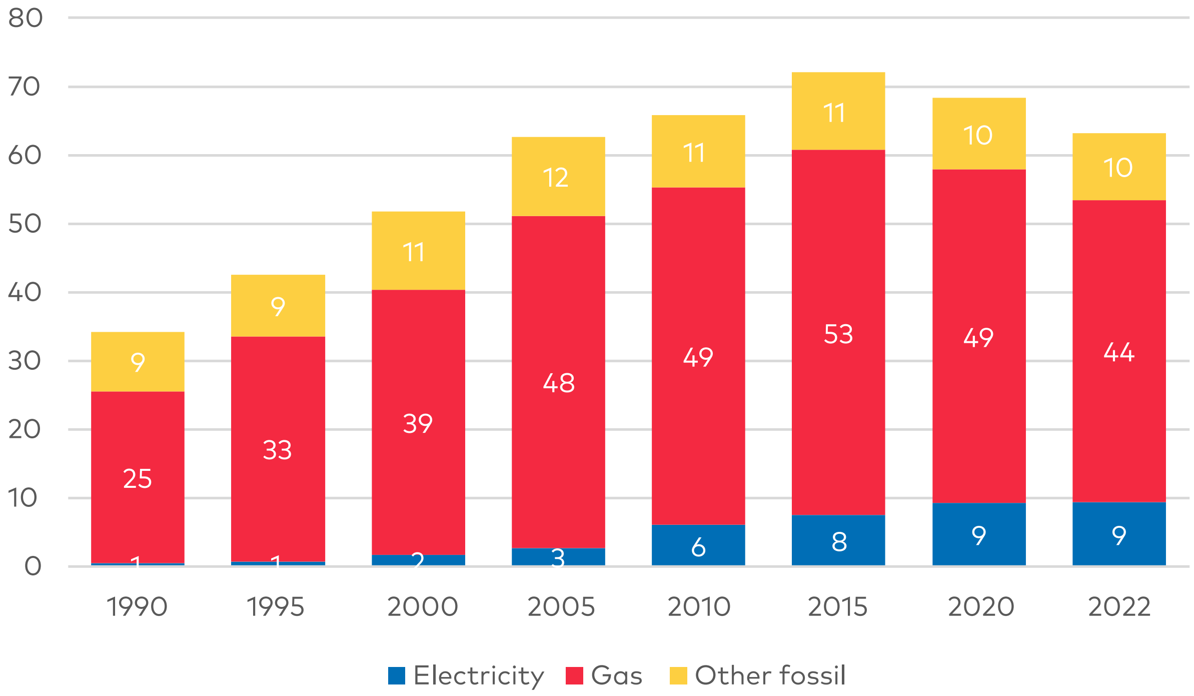
Source: Midttun et al. (2022).

chain's essential elements with incorporation of a modest array of renewable resources. The strategy thus not only mitigates environmental impact but aligns with evolving global energy demands.

Green electrification of offshore petroleum

Green electrification of offshore petroleum has been a primary climate-target for Norway. As previously mentioned, the main sources of CO_2 emissions from petroleum production are natural gas and diesel combustion in turbines, engines and boilers. By shifting to hydro and wind-powered electrification, the industry may significantly reduce its carbon footprint, aligning with broader environmental objectives and sustainability goals. The aim has been to convert as many of the more than 160 turbines on offshore oil and gas platforms as possible from gas to green electricity. However, for several reasons this strategy has been lagging behind, and only 9 out of the 63 TWh of energy used offshore in 2022 came from renewable sources (Figure 13).

Figure 13. Energy use in Norwegian offshore petroleum production



Source: NVE (n.d.).

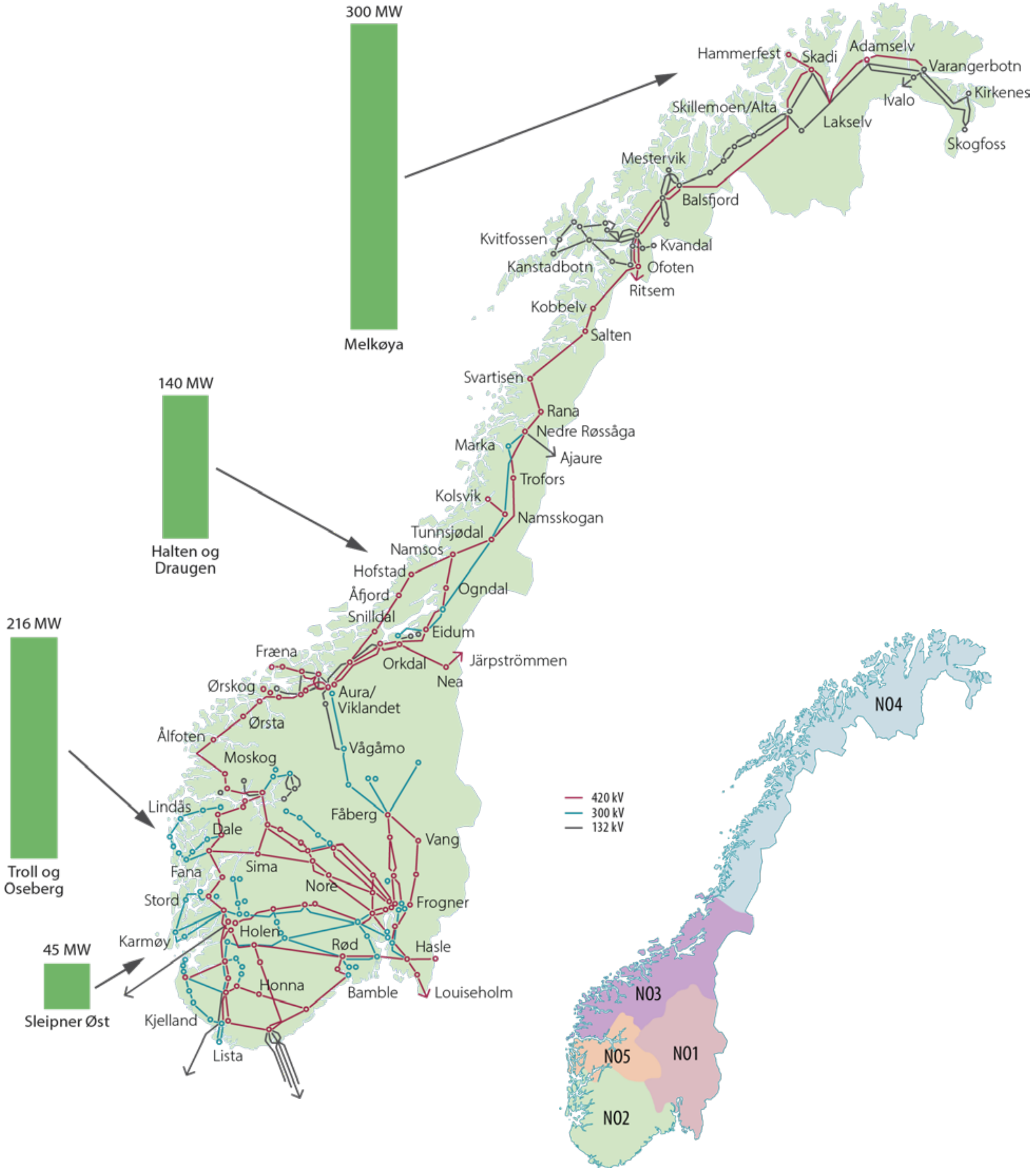
The electrification of offshore petroleum production initially came from onshore hydropower and wind, driven largely by market prices and carbon taxes. Though, as competition for electricity increased and public opposition to wind and large hydro escalated, the onshore supply of green electricity dried out. Further onshore wind power construction has been seen as too invasive to the natural and/or social environment, prompting local protests, as described in later sections. Offshore wind, which could be an alternative, has becomes far more expensive and has made it more difficult to expand the electrification of petroleum production programme.

The regional dimension

One of the challenges of offshore electrification has been its regional implications. Firstly, large offshore electricity consumption increases onshore electricity prices, which is not well received by the public at large. Secondly, offshore electrification has had diverse effects on different onshore regions. Norway is divided into five price areas for electricity. These are the result of power grid bottlenecks that limit the physical flow of electricity between different regions.

As indicated in Figure 14, the oil fields are spread out from north to south of Norway and are well adapted to the existing production and grid structure. Increased power consumption arising from the electrification of offshore installations using power from the mainland will largely occur in areas that currently have a power surplus. This applies to Southwest Norway (NO2), Northern Norway (NO4), and Western

Figure 14. Electricity price areas and future transmission grid, with assumed connection points for land-power projects and assumed maximum power demand



Note: The green bars in the figure indicate assumed maximum power demand. The left-hand figure shows the future transmission grid in Norway, including assumed connection points for land-power projects. The right-hand figure shows electricity price areas.
Source: Norwegian Offshore Directorate (2020).

Norway (NO5) (see overview in Figure 14), with the exception being Central Norway (NO3), which has experienced a negative power balance in recent years. Historically, Central Norway has faced challenges with supply security, but these have been addressed by the network investments carried out since 2008. Even when prices are equalised across regions, however, such efforts are not necessarily greeted with enthusiasm. Offshore electrification will reduce the price differences between the north and south of the country, with greater demand in Northern Norway arising from increases in offshore electricity use leading to increased prices. This will reduce the region's attractiveness when it comes to other types of industrial investment, while also increasing electricity costs for households in the northern regions.

4.2 Beyond petroleum

With pressure mounting to accelerate the green transition, Norway and its petroleum industry have committed to stepping up from the reformist 'clean petroleum' strategy outlined above to a more radical 'beyond petroleum' strategy. A core element of this strategy is speeding up the green repowering of petroleum production through offshore wind development. Offshore Norway (the petroleum industry trade association) and the government are in collaboration aiming for a 50% reduction of oil and gas emissions by 2030 (Offshore Norway 2023). In the longer run, offshore wind and other initiatives will be used to foster a transition towards a sustainable offshore hub for floating wind, hydrogen and carbon sequestration (Equinor 2022).

Such objectives require a shift in business practices and policy directives from incremental reform to transformative approaches. Businesses will have to leverage their resources and capabilities not merely for the purposes of adjusting their existing product sphere, but to pioneer new market sectors. Similarly, in a transformative stance, government will engage not solely through financial incentives but also via innovation-driven measures.

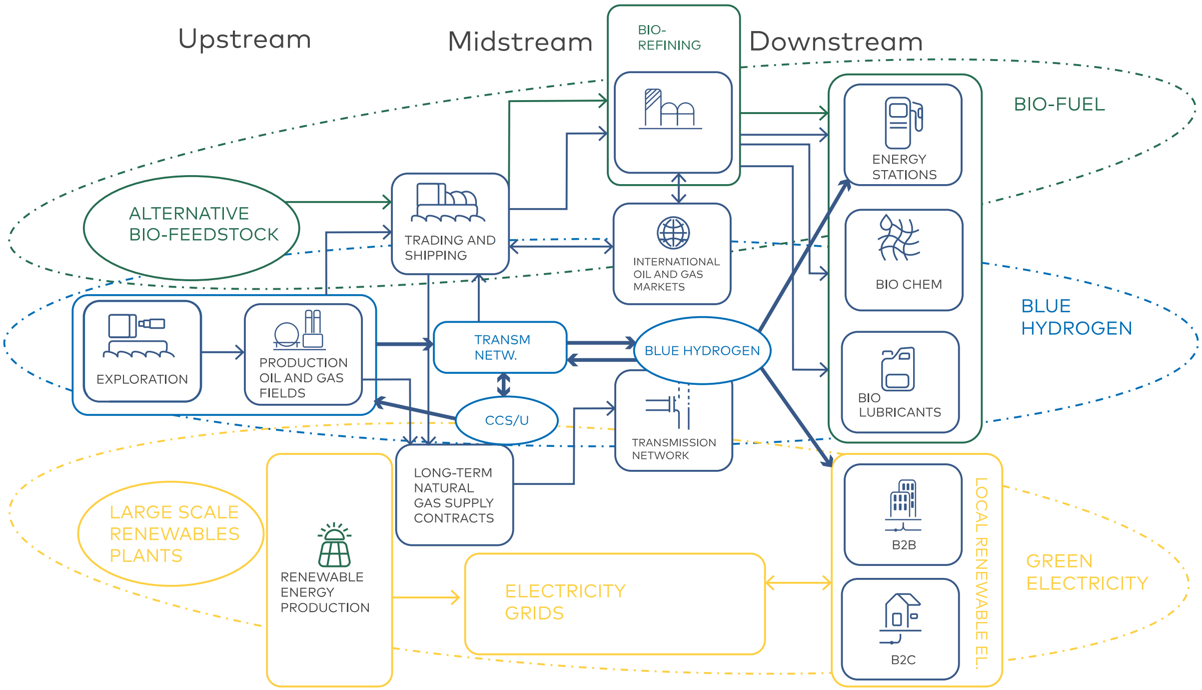
Key business models for the petroleum industry's green transition include: 1) transitioning to biofuels; 2) adopting blue hydrogen with CCS; and 3) generating green electricity as a substitute to petroleum. Figure 15 demonstrates how these models can be integrated into the petroleum value chain.

In the Nordic context, the move beyond petroleum is already taking place: Finnish company Neste is pursuing a biofuel strategy, while the Danish Oil and Gas Consortium (now Ørsted) is transitioning to green electricity generation. Equinor in Norway, with abundant upstream reserves, has moved more slowly towards a mixed strategy of blue hydrogen with CCS, as well as offshore wind. Meanwhile, the company's downstream petroleum outlets – which were sold to the Canadian Circle K company in 2012 – have adopted a multifuel approach, adding biofuel and electrical charging to their fossil fuel repertoire.

Although these initiatives may not be inherently transformative when implemented within limited portfolios, their potential to become predominant practices and replace petroleum-based products on a large scale signifies a transformative shift.

On the governmental side, advocating for a transition beyond petroleum requires an innovation-driven agenda that encompasses, among other things, the creation of strategic partnerships;

Figure 15. Business models for radical transition



Source: Midttun et al. (2022).

provision of early-stage investments; encouragement of technology-oriented public procurement; and development of supportive infrastructure.

Three major initiatives indicate a repositioning beyond petroleum in the Norwegian case: 1) the move towards offshore and floating wind, 2) the establishment of a CO_2 capture and sequestration value chain, and 3) the development of natural gas-based hydrogen production. The two first initiatives will likely matter in the fulfilment of the 2030 climate goals, moreover hold potential for the necessary evolution into a post-carbon future. The third initiative, meanwhile, carries the promise of a close-to-CO_2-free fossil future: in other words, it is not strictly 'beyond petroleum' but rather beyond petroleum's negative side effects.

Offshore wind

The scale and scope of offshore wind goes far beyond simply being a means of removing CO_2 emissions from offshore oil and gas production. In the first round, the government's vision is to have 30 GW of new offshore wind capacity before 2040, most of which will come from floating installations. Even though this level of capacity is close to Norway's total electricity production in 2023, it is only seen as the start: as has been the case with petroleum, the long-term intention is to facilitate industrial engagement of North European dimensions.

In contrast to onshore wind, offshore wind – particularly floating wind – needs extended support beyond emission quotas and carbon taxation. Offshore wind projects have therefore only been initiated once the government has put in place deeper financial support mechanisms. With this in mind, wind projects have received heavy investment from Enova, Innovation Norway and specialised vehicles for financial development support, such as contracts for difference (CFDs) that involve heavy state engagement. All this on top of emissions trading and CO_2 tax regimes.

Against this backdrop, Hywind and Southern Northsea II (Sørlige Nordsjø II) are two pioneering offshore wind projects that have already been initiated, while several new initiatives are planned for the near future.

The *Hywind project*, which Equinor inherited from Norsk Hydro, was initially a demo-project outside Karmøy, Haugesund, in southwestern Norway.[10] However, the design was first put into operative use by Equinor in Scottish waters. Later, the Hywind concept was applied to a larger wind farm 86 miles off the Norwegian coast outside Sogn, with production – again under Equinor – starting in November 2022. The company has 11 floating wind turbines with a capacity of 88 MW (Shea n.d.), serving the Snorre and Gullfaks platforms with what amounts to 35% of their energy use – equating to a 200,000 tonne reduction in CO_2 per year (Inpex Idemitsu Norge n.d.).

Equinor claims that, between the Hywind Demo and Hywind Scotland, extensive savings have been achieved: Capital expenditure per Megawatt (CAPEX/MW) has been reduced by 70%, with a further 40% drop expected between Hywind Scotland and Hywind Tampen (Equinor n.d.).

In attempting to re-invent itself as an offshore floating wind industry, the petroleum industry is drawing on its offshore petroleum experiences. Equinor claims that most offshore wind floater designs are similar to those used by oil and gas platforms: floating turbines are moored to the seabed with multiple mooring lines and anchors in much the same way as a floating oil platform. Equinor has thus opened a gateway to massive wind potentials with its Hywind engagement, both regionally in the North Sea/Norwegian Sea and globally.

Meanwhile, the *Southern North Sea II* project – which uses bottom-fixed turbines – is expected to be developed in two phases, each with a capacity of approximately 1,500 MW. The first phase focuses on supplying power to the Norwegian mainland in order to allow further electrification of offshore petroleum, while the second phase includes a potential hybrid project capable of delivering power both to Norway and other European countries.

As with Hywind, the project only became attractive after the government secured a NOK 23 billion transfer as part of a CFD. Unlike Hywind, however, the project is being undertaken by foreign investors and will be jointly built by IKEA's parent company Ingka along with Parkwind, the Belgian subsidiary to Japan's largest power company Jera (Government of Norway 2024). The project is anticipated to generate a total capacity of 3 GW.

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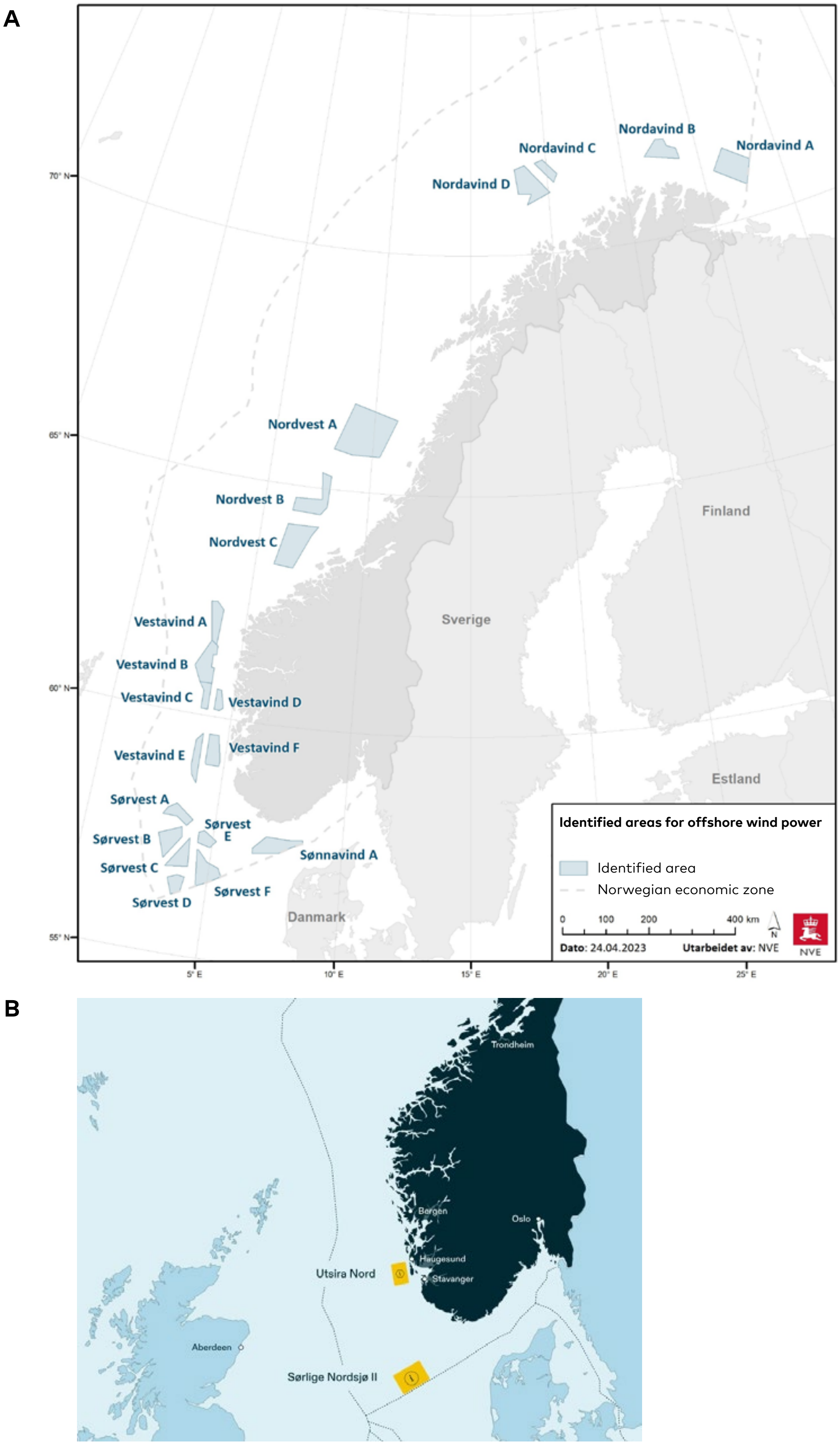
[10] The Hywind concept was originally developed by Dagfinn Sveen in 2001 at Norsk Hydro's new energy division. The concept was patented and industrial relations were established with, among others, Siemens. When Statoil took over Hydro's oil division in 2008, Hywind was also transferred to Statoil.

Figure 16. Areas for ocean wind in Norway



Sources: NVE (2023) and Havvind (n.d.).

The regional dimension

Regulatory frameworks and infrastructure are a core element of the beyond petroleum innovation strategies that government and the petroleum industry are developing together. Based on the areal conflicts experienced in onshore wind farms, the Norwegian government has mapped competing seawater use and stakeholder interests in various locations (see Figure 16, Panel a).

As shown in Figure 16 (Panel a), the Norwegian Water Resources and Energy Directorate (NVE) has mapped out 20 offshore areas for offshore wind in dialogue with agencies representing potentially affected interests, such as fisheries, defence, aviation, communication and meteorology.

These 20 areas are those that the directorate group considers the most viable for offshore wind, both in terms of technical suitability and attempting to avoid conflicts of interest. Further development of offshore wind is likely to come in the southern North Sea and Utsira in the west. Based on studies already conducted, the directorate group believes it will be possible to carry out an allocation in 2025. Should this be the case, it will involve expansions of Southern North Sea II and Utsira Nord, where potential for both capacity expansion and new areas have been identified (See Figure 16, Panel b).

The Longship and Northern Lights project

Carbon sequestration and storage is another key strategy beyond petroleum for Norway. Several of the large CO_2 reservoirs emerging out of depleted offshore oil fields hold the potential to be turned into excellent storing facilities for CO_2. In line with circular thinking, CO_2 – which is unleashed when burning petroleum products – may in many cases be captured and returned to the ground. Norway is currently initiating the Longship and Northern Lights project, a full-scale CCS project that involves capturing CO_2 from industrial sources, transporting it, then permanently storing it beneath the North Sea seabed (Northern Lights n.d.).

The Northern Lights part of the project – the transport and storage of CO_2 – is a joint venture between Equinor, Shell and TotalEnergies, representing a significant collaboration in efforts to mitigate climate change by addressing CO_2 emissions from industrial activities around the North Sea. The project aims to transport CO_2 from capture sites to a receiving terminal in Western Norway, where the CO_2 will be pipelined for safe, permanent storage at depths of around 2,500–2,600 metres under the seabed. The first phase of the project will produce the capacity to handle up to 1.5 million tonnes of CO_2 per year, with facilities scheduled to become operational in 2024.

The project's total costs have been estimated at NOK 25.1 billion, with the Norwegian government covering NOK 16.8 billion – around two-thirds of the project costs. Given the activities involved are first-of-a-kind, the uncertainties are higher than usual for the industrial partners, requiring maximal cost-sharing from the state. The Longship and Northern Lights project is therefore heavily reliant on government playing a supportive role. This function is co-ordinated by Gasnova, the Norwegian state enterprise for carbon capture and sequestration. Beyond generous cost-sharing that extends far beyond emissions trading and CO_2 taxation, this state partnership is necessary for orchestrating licences and helping co-ordinate a complete CO_2 value chain.

One of Longship and Northern Lights's key customers, Heidelberg's Brevik cement plant in Norway, is currently in the process of installing the world's first cement plant CCS facility, which is expected to become operational in 2025. The facility aims to immediately reduce carbon emissions from the cement production by 50% (Heidelberg Materials n.d.).

The other industrial customer, Hafslund Celsio, which operates one of Oslo's largest waste-incineration plants, has halted its carbon sequestration project due cost increases. The plan was for the plant to go carbon negative through burning organic waste, thereby reducing Oslo's carbon footprint by up to 400,000 tonnes (Norwegian Environmental Agency 2023). In April 2023, however, Hafslund Oslo Celsio announced project implementation had been put on hold to reduce costs and that the company is considering various cost-reducing alternatives.

In the meantime, Northern Lights has started contracting CO_2 deposits with actors outside Norway. For example, it has entered into a transport and storage agreement with Ørsted to store 430,000 tonnes of biogenic CO_2 per year from 2026 produced by two power plants in Denmark. Northern Lights sees this as an essential step towards a commercial market for CCS in Europe. In August 2022, Northern Lights agreed main commercial terms with the large fertiliser company Yara on cross-border CO_2 transport and storage. From early 2025, up to 800,000 tonnes of CO_2 will – if things proceed according to plan – be captured from Yara's ammonia and fertiliser plant in Sluiskil in the Netherlands, before being transported and stored by Northern Lights (CCS Norway 2024).

A pathway to blue hydrogen

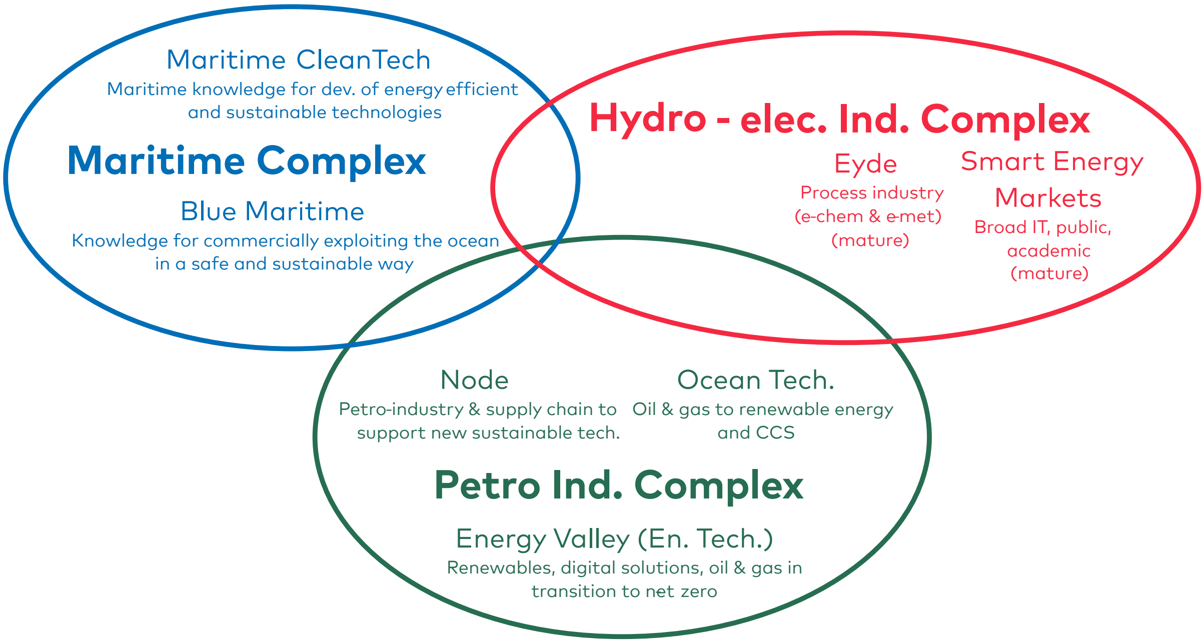
The Longship and Northern Light project also provides a pathway towards the export of so-called 'blue hydrogen', which involves the petroleum industry using its gas reserves to produce hydrogen while catching and sequestering CO_2. The EU Commission envisages hydrogen as playing a substantial role in the repowering of Europe, but has signalled a preference for renewables-based hydrogen production. Nevertheless, it acknowledges that blue hydrogen may have a role to play as a transition fuel, especially given its much lower costs and the EU's envisaged step-up towards 40 GW of hydrogen capacity in 2030 (European Commission n.d.).

Blue hydrogen projects are already appearing on the horizon. Encouraged by their respective Norwegian and German political leaders, Equinor and RWE are working to develop large-scale value chains for low-carbon hydrogen. Initially, this will involve blue hydrogen: hydrogen produced from natural gas using CCS, with more than 95% of the CO_2 generated from hydrogen production to be captured and permanently stored under the Norwegian continental shelf. The long-term goal, however, is to transition to a solely green hydrogen supply (hydrogen produced from renewable energy via electrolysis) (Equinor 2024).

Green transition beyond petroleum

Norway's move away from a fossil-based economy has impacts that extend well beyond the petroleum industry. This broader focus is exemplified by Innovation Norway's cluster programme, which

Figure 17. Sustainability-oriented clusters in core Norwegian industrial complexes 2023



Source: Based on Innovation Norway's 'Norwegian Centres of Expertise' (NCE) and 'Global Centres of Expertise' (GCE) cluster registration.

has seen a diverse array of companies come together to collaborate on advancing green transitions across various key sectors of the Norwegian economy (Innovation Norway 2023).

The programme, backed by government funding, is designed to initiate and enhance collaborative sustainability-focused development efforts within major industrial complexes. An illustrative example of this dynamic can be seen in Figure 17, which provides an overview of the programme's major sustainability-oriented innovation clusters.

Starting with the *petro-industrial complex*, core stakeholders have synergised their endeavours within three innovation clusters: 1) Node; 2) Energy Valley; and 3) Ocean Tech. All three, from various regional competency bases, seek to transcend their petroleum heritage by engaging in the green transition.

Node is an industry-driven cluster for ocean technologies, located in Southern Norway. It represents a world-leading value chain that predominantly serves as supplier to the oil and gas, offshore, energy and maritime industries. The cluster is exploring new industrial opportunities, coupled with the seamless transfer of technology from the oil and gas sector to offshore renewables and emerging green markets.

Energy Valley, strategically situated in the capital region, envisions itself as a catalyst for innovation and sustainable growth in the energy sector with a broader mission to position Norway as a global hub for energy technology.

Ocean Technology, centred in Bergen in Western Norway, is dedicated to championing the green transition and fostering sustainable growth within the ocean industries. This cluster spans the entire offshore value chain – from traditional subsea oil and gas extraction to renewable energy, carbon capture and storage, and deployment in marine transport. Again, we can observe the alignment of various parts of the fossil fuel value chain with novel green agendas.

The *hydroelectric industrial complex* is an old centre of gravity in the Norwegian economy. Given its green energy basis, this sector has experienced renewed appraisal under intensified climate policy. Together with public authorities like NVE and Statnet it plays a central role in facilitating the transition to an 'electric society'. However, its associated electro-metallurgical and electro-chemical industry (often referred to as 'process industry') has a major set of climate emissions that needs innovative technological solutions.

Within this complex, two clusters - the *Eyde cluster and Smart Energy Market* - both aim at being catalysts for innovative business opportunities under Norway's green transition - the *Eyde cluster* based in Agder in Southern Norway and *Smart Energy Markets* based in Halden in Southeastern Norway. While the Eyde cluster aims at developing profitable value chains in the circular economy, the Smart Energy Markets cluster aims to be in the internationally top class in applying digital technologies and developing digital services and solutions (NCE Smart Energy Markets n.d.).

The green transition is leading to significant changes in the structure of maritime value chains, with fossil fuels increasingly giving way to low- and zero-emission solutions. In addition, the downscaling of service needs in the petroleum industry leads to new options – such as servicing fish farming and offshore renewables – being sought. Two clusters are operative within this agenda: the *Maritime Cleantech* cluster anchored in Hordaland and Rogaland on the west coast, and the *Blue Maritime Cluster* anchored in Ålesund on the northwestern coast.

A plethora of green initiatives are imminent both within and outside petroleum industry. Some of these are, however, arriving undesirably late in light of the current Paris and EU/European Economic Area (EEA) green transition agenda. While the petroleum industry has given Norway enormous financial and technological assets, the question remains as to whether these resources have to some degree been mobilised the wrong way. The massive tax stimulus package given to the petroleum sector in order to drive the post-Covid expansion of conventional petroleum activities (Norwegian Petroleum n.d.e) has, for instance, locked in a reliance on the fossil economy at a time when resources should have gone to greening.

5. Conflicting policy perspectives

Attempting to balance an ambitious climate policy with extensive petroleum production has not only presented significant techno-economic challenges, it has provoked contestation in several political arenas. When it comes to *parliamentary democracy*, the tension between Norway's climate goals and its petro-economy have led to new cleavages across the country's traditional divides. Given Norway's vibrant civil society and well-organised lobby groups, such tensions have also spilled over into *monitory democracy*,[11] where arenas for political dispute have been created by social mobilisation, via both demonstrations and new and old media.

More recently, energy-climate debates have escalated into legal battles fought out in court, where national economic interests must be weighed against global climate concerns. Additionally, local Sami reindeer-herding practices have come into conflict with wind power developments.

5.1 Petroleum and climate in parliamentary democracy

In Norwegian parliamentary politics, as in many other European countries, the left–right cleavage stands out as a significant foundational element. The climate issue has disrupted this traditional divide giving rise to challenges in its political expression, as reflected in the current (2021–2025) party programmes.

There is potentially a broad consensus on a 'two-track' policy across the two largest parties (Conservatives and Labour). The parties converge in their support for the ongoing expansion of oil and gas exploration, while simultaneously emphasising the necessity of aligning with climate commitments that are consistent with EU standards. In attempting to reconcile these seemingly disparate objectives, they propose a strategy involving the green electrification of petroleum extraction and distribution, complemented by the acquisition of climate quotas from international sources. To quote the Conservative Party, it:

"*believes that we should not set an end date for the Norwegian petroleum industry, but rather support the industry in its ongoing efforts to explore new resources and transition to a green shift … At the same time, greenhouse gas emissions from the Norwegian continental shelf must be reduced for us to achieve the climate goals.*" (author translation) (Conservative Party 2021, p. 13)

While a similar 'two-track policy' can be found in the Labour Party's (2021) programme, the need to mobilise voters along the traditional left–right divide prevents the two parties from forming a government together. As neither party has a majority, their policies must be negotiated in dialogue with other coalition partners, including minor fringe parties on the right (for the Conservatives) and left (for Labour). This fringe mobilisation tends to polarise both climate and energy policy, frequently leading to seemingly unresolvable dilemmas.

On the right, the Progress Party has taken a strong pro-petroleum position and only reluctantly engages in climate mitigation, leading to a policy that could set Norway on a collision course with its EU partners:

"*[The Progress Party] emphasises strengthening the foundation for further mapping and exploration in the oil and gas sector … [and] aims to facilitate increased investment in research and development in the sector, so that the oil adventure on the Norwegian continental shelf can continue into the foreseeable future.*" (author translation) (Progress Party 2021, p. 68)

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[11] Monitory democracy includes both idealistic and industrial associations, each lobbying for their respective causes and interests. It complements the more formal parliamentary democracy, often stimulating it as issues heat up and generate societal debate.

While the party programme does not explicitly dismiss 'climate mitigation', this perspective is evident in the measures proposed, such as no electrification of the continental shelf; a dynamic definition of the ice edge zone; and impact assessments for the Lofoten, Vesterålen and Senja (LoVeSe) area that would allow new oil exploration.

On the left, the Socialist Left Party has added a strong pro-climate policy to its traditional socialist-welfare outlook, leading to a high risk of confrontation with industry and strong industrial trade unions:

"*The entire economy should be geared towards the future, with climate and nature integrated into all calculations. The state should take the lead and make significant investments. The transition cannot be left to the market.*" (author translation) (Socialist Left Party 2021, p. 5)

The Marxist-oriented Red Party has followed suit with a pro-climate orientation, although it also has a restrictive attitude to green energy, blocking electrification as a means of reducing the massive emissions caused by petroleum production and distribution:

"*The climate changes are caused by emissions from the use of fossil energy sources, but at the same time, the solution cannot be to switch to renewable energy produced with significant disruption of the natural environment. Primarily, we must reduce energy consumption because the most environmentally friendly energy is the one that is not used … Electrification of the continental shelf from land or based on offshore wind only entails an increase in energy demand and will result in the gas being sold and burned elsewhere.*" (author translation) (Red Party 2021, p. 55–57)

Finally, on the radical pro-climate side, the Green Party (MDG) has adopted the most radical position, demanding a systematic, controlled transition away from petroleum activities by 2035. It has opposed issuing new permits to the petroleum industry for search and production or extending existing ones. Additionally, it has proposed a transition tax per extracted barrel of oil and gas to speed up the dismantling of the petroleum sector:

"*As a wealthy country with favourable conditions for transition, Norway must take extra responsibility to reduce our production. The Green Party therefore proposes to phase out the oil and gas industry within 14 years from the beginning of the parliamentary term – by 2035.*" (author translation) (Green Party 2021, p. 20)

In the middle are parties such as the Centre Party, which has a district/agrarian profile, and the Christian People's Party, which holds an ecological ethics perspective:

"*The petroleum policy must be designed in such a way that it, to the greatest extent possible, stimulates local value creation and provides positive spillover effects in the area where the activity takes place.*" (author translation) (Centre Party 2021, p. 42)

"*Take initiative towards international cooperation to encourage the world's oil-producing countries to collaborate on reducing oil production.*" (author translation) (Christian People's Party 2021, p. 69)

Rather than solving the petro-climate dilemma along lines acceptable to the two largest parties, the fringe parties may instead block any such pragmatic compromise. The idea of powering the offshore oil sector with green hydropower has, for instance, provoked fierce political debate. The Progress Party in particular has come out against it, as it argues this approach will lead to energy scarcity and higher electricity prices in Norway, in turn hampering onshore industrial development.

Additional power from wind turbine expansion, that was seen as a solution to the scarcity problem, has also triggered controversy, with the Progress Party and Red Party finding common ground against onshore wind. Meanwhile, offshore wind has proven even more problematic. The Centre Party, which is currently in a coalition government with the Labour Party and Progress Party, has taken a strong nationalist position, marked by a critical attitude to sharing electricity with Europe. Pursuing such an avenue would seriously limit the chances of a return on investment from the most expensive windmills around.

To sum up, parliamentary politics has left Norway with unresolved dilemmas between climate mitigation and petro-expansion on the one side, and wind turbines and nature conservation on the other. One could argue that Norway can get away with 'cleaning petroleum production' and leaving the climate effects of consumption to its customers abroad, but green policy-makers would see this as hypocritical. In addition, there is contention between offshore wind proponents who want to build scale and scope for European markets, and proponents of national restrictions aimed at prioritising national low-priced electricity supplies. Finally, there is the potential for conflict with fisheries, which will remain latent for as long as the oil industry does not expand into Lofoten and its surroundings – a key spawning ground for Arctic cod.

5.2 Petroleum and climate under monitory democracy

Norway, like its Nordic neighbours, hosts a diverse civil society that is routinely consulted in political decisions. This not only takes place via hearings, but through self-organised protests, demonstrations and other civic initiatives, in part voiced through the press, radio, TV and social media. This monitory democracy complements the more formal parliamentary democracy, often spilling over into the latter and generating societal debate. Monitory democracy includes both idealistic and industrial associations, which lobby for their respective causes and interests. Against this context, the chapter below reviews the groups and organisations that have responded to the Government's call for comments and voiced concerns about the Norwegian government's 2023 Government bill: Changes in the Climate Law (Government of Norway n.d.b), the latest comprehensive climate document.

Civil society and advocacy groups

During the hearings on the latest amendment to the Climate Law, a consensus emerged among the idealistic civil society organisations advocating for a more robust domestic climate action framework and heightened compliance obligations (Government of Norway n.d.b). A multitude of noteworthy participants – including Amnesty, Change Maker, ForUM, Future in Our Hands, the Norwegian Human Rights Institute, Spire and WWF – jointly called for the Climate Law's efficacy to be anchored in actual emission reductions within Norway, aligning with the objectives outlined in the Hurdal Platform (the programmatic agreement between the coalition parties in government).

Furthermore, a shared perspective championed by organisations including the Norwegian Red Cross emphasised the necessity of establishing an independent climate commission. Moreover, Amnesty, Future in Our Hands, the Human Rights Institute and Save the Children pressed for the incorporation of specific annual emission reduction targets in the Climate Law, harmonised with the 1.5-degree budget. While the Climate Change Committee, which delivered its report in 2023, worked in this direction, it was a one-off exercise that did not fulfil the need for ongoing debate concerning the revision of climate policy.

In terms of transparency, several entities – including Change Maker, ForUM and Spire – underscored the importance of greater openness regarding Norway's annual domestic emission reductions. Adding to this, Amnesty and the Norwegian Institute for Human Rights called for the emissions resulting from the export of fossil fuels to be included within the Climate Law's ambit. Additionally, ForUM and Spire recommended explicit provisions specifying Norway's responsibilities when it comes to climate finances directed at developing countries.

Industry-based interest groups

The reactions from various industrial associations to the Government's upgrading of Norwegian climate commitments (Government of Norway n.d.b), such as increased emission reduction targets, strengthening the hydrogen value chain and participation in EU climate initiatives, have basically been positive, but are conditional on the state facilitating industrial adaptation and covering the extra costs incurred.

While Offshore Norway supports the proposal, it has pointed out that the restructuring of Norway's oil and gas industry requires competitive framework conditions that enable a long-term perspective on investments, as well as a strengthened set of tools that can stimulate new activity and expedite the development and implementation of effective climate measures. The association argues that, among other things, a CO_2 fund should be established to realise emission reductions on the Norwegian continental shelf and contribute to new value chains, such as offshore wind, CCS and hydrogen.

The municipal service industries association is also positive to the Government's upgrading of the climate law although it has stressed that all businesses contributing to the green transition should – regardless of ownership – have the same opportunity to apply for funding towards innovation and infrastructure.

Municipal reactions

The few municipalities that have answered the call for comments to the climate law upgrading are positive but call for national-level support measures to back up climate policy and biodiversity at the municipal level.

To sum up, idealistic advocacy and interest groups are generally positive towards strong climate policy initiatives, although they are continuing to push for more concerted efforts and better monitoring and accountability. Industrial interests and municipalities are also positive, but regard such policies as being conditional on adequate, long-term transfers of resources.

5.3 Petroleum and climate under judiciary democracy

Over recent decades, courts have become important arenas for climate and energy policy contestation, with environmental organisations engaging in legal proceedings against the Norwegian state for climate negligence. These proceedings have been pursued under the state's constitutional obligation to secure public health and the long-term sustainable use of natural resources, as well as in the European Court of Human Rights.

Two particular cases stand out in the Norwegian context. The first concerns the Norwegian state's right to open oil and gas exploration in the southeast part of the Barents Sea, as this may conflict with the environmental regulation embodied in the country's constitution. The second concerns the ecological and cultural impacts of wind turbines in Norway.

The climate lawsuit

In 2016, environmental organisations Greenpeace and Nature and Youth (Natur og Ungdom) filed a lawsuit against the Norwegian state, represented by the Ministry of Petroleum and Energy. The organisations alleged that the decision to grant extraction permits for petroleum activities in the Barents Sea (23rd licensing round) was in violation of Article 112 of Norway's constitution, which serves as an environmental provision designed to protect nature for future generations.

In January 2018, Oslo District Court ruled in favour of the state, determining that although Article 112 grants substantive rights subject to judicial review, the article's provisions had not been violated by the contested extraction permits. In January 2020, the case moved to the Borgarting Court of Appeal, which, like the district court, found no breach of Article 112 and identified no procedural errors. The case then proceeded to the Supreme Court, where the state was acquitted on all counts on 22 December 2020. A minority (4 against 11) did, however, argue there had been procedural errors in granting the concessions – specifically, that the climate consequences were inadequately assessed. Furthermore, the Supreme Court affirmed that while Article 112 functions as a safety valve for when parliament grossly neglects its duty to protect the environment, there is a very high threshold when it comes to overturning parliamentary decisions. According to the Supreme Court ruling, the stringent conditions required for declaring the decision invalid had not been met.

Although Greenpeace and Nature and Youth lost in all three instances, they – along with six other climate activist organizations – appealed the lawsuit to the European Court of Human Rights in Strasbourg in June 2021, where the complaint is awaiting consideration.

The lawsuit has garnered significant media coverage and been referred to as 'historic'. Various actors have become involved, sparking debate in legal circles. For instance, law professors Beate Sjåfjell (University of Oslo) and Jøre Øyrehagen Sunde (University of Bergen) argue that the Supreme Court has undermined the constitution's environmental provisions. Meanwhile, fellow law professor Stig Harald Solheim (University of Trondheim) contends that the climate lawsuit could have implications for democracy and the principle of separation of powers, questioning whether it is desirable for judges, rather than politicians, to take the lead in difficult value prioritisations concerning environmental and business interests. Additionally, Greenpeace and Nature and Youth receive support from many quarters, including the Norwegian Society for the Conservation of Nature (Naturvernforbundet) and the Norwegian Grandparents' Climate Campaign. The Norwegian parliamentary ombudsman, NIM (Norway's National Institution for Human Rights), also believes that the state has failed in its environmental duties on several fronts and that the climate lawsuit appeal to the Supreme Court should be followed up.

In the meantime, however, the green proponents initiated a new lawsuit against the state (a continuation of the initial climate lawsuit) challenging the validity of the approval granted to three new oil projects (Yggdrasil, Breidablikk and Tyrving). Greenpeace and Nature and Youth contend that assessments of the global climate impacts of these three fields are severely deficient to non-existent. In January 2024, to the surprise of many, the Oslo District court supported the complainants in declaring that the state's acceptance of development plans for the three projects was deficient. It remains unclear, however, whether the state will appeal the verdict or make appropriate adjustments in order to ensure the licenses are accepted.

Feuds over regional rights: Wind turbines against reindeer herding in Fosen

The second prominent court case concerns the building of wind farms in Fosen – an area in Trøndelag county in mid-Norway – against the wishes of indigenous Sami reindeer herders. Not only did this provoke a spectacular demonstration-siege of the Ministry of Oil and Energy, it threatens to block future wind turbine construction across large parts of Norway.

The court case arose due to NVE granting concession and expropriation permits in 2010 for two extensive wind power developments in Fosen. The Storheia and Roan wind farms are located in the winter grazing area of Fosen's reindeer grazing district, where two Sami siidas practice reindeer husbandry in their respective parts of the district (Sør-Fosen sitje and Nord-Fosen siida).[12] Numerous organisations immediately opposed the decision, including local reindeer herders, the Sami Parliament and the Norwegian Society for the Conservation of Nature (Naturvernforbundet). Despite this opposition, the Ministry of Petroleum and Energy gave the green light for wind power development in 2013, arguing that the power plants would not significantly harm reindeer husbandry. Following the decision on pre-accession,

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[12] The Sami terms "sitje" and "siida" both refer to traditional social structures of the Sami people. "Sitje" can be translated as "Sami village" or "community." "Siida" is often translated as "Sami reindeer herding group" or "herding district." Both terms describe organizational units of Sami society, often associated with reindeer herding and communal living.

the Roan and Storheia wind farms were completed in 2019 and 2020 respectively.

The case has undergone multiple rounds in the legal system, centred around whether the two wind farms violate the Sami's right to cultural practice under Article 27 of the UN International Covenant on Civil and Political Rights (ICCPR), referring to the Human Rights Act § 2 no. 3. In June 2018, Inntrøndelag District Court awarded compensation of NOK 8.9 million to Nord-Fosen siida and NOK 10.7 million to Sør-Fosen sitje for issues such as loss of pasture, crisis-year feeding and additional work. Nevertheless, the court concluded that the concession and expropriation decision was valid. The wind power developers, Statnett and Fosen Vind, sought new arbitration, claiming the compensation awarded was too high. Meanwhile, Nord-Fosen siida and Sør-Fosen sitje also sought new arbitration, demanding the original arbitration decision be denied with reference to Article 27 of the ICCPR. On top of this, they submitted objections to the actual determination of compensation. The case moved to the Frostating Court of Appeal which decided on 8 June 2020 to increase the level of compensation to approximately NOK 89 million, as the development threatened the very existence of reindeer husbandry in Fosen. Even so, the Court of Appeal remained 'somewhat doubtful' as to whether the development constituted a violation of Article 27 of the ICCPR. Both Statnett and Fosen Vind on the one hand and Sør-Fosen sitje on the other appealed the case to the Supreme Court. Nord-Fosen siida did not initially appeal, but asserted before the Supreme Court that the arbitration should be denied. The Supreme Court relied on the Court of Appeal's conclusion that the winter grazing areas near Roan and Storheia are practically lost to reindeer husbandry, unanimously coming to a judgement on 11 October 2021 that the development constitutes a violation of Article 27 of the ICCPR. As such, the concession and expropriation decision was rendered invalid.

Since then, there has been disagreement regarding the significance and consequences of the judgement. Several actors, including reindeer herders and the Sami Parliament, argue that the wind farms are illegal and must be dismantled. However, the Ministry of Petroleum and Energy's assessment is that there is no legal basis for such an interpretation, and that it intends to follow up the judgement by implementing mitigating measures. Until then, it believes the wind farms can operate in accordance with the original concessions. The Norwegian National Institution for Human Rights (NIM), by contrast, asserts that the two years since the Supreme Court ruling constitute a new violation of human rights (Article 2(3) of the ICCPR concerning human reparation obligations) – a claim rejected by Prime Minister Jonas Gahr Støre.

This has led to several major actions by civil society – including environmentalists in the Sami organization NSR-Nuorat and Nature and Youth, accompanied by climate advocate Greta Thunberg, blocking the entrances to several ministries (including the Ministry of Petroleum and Energy) and Statkraft – aimed at highlighting the time that has elapsed since the Supreme Court ruling. Upon the request of the Ministry of Petroleum and Energy, it was clarified on 15 May 2023 that the parties in the Fosen case were to engage in mediation in order to find a means of settling the case.

The mediation resulted in a December 2023 agreement between Sør-Fosen sijte and Fosen Vind, which includes several key elements, including additional grazing area for winter and veto rights over the wind power plant's further operation after 25 years. It also specifies financial compensation, with Fosen Vind committing to pay NOK 7 million annually to the southern group in the Fosen reindeer grazing district for the duration of the concession period – amounting to NOK 175 million over 25 years (NRK 2023, Dagens Perspektiv 2023, Government of Norway 2023c).

In March 2024, an agreement was also reached in the mediation between Nord-Fosen siida and Roan Vind[13] that secures the rights of the reindeer-herding community and – similar to the agreement with Sør-Fosen sijte –– includes an additional winter grazing area outside the Fosen reindeer grazing district. The agreement also involves financial compensation and specific measures aimed at strengthening South Sami culture and ensuring reindeer-herding siidas receive a portion of the income from wind power production. The Sami Parliament president, in emphasising the importance of securing necessary additional grazing areas for the future of reindeer herding, has expressed that the agreement contributes to ending a human rights violation. For his part, Prime Minister Jonas Gahr Støre expressed gratitude that an agreement had been reached (Finansavisen 2024, NTB Kommunikasjon 2024).

6. Can Norway achieve its climate goals? An epilogue

Can Norway achieve climate leadership and meet its climate goals despite its substantial petroleum economy? In accordance with the government's proposal, we argue that these objectives are technically feasible through the electrification of offshore petroleum production, utilising Norway's existing and potential renewable electricity resources. However, success depends on Norway's ability to synchronise its efforts sufficiently swiftly to deliver the energy volumes required amidst regional and political discord. As of early 2024, the country is trailing behind, having so far acted inadequately and without the necessary urgency.

6.1 Experts are pessimistic

Various expert groups have noted that Norway appears to be falling behind its Paris climate commitments. A 2023 study commissioned by Norwegian Industry and executed by the respected certification and analysis group DNV states that:

"The 2023 edition of the Energy Transition Norway 2050 reconfirms that Norway is not on track to meet Paris Agreement targets for reducing greenhouse gas emissions. Despite cross-political support for 55% and 100% GHG reductions by 2030 and 2050, respectively, Norway is heading for 27% less in 2030 and 80% in 2050." (DNV 2023)

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[13] Roan Vind was originally part of the Fosen Vind project, which is a large wind power development in Norway comprising multiple wind farms. However, in 2021, the Roan wind farm was sold and became a separate entity owned by Aneo and Stadtwerke München. Fosen Vind continues to operate other wind farms within the larger Fosen project area.

These conclusions are echoed by a European Surveillance Authority (ESA) report that points out Norway is expected to face a significant gap when it comes to achieving its current climate targets – even those targets set before the Fit for 55 extension (ESA 2023). On this basis, the ESA has strongly encouraged the Norwegian government to consider additional measures to reduce emissions (ESA 2023).

The ESA and DNV reports align with a previous OECD report that predicted Norway would not reach its goal of a 55% cut in climate emissions by 2030 (OECD 2022). Elsewhere, Climate Action Tracker evaluates Norway's overall climate efforts as 'almost sufficient', indicating that while some elements are world-leading, there are areas where substantial improvements are needed to fully align with the 1.5°C goal set by the Paris Agreement (Climate Action Tracker n.d.).

6.2 From onshore bickering to offshore volumes

The sceptical tone struck by outside experts arises less from technical difficulties and more from slow implementation. On this point, it is easy to agree: as has been shown, regional and political disagreements over wind power have flourished with respect to both size and localisation. Nature conservation interests have come out strongly against wind projects in many cases, while extensive indigenous rights have blocked wind power in favour of reindeer herding in large parts of central and northern Norway. On top of this come concerns about regional electricity price effects and competing industrial user interests that oppose prioritising power for use in the oil and gas industry.

6.3 From adjustment to innovation

Competing political and regional interests in wind have led to available onshore wind sources reaching saturation point, limiting the green electricity supply available to power turbines for offshore petroleum production. As such, the next step in renewable energy procurement appears to lie in less commercially mature, more costly offshore wind. This will require more powerful innovation policy tools – such as feed-in tariffs and specialised auctions – to supplement existing emissions trading and carbon taxes. While the costs of onshore wind could be borne by general market prices reflecting the built-in effects of emission trading and extra carbon taxes, bottom-fixed deep sea offshore or floating wind turbines would need considerable additional financing.

In this context, Norway's shift to stronger innovation policy tools has come fairly late: the country's first offshore project was only given the green light in February 2024. Nevertheless, the offshore location opens up wind energy development at a scale that goes far beyond the needs of petroleum production greening. As previously noted, the government has signalled plans for 30 GW of offshore wind – which would almost double Norway's electricity generation – by 2040, with this representing merely a start.

Contracting and development is time-consuming, however, and the contracting terms must be cleared by the EEA. Norway therefore risks having done too little too late to unproblematically reach its 2030 climate goals. Furthermore, even if offshore wind farms can avoid regional and political bickering, they will still require onshore connectivity in many cases, which will affect regional power balances and electricity prices. This raises the political and regional debate over electro-nationalism versus a broader North European perspective, which will also affect offshore wind. On top of this, fishery interests are of concern. Having learnt from onshore wind challenges, several government agencies are currently investigating low-conflict offshore zones for the siting of wind turbines. Despite these various obstacles, the ambitions flagged are impressive: the envisaged scale and scope of the new offshore wind era clearly goes beyond the greening of offshore petroleum.

More radical voices have asserted that further steps are needed to solve the petroleum–climate dilemma. The Green Party has proposed halting oil and gas production altogether by 2035, preceded by an 80% reduction by 2030, although this position remains an outlier in the Norwegian debate. Together with the Marxist Red Party and the Socialist Left Party, however, it has proposed a moratorium on petroleum exploration, which would leave approximately 50% of reserves in the ground.

6.4 Petroleum and Europe's security

In the longer run, Norway will have to find a way out of its petroleum dependency, with some voices – such as the Green Party – placing prime responsibility for this on the oil and gas producers. It is very hard, however, to conceive of such a development being producer driven, as few if any workers or investors would voluntarily pull out of an industry with well-paid jobs and lucrative profits in order to leave the market to competitors.

The key to Norway successfully pursuing a radical transition out of petroleum therefore arguably lies in Europe, which consumes most of the country's petroleum. Only when European no longer consumes fossil fuel will it make sense to finally end Norwegian petroleum production. As pointed out in previous sections, Norway provides Europe with around 25–30% of the region's gas and around 13% of its oil.

Furthermore, Russia's weaponising of energy supplies to Europe has demonstrated the important security policy implications of relying on non-EEA suppliers. While the green transition will ultimately leave Europe self-supplied with energy, the transition up to this end point – in which fossil fuel remains crucial – renders the continent vulnerable to strategic blackmail.

6.5 Solutions abroad

In order to fulfil its 2030 climate commitments, Norway is likely to have to address its 'climate deficit' through investments abroad, as it did under the Kyoto round previously.[14] Then, Norway purchased Clean Development Mechanism quotas totalling NOK 2.9 billion, distributed across approximately 76 million credits (PWC 2022, Øvrebø 2020).

Article 6 of the Paris Agreement (UNFCC n.d.) sets out principles for how countries can pursue voluntary cooperation to reach their climate targets, although it is unclear how these apply within the EU/EEA agreement.

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[14] More precisely, this relates to Prime Minister Jens Stoltenberg's pledge in his second government (2005–2013) to meet the goals of the Kyoto Protocol's two commitment periods (2008–2012 and 2013–2020).

7. Summary

Norway's pursuit of environmental leadership in the 21st century presents a profound paradox, as the nation grapples with being both a sustainability pioneer and deeply entrenched in a petroleum-dependent economy. Over 50 years of petroleum activities have led to the country forging an inextricable bond with the sector, which has become pivotal to Norway's macroeconomic stability and industrial growth particularly in its southern and mid-Norwegian coastal regions. This chapter explores the implications of this complex relationship and Norway's strategies to deal with it.

Norway has come up with two main strategies to deal with its petro-climate dilemma. On the one hand, the Green Party and environmental activists have repeatedly, if unsuccessfully, demanded that the country move towards pulling out of petroleum altogether. On the other hand, mainstream political parties and industrial interests in petro-dependent coastal regions moved forward with a 'clean petroleum' strategy, which involves greening petroleum productions through renewables-based power supply.

Powering offshore petroleum production from onshore hydro and wind power has, however, provoked considerable political and regional conflict over nature conservation, the siting of new wind farms, and price effects. This has resulted in more limited access to renewable energy than had been hoped, delaying Norway's progress towards fulfilling its 2030 climate obligations and fuelling a push for offshore wind as a means of meeting the petroleum industry's renewable energy demands.

Offshore wind, however, trails behind onshore wind when it comes to industrial maturity, meaning more powerful policy tools are needed to drive it. Although stronger innovation support measures are now arriving, it is somewhat late in the day. Thus, despite a pioneering offshore wind project and plans are for several more wind farms to follow, Norway is already behind in the race to meet its 2030 climate obligations, which will likely have to be delayed. As such, the country will have to supplement its domestic actions with green investments abroad, as it did under the Kyoto round.

In addition to wind, the chapter highlights promising green transition initiatives involving carbon capture and sequestration, and blue hydrogen, building industrial collaboration in the larger North-sea region while repurposing de-commissioned oil and gas fields benefitting Norwegian coastal regions in a low-carbon future.

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Effects of an expansion in mining and manufacturing on public sector employment

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ABSTRACT
This chapter analyses the dynamic interdependence between employment in the mining and manufacturing industries and employment in public administration, education and health. In doing so, its focus on northern Sweden is motivated by the large investments made in this territory over the past couple of years, coupled with the projected labour demand shock as the private and public sectors compete for qualified labour. Using longitudinal register data covering all fully employed residents in northern Sweden from 1990 to 2019, our results suggest that a positive employment shock in mining and manufacturing induces negative short- and medium-term employment changes in the public sector – mainly in public administration. The chapter also analyses which factors affect the probability of a worker leaving the public sector for a job in mining or manufacturing and offers policy suggestions aimed at addressing increased labour demand.

Keywords: employment, public sector, mining, manufacturing, northern Sweden

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1. Introduction

While the challenges of climate change are commonly understood as borderless, it is also evident that the green transition is framed by place- and context-specific contingencies (Coenen et al. 2012). As such, the effects of climate change and the associated investments needed will inevitably create regional winners and losers (McCann & Soete 2020). According to Rodriguez-Pose and Bartalucci (2023), this is likely to reinforce already existing urban–rural divides: while urban regions are expected to attract the majority of green investments (and rewards) due to their predominance in terms of infrastructure, skills and governance, rural regions risk being less attractive for capital and therefore locked into low-skilled, low-productivity activities.

Even so, despite being peripheral and sparsely populated, northern Sweden's abundance of minerals (e.g. iron ore) and stable 'green' energy mean the region (especially the two northernmost counties of Norrbotten and Västerbotten) is currently attracting large investments, placing it centre-stage when it comes to Sweden's and the EU's broader ambitions of reducing net greenhouse gas emissions by at least 55% by 2030. Massive investments associated with the manufacturing of batteries (Northvolt) and fossil-free steel (Hybrit and H2 Green Steel) – both those that have already materialised and those anticipated over the coming years – together with an anticipated mining boom for rare earth minerals crucial to the green transition, are expected to lead to thousands of new jobs in the territory.

The national coordinator for the investments estimates that 100,000 new inhabitants will be needed over the next two decades to meet expected increases in labour demand. This corresponds to population growth of about 20% (Larsson 2022) in a territory characterised by low unemployment, decreasing labour supply and increasing welfare demand due to an ageing population. This growth prediction has been bolstered by the unexpectedly large increase in the population of Skellefteå municipality (Northvolt), with the 1,009 persons increase in 2022 representing the biggest annual population growth in 50 years.

The anticipated economic injection to the territory will not, however, automatically trigger regional development in terms of employment, income and tax revenues. Without in-migration, the labour demand shock will likely stiffen competition for workers in regions already facing severe labour shortage (Blombäck et al. 2024, Sveriges Kommuner och Regioner 2023), leading to labour poaching from incumbent firms (Adjei et al. 2023) and the public sector (Ejdemo & Söderholm 2011, Valestrand 2018). Given that the public sector provides welfare (education, health, social care, etc.), is a key actor in the planning associated with societal transformation, and contributes to human capital formation, this is potentially detrimental for regional development (e.g. Alesina et al. 2001, Becker et al. 2021, Hansen & Eriksson 2023, Hansen & Winther 2014, Jofre-Monseny et al. 2020).

The aim of this study is to analyse the dynamic effects of labour demand shocks in the mining and manufacturing industries on employment in three parts of the public sector: 1) education; 2) health; 3) and public administration. This division is motivated by the assumption that different groups within the public sector exhibit different propensities – based on both skill requirements and work-life identity – to transition to the private sector. In addition, we explore the factors affecting the likelihood of a particular public sector employee leaving for a job in mining or manufacturing.

While previous studies have identified that the mining industry has an adverse effect on public sector employment, this chapter uses longitudinal micro-data on all employed residents in Sweden between 1990 to 2019 to extend the literature in three ways. First, by analysing both the combined and separate effects of increased labour demand in mining and manufacturing on public sector employment. Second, by detailing which parts of the public sector display stronger interdependencies with mining and manufacturing employment fluctuations. And third, by taking a micro-approach to assess the workforce demographics of public sector exits and entries. The latter is of particular importance given the general scarcity of skilled labour. If, for example, trained teachers leave the public sector for mining or manufacturing only to be replaced by unqualified teachers, the local welfare effects will most likely be negative.

The remainder of the chapter is organised as follows. Section 2 discusses the literature on public sector employment and regional development, before Section 3 explores the industrial history of northern Sweden. This is followed by a presentation of the dataset and descriptives in Section 4, with sections 5 and 6 then presenting the relevant findings. Section 7 offers some concluding remarks.

2. Public sector employment and regional development in resource-based regions

Following Canadian regional scientists such as Innis (1933, 1956), it was generally assumed that economic development based on natural resources and the export of staple commodities leads to regional economic injections, in turn spurring further development and diversification of the labour market. In reality, however, these export-led widespread multipliers have seldom occurred, as many of the benefits are typically captured by actors outside the region – such has been the experience in Canada (Halseth & Ryser 2017), Australia (MacKinnon 2013) and Sweden (Dubois & Carson 2017). Instead, resource-dependent regions tend to follow world market prices for minerals and metals (Halseth & Ryser 2017), with local welfare effects tied to the strategy of the lead firm, as well as local institutional arrangements for governing the resource and distributing its risks and rewards (Plummer & Tonts 2013). More recent accounts go as far as suggesting that a resource-based region's long-term growth potential and resilience is not determined by the export base, but rather driven by developments in unrelated sectors or sectors only indirectly connected with the resource industry (Plummer & Argent 2023).

Previous research on mining has found strong correlations between booms and busts and economic development (e.g. employment, income). Black et al. (2005) found that total employment in US coal-producing counties grew about 2% faster than in non-coal counties during booms but declined about 3% faster during busts. This is mainly attributable to an increase of jobs requiring medium-to-high education levels (Rajbhandari et al. 2024). Analysing Sweden's previous mining boom, Tano et al. (2016) find significant income effects in mining municipalities during the analysed boom period (2004–2006) compared to a matched reference group.[4] The effects were mainly confined to mining, with only moderate spillovers to other sectors (primarily in manufacturing and construction) and were concentrated in the largest mining towns of Norrbotten.

In one of the few studies on mining investments and regional employment in northern Sweden, Ejdemo and Söderholm (2011) find that total employment increases by 2.47 for every additional employee in mining during the maximum production phase. Municipalities dominated by public sector employment are more likely to experience a shift towards industrial sector employment where wages are comparatively higher (Ejdemo & Söderholm 2011). In a follow-up on both Norrbotten and Västerbotten, Moritz et al. (2017) also identify significant employment multipliers, particularly in private services and manufacturing.

The local effects of manufacturing expansion are less clear, with much of the recent research focusing on disinvestments rather than investments. Giroud et al. (2021), however, demonstrate that the opening of a billion-dollar plant raised productivity among incumbent firms by about 4%, despite the local benefits being unevenly distributed. Densely populated areas benefit the most due to more favourable regional endowments, including skilled labour, diversity of industries, functioning entrepreneurial ecosystems (Rodriguez-Pose & Bartalucci 2023), and a higher likelihood that incumbent firms share workers and use similar technologies (Greenstone et al. 2010). Although Moretti and Thulin (2013), in a comparison between Sweden and the US, find significant manufacturing multipliers in the former, they are somewhat more moderate compared to the latter, and are primarily attributable to high-skilled manufacturing jobs. This makes comparisons to the developments currently taking place in northern Sweden difficult, as most of the high-skilled jobs in the value chain are located elsewhere.[5] A key reason behind the lower multiplier in Sweden relates to labour market inelasticities.[6] Adjei et al. (2023), for example, show that the employment effects of a manufacturing entry into a small, peripheral labour market is unlikely to alter a region's negative employment trajectory. This is mainly attributed to the fact

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[4] Ejdemo (2017) also finds that although incomes in Pajala were still lower than the national average in 2013 following the mining boom, the income growth rate (average annual growth rate of 6.5%) between 2005 and 2013 exceeded the national average (average annual growth rate of 2.2%).

[5] The battery manufacturing company Northvolt has located its production plant in Skellefteå, while its R&D is based in Västerås and its management in Stockholm.

[6] Where labour market characteristics or factors like total employment remain unaffected by shocks such as the entry of a cluster or pioneer industry, or an expansion of existing industries.

that recruitment is local, meaning the regional workforce entry is merely redistributed, rather than expanded. In the case examined by Adjei et al., poaching occurred mainly from incumbent firms engaged in similar activities and from the public sector.

Thus, while the effects of mining in terms of employment and incomes are significant, they appear mainly confined to mining itself and related activities. In the case of manufacturing, the evidence points to significant negative multiplier effects in peripheral regions. If anything, a radical expansion adversely affects incumbent firms and/or the public sector through the poaching of local workers. By extension, these local shifts in sectorial employment can lead to labour distribution problems and supply shortages in the public sector. As discussed by Valestrand (2018) in relation to the reopening of the Sor-Varanger mine in northern Norway, the immediate policy response clearly prioritised the productive sector in its new growth narrative, thereby downgrading reproductive activities such as public sector development.

In this context, it is worth noting that the public sector is not merely a welfare provider or conduit for the planning and absorption of investments. Rather, evidence from Denmark suggests public sector employment promotes regional development by attracting human capital and facilitating economic growth, income distribution and quality of life in the region (Hansen & Winther 2014). Based on French data, Guillouzouic et al. (2021) find causal evidence that a drop in local public sector activity and employment has a negative effect on the private sector. This is particularly the case in local labour markets where the public sector holds monopsony power (i.e. is the dominant employer). Evidence also shows that regional public sector employment is counter-cyclical, thus contributing to resilience during crises (Davila et al. 2016, Moomaw & Williams 2009). As such, some have called for public sector employment to be taken more seriously in regional studies (Hansen & Eriksson 2023).

3. Northern Sweden: Historical background

Northern Sweden is not new to industrial development. The region has experienced significant economic development as well as challenges, largely tied to the rise and fall of various activities in the extractive and forestry industries. Both Norrbotten and Västerbotten are characterised by early industrial development based on natural resources. In European terms, Sweden is a relatively major mining economy (Geological Survey of Sweden 2022). Most of the 12 mining sites still remaining in Sweden are in Norrbotten and Västerbotten, accounting for about 83% of the country's export value in mining (Moritz et al. 2017). While the export of iron ore and other natural resources in the 20th century significantly enhanced industrial and economic growth, it also – as in many regions largely dependent on their natural resources (e.g. Halseth & Ryser 2017) – stunted diversification, locking regional economies into a narrow scope of activities. This in turn tied local and regional development to global price fluctuations. The rationalisation of primary industries (mining, forestry etc.) and decline in manufacturing starting in the 1950s can be attributed to numerous factors, including changes in global markets, technological advances and price fluctuations (see Figure 2, especially for manufacturing).

The decline in the numbers of mining and forestry workers had direct consequences for public sector employment. Hansen and Eriksson (2023) discuss how the centralisation of public administration during recent decades has negatively impacted small rural areas in relation to urban regions, with demand for high-skilled jobs in public administration having declined. In discussing the implications for regional development, Hansen and Eriksson distinguish between mobile and less mobile parts of the public sector.[7] While public sector activities more generally serve as a shock-absorber (employing otherwise redundant workers during times of crisis in the industrial sectors), the public sector's less mobile parts – which are a direct function of population (day care, elderly care, etc.) – decline in periods of industrial expansion. This suggests a symbiotic relationship between public sector and mining employment.

As can be seen in Table 1, between 1990 and 2019 total employment in northern Sweden increased by 2.56% (constituting a 9.26% increase in Västerbotten and a 3.98% decrease in Norrbotten), compared to 10.7% employment growth across the rest of Sweden. During the same period, total public sector employment decreased by 18.72% in northern Sweden (a 5.16% decrease in Västerbotten and a 29.77% decrease in Norrbotten). The core public sectors analysed in this study (education, healthcare, public administration) decreased by 3.33% (a 9.09% increase in Västerbotten and a 15.2% decrease in Norrbotten). Mining and manufacturing employment display a similar negative trend for the period across northern Sweden.[8]

Diversifying northern regional economies (e.g. tourism, renewable energy transition) is thus depicted as a promising strategy for offsetting future bust-and-boom in the resource-dependent region (e.g. Stihl 2022). Northern Sweden has attracted massive investments in climate-related projects since 2017, with many more envisaged over the coming years, making the territory a focal point for Sweden's green transition (Larsson 2022). While the bulk of investments are projected to take place in three municipalities (Gällivare and Boden in Norrbotten, and Skellefteå in Västerbotten), it is anticipated that other municipalities in the two regions (e.g. Luleå and Kiruna) will also benefit from the investments through new climate-related initiatives. According to Larsson (2022), these investments have attracted attention to the region due to, among other reasons: 1) the scale of the investments; 2) the type of activities; 3)

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[7] The mobile parts of the public sector encompass activities not directly dependent on population size (e.g. Försäkringskassan, Skatteverket and similar governmental agencies), while the less mobile parts encompass activities that are directly dependent on population size (e.g. education, healthcare, social care).

[8] Table 1 shows changes in employment in different industries. It does not show causality between industries (causality is discussed in Section 5). However, the takeaway from Table 1 is that while total employment is growing in northern Sweden, it is attributable to employment growth in the public sector (education, healthcare, public administration) in Västerbotten.

Table 1. Changes in employment in northern Sweden (1990–2019)

Employment/Year	1990	2019	% change
Northern Sweden			
Total employment	228,415	234,254	2.56
Public sector (general)	121,201	98,515	-18.72
Public sector (education, healthcare, administration)	79,126	76,491	-3.33
Mining	8,143	5,719	-29.77
Manufacturing	37,566	24,278	-35.37
Västerbotten			
Total employment	112,839	123,283	9.26
Public sector (general)	54,433	51,625	-5.16
Public sector (education, healthcare, administration)	38,673	42,187	9.09
Mining	2,491	1,137	-54.36
Manufacturing	21,339	13,895	-34.88
Norrbotten			
Total employment	115,576	110,971	-3.98
Public sector (general)	66,768	46,890	-29.77
Public sector (education, healthcare, administration)	40,453	34,304	-15.20
Mining	5,652	4,582	-18.93
Manufacturing	16,227	10,383	-36.01
Rest of Sweden			
Total employment	4,209,883	4,714,281	10.70

Note: Public sector (education, healthcare, administration) is a subset of public sector (general). Also, see Section 4 for the definition of industries (SNI code). Rest of Sweden excludes the counties of Västerbotten and Norrbotten. Source: Authors' own calculation based on data from Statistics Sweden (SCB).

where investments are taking place; and 4) how this is likely to contribute to economic and demographic development in a territory that has experienced outmigration of young people for decades.

The investments in northern Sweden are expected to have both direct effects (often in the short term), such as the poaching of skilled labour from local (related and unrelated) industries, and indirect effects, such as employment expansion in the public sector (often in the medium to long term), due to increased need for public and private services. The economic and social implications are also set to include new residents arriving to take jobs in the new industries, as shown in the report by Blombäck et al. (2024) on population growth in Skellefteå municipality. Thus, the overall derived demand for labour may have disproportionate impacts on different industries.

The green transition in northern Sweden means increases in demand for and the supply of post-secondary-educated workers in the coming years (Statistics Sweden 2014, 2017). Although the exact labour market effects of the green transition are ambiguous in terms of numbers and geography (Norlén & Berbert 2024), Montt et al. (2018) suggest that by 2030 most green transitioning economies will experience net job creation and a reallocation of workers across industries. Most of these jobs will be created in the construction, manufacturing and renewables sectors.

Evidence indicates that the energy sector has the highest employment multiplier effect in the economy (World Economic Forum 2012). Moreover, Moretti (2010) shows that multipliers tend to be higher for high-skilled jobs, which can partly be explained by the correlation between earnings and formal education. Given the persistent spatial division of labour that has locked the majority of northern Sweden into – for the most part – value-creation rather than value-capturing functions (Hane-Weijman et al. 2022), the question of whether high-skilled functions will be localised in the north and so ignite a new development path that 'beats the casino' remains open (Gong et al. 2023).[9] Alternatively, the region may simply end up playing host to production sites, as is the case for Northvolt, which has its production in Skellefteå and its R&D in Västerås. Early evidence on Skellefteå suggests that it is primarily low-skilled jobs being created, and that these vacancies are mainly being filled by workers originating from neighbouring municipalities (migrants or commuters). This casts doubt on the degree of regional upgrading taking place during this period of rapid growth (Blombäck et al. 2024).

4. Data and descriptive statistics

4.1 Data

The data used in this study comes from matched employer–employee registers from Statistics Sweden (SCB). The data consists of all employed individuals aged 18–75 years in Sweden's two northernmost regions: Norrbotten and Väster-

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[9] The concept refers to a diversification strategy into more complex industries unrelated from a region's current knowledge pool and capabilities (Balland et al. 2019).

botten. Our dataset contains annual information on place of birth, age, gender, place of residence (municipality), highest level of education, income from work, and workplace (municipality and sector) from 1990 to 2019. Hence, we can follow each individual employed in these regions between 1990 and 2019, and moreover trace whether they left to work elsewhere (or, alternatively, moved into either of the regions to work). Due to the Covid-19 pandemic, it is difficult to fully assess labour market dynamics for the years 2020–2022 (the latter year is the latest currently available at SCB). As such, these years are omitted from the analysis. Also omitted are individuals for whom the registers lack information about workplace, region of residence or industry; individuals engaged in extraterritorial activities (e.g. work for extraterritorial bodies); and activities involving households as employers. Individuals who received their main income from studies (i.e. students), parental allowance or equivalent non-work sources are likewise excluded. It should be acknowledged that we risk losing a relatively large share of women, as more women than men are assumed to go on parental leave (Evertsson 2016, Paull 2008, Kennerberg 2007). In total, our data cover about 86% of the total population aged 18–75 years.

The spatial units of analysis are the 29 municipalities in Norrbotten (14) and Västerbotten (15) (see Figure 1). These areas constitute about 29% of Sweden's total land area, 5% of its total population (equating to an average population density of 3.7 inhabitants per km2), and 5% of total employment in the country.

Industries and sectors are defined based on the Swedish standard industrial classification (SNI 2007). Since our data covers a lengthy period encompassing different administrative definitions of SNI, we have redefined the SNI codes to align with the current broader industrial definitions.[10]

Data for the micro-analysis (multinomial logistic regression) covers all those employed in the public sector in Norrbotten and Västerbotten between 2006 and 2008.[11] This range was chosen due to the increasing demand in, especially, the mining sector during the period in question, which bears comparison with current increases in labour demand (see Figure 2). Our dependent variable is a categorical variable indicating the likelihood of an employee leaving the public sector to enter either *mining, manufacturing* or any *other sector*, compared to *remaining in the public sector*.

The explanatory variables consist of categorical variables indicating income (annual income below SEK 250,000; above SEK 390,000); gender (male); age (18–25; 26–35; 65–75 years); level of formal education (more than

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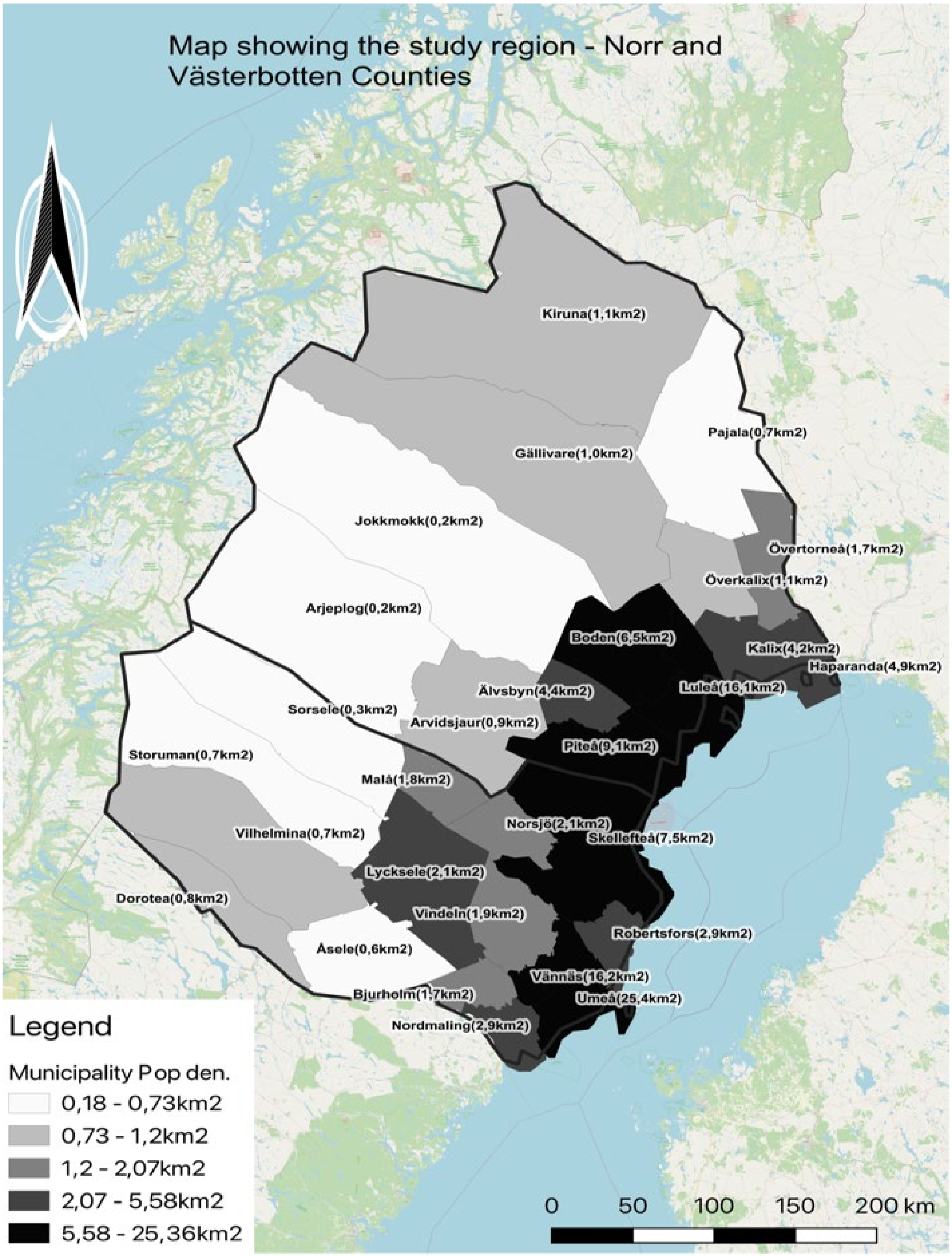
[10] Individuals working in the mining sector are defined by SNI codes 5–9, manufacturing by SNI codes 10–34, public sector administration by SNI code 84, public sector healthcare by SNI codes 86, 87 and 88, and public sector education by SNI code 85. A more detailed presentation of the definitions is provided in the Appendix, Table A6.

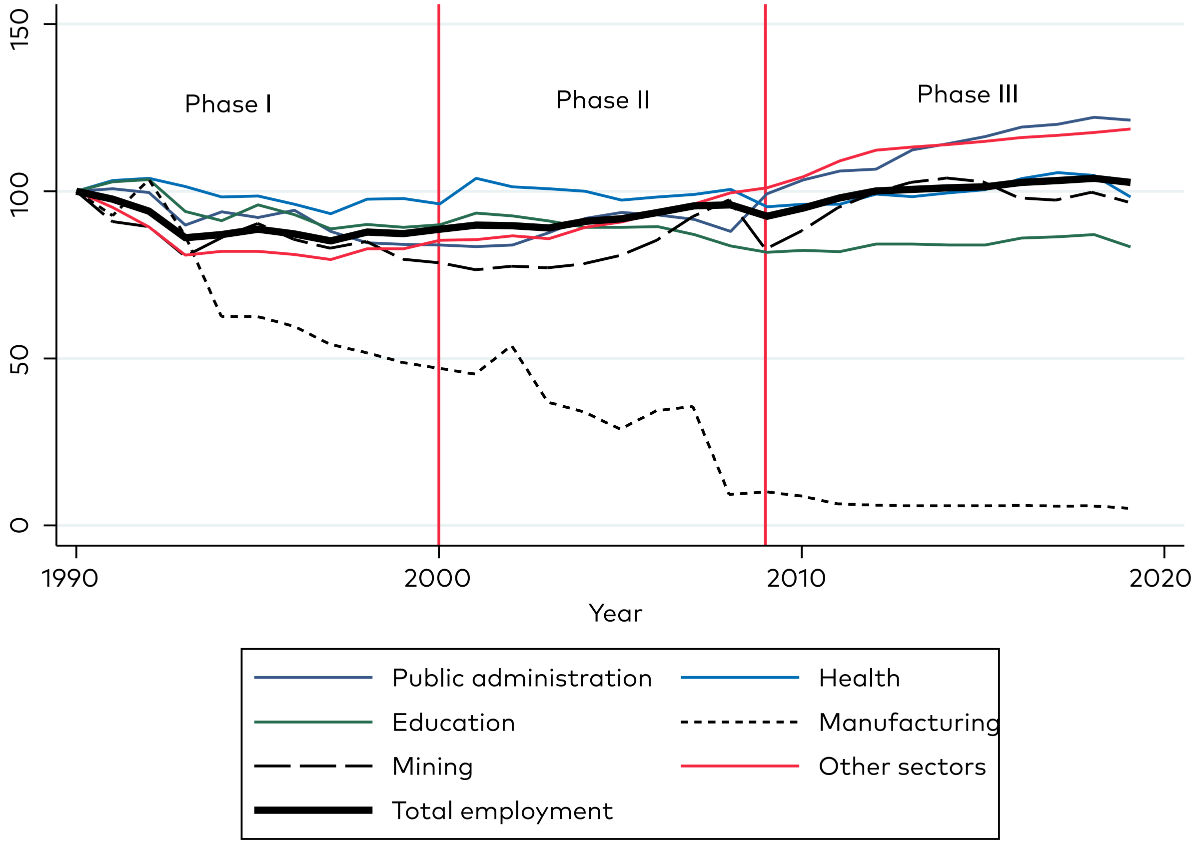
[11] We also estimated models for the period 2006–2012, a period characterised by a decline in mining attributable to the global financial crisis of 2008–2012. We chose to stick to the period 2006–2008 in order to avoid the potential effects of the decline that took place in 2009. Even so, the results are strikingly similar irrespective of which period is applied.

Figure 1. Map of the study region



Note: Region borders in bold and population density of municipalities in parenthesis. Map may differ from other maps using a different scale.
Source: Authors' own design, using ESRI base map.

Figure 2. Employment dynamics in Norrbotten and Västerbotten (index 100 in 1990)



Source: Authors' own calculation based on data from SCB.

three years of university education; less than three years of university education); educational fields (STEM; general; health; pedagogic/teacher); and family characteristics (married without children; single with children; single without children). We also control for type of municipality (mining; mining fringe; other small municipalities).

Hence, the reference category is set to be a representative public sector worker (a woman aged 36–64; with a medium-high education; in social sciences, law and business; living in the regional centre – Umeå in Västerbotten and Luleå in Norrbotten; married with children; with an annual gross income of SEK 250,000–390,000). The parameter estimates should be interpreted as higher (positive parameter estimates) or lower (negative parameter estimates) probabilities, compared to the reference category described above. The exact definitions of these variables are given in Table A6 in the Appendix.

4.2 Descriptive statistics

Figure 2 shows employment changes – both total and for selected industries – between 1990 and 2019 (1990 = index 100). Three phases are revealed by the figure. In the first period (Phase

I: 1990–2000), there is a decrease in total employment between 1990 and 1993, followed by stabilisation (including all sub-sectors except manufacturing). As evidenced in previous studies, the early-1990s recession hit the economy hard, with the northern labour markets (excluding Umeå) experiencing particular difficulties in entering a new growth trajectory (Eriksson & Hane-Weijman 2017). As displayed in Figure 2, this is mainly attributable to a sharp decline in manufacturing employment, alongside a somewhat less marked decline in 'other sectors' (i.e. all sectors other than the selected industries). The second period (Phase II: 2000–2009) is characterised by a general plateau (slow increase) in total employment. At the same time, however, there was a continuous decrease in manufacturing employment, while increasing world market prices for minerals led to employment growth in mining (c.f. Ejdemo & Söderholm 2011) and other sectors.

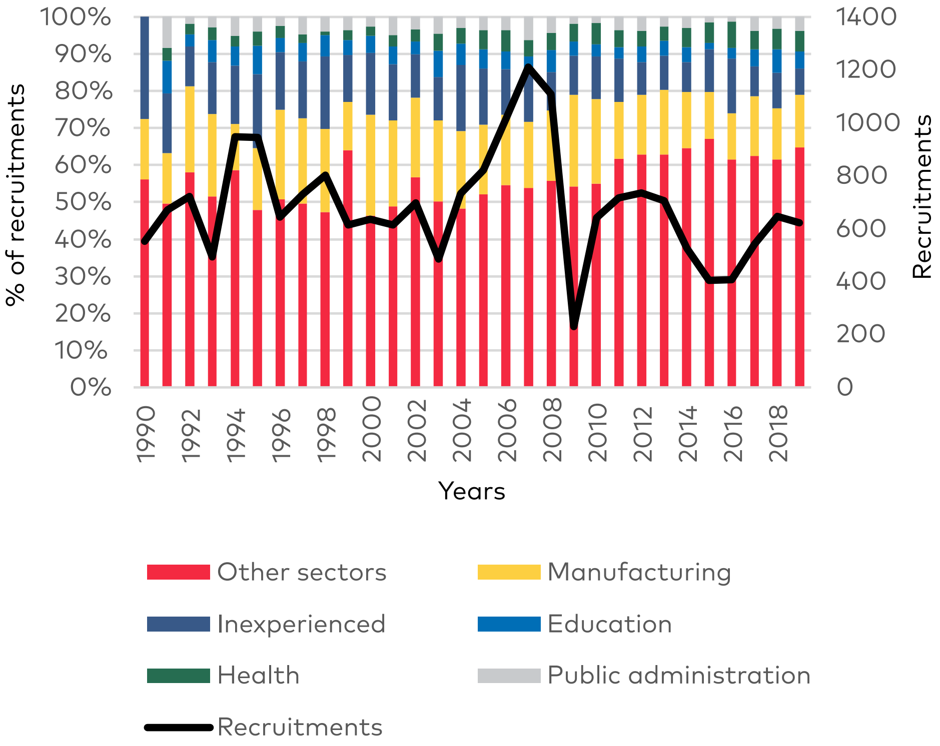
The final period (Phase III: 2009–2019) reveals that, in the wake of the employment impacts of the Great Recession in 2009, there was moderate but still notable total employment growth over the ensuing decade. This is attributable to the stabilisation of manufacturing employment and steady (although with a decline in 2015) employment growth in mining and public sector activities such as health and, especially, public administration. Above all, the period points to growing diversification in the two regions, as it is the 'other sectors' (services, etc.) that are expanding the most.

The three phases display both similarities and a number of striking differences across industries (see Table A1 in the Appendix for a comparison of Phase II and Phase III). First, Phase III saw a higher share of female employees in the mining industry (see Figure A1-A in the Appendix for a time series comparison), a trend also reported by Geological Survey of Sweden (2022). Second, Phase III saw an increasing number of workers with a higher education in the public sector, a phenomenon that began prior to this time period (see Figure A1-B in the Appendix for a time series comparison). Third, Phase III saw a decline in the number of employees with a general education (e.g. general knowledge in social/natural sciences; adult education; personal development), alongside an increase in those with a technology-oriented education in the manufacturing industry. Fourth, Phase III saw growth in the number of foreign-born workers in almost all industries, especially non-European foreign-born in the public sector. Finally, compared to Phase II, Phase III is characterised by a public sector workforce increasingly engaged in jobs requiring theoretical competences.

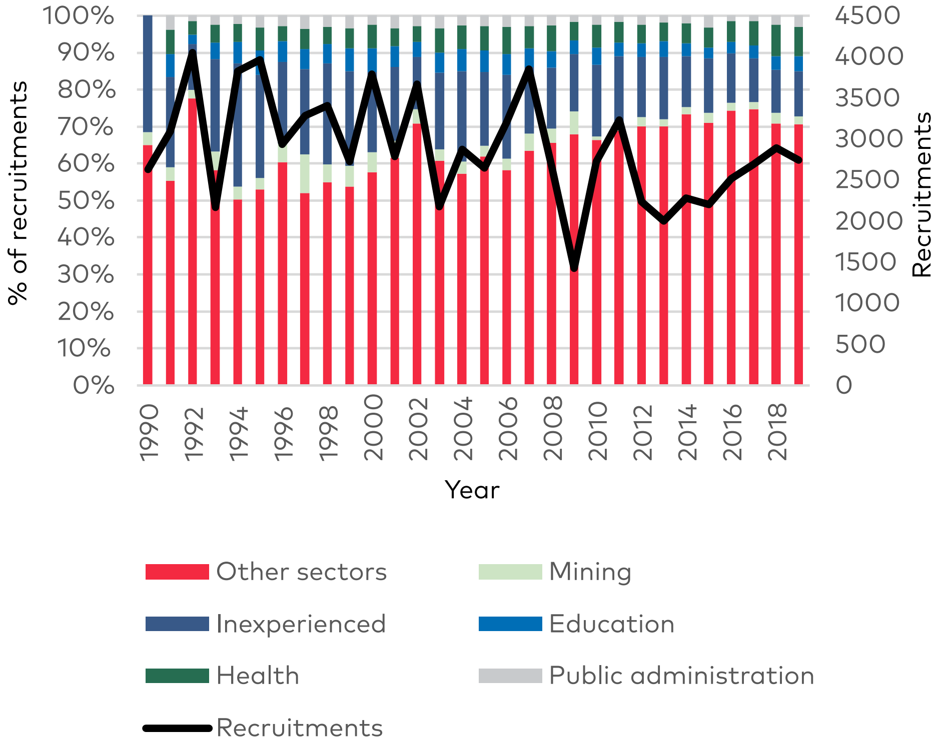
Figure 3 shows the origins of workers entering mining (A), manufacturing (B) and the public sector (C). Figure 3A shows that new hires in mining are primarily from other sectors of the economy (e.g. construction, accommodation and food services, transport and storage, real estate, but excluding the public sector categories of education, health and public administration), followed by manufacturing and inexperienced workers (i.e. people with no registered working experience in Sweden's official statistics, such as immigrants and newly graduated students). Those entering manufacturing are mainly from other sectors or are inexperienced (Fig-

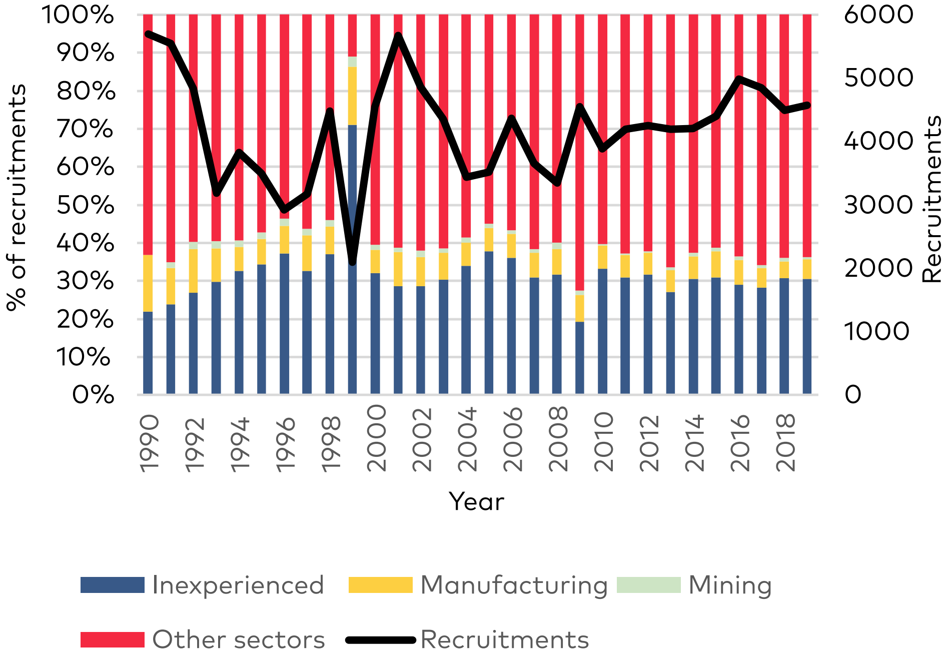
Figure 3. Sectorial employment switches to the mining industry, manufacturing and the public sector

A: To mining



B: To manufacturing





C: To public sector (education, healthcare, public administration)

Note: 3A and 3B exclude switches within the mining and manufacturing sectors respectively, while 3C excludes switches within education, health and public administration.
Source: Authors' own calculation based on data from SCB.

ure 3B). The composition of experiences is relatively stable over time, although a small increase in recruitment from the public sector into mining can be seen during the boom years prior to 2008. Thus, figures 3A and 3B indicate that an expansion in the mining and manufacturing sectors could adversely affect employment in the public sector, albeit at a relatively small rate.

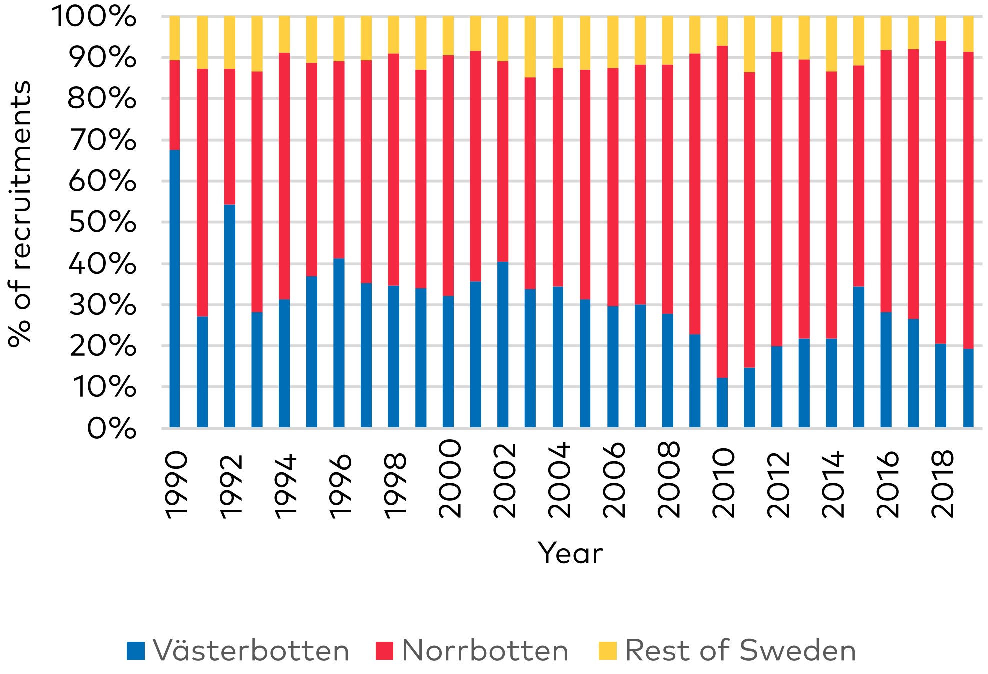
Figure 3C, on the other hand, shows the prior experience of workers entering the public sector. Most of the new hires are from *other sectors* of the economy, with the second most common worker being *inexperienced*. Even though the proportion of public sector hires from *manufacturing* and/or mining industries is small, it is still a considerable number of workers.

Figure 4 shows the regional dimension of recruitment into mining (A) and manufacturing (B) in northern Sweden. Most of the hires in the mining industry are from Norrbotten county, which testifies to the fact that most mining sites are located in the region. Turning to manufacturing, hires are almost evenly distributed between Västerbotten and Norrbotten. Within these two broad sectors, only an average of about 10% of hires come from outside the two counties, highlighting the fact that job mobility is primarily a within-regional phenomenon (Eriksson & Rodriguez-Pose 2017).

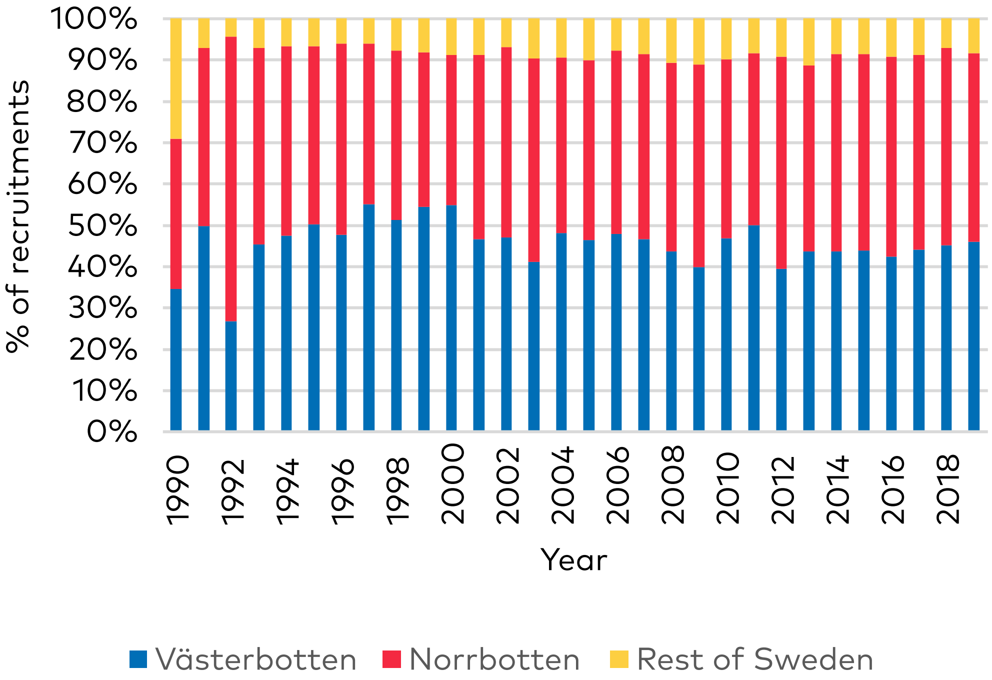
Figure 5 focuses on the geographical origin of hires to the public sector (i.e. administration, healthcare or education) in Norrbotten and Väster-

Figure 4. Origin of workers entering mining (A) and manufacturing (B) in northern Sweden

A: Mining

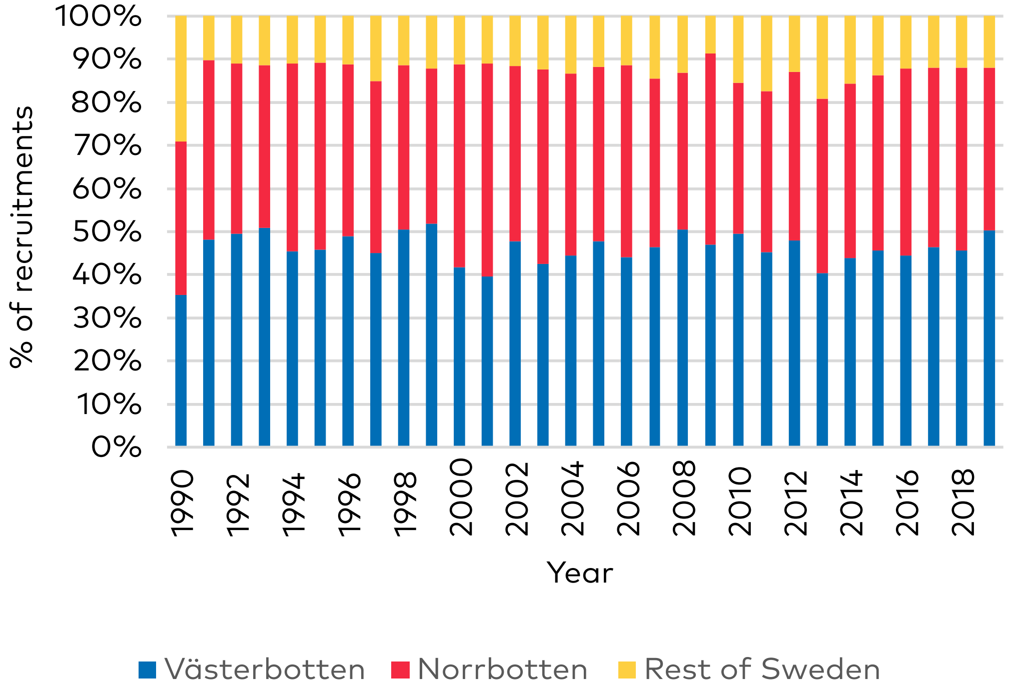


B: Manufacturing



Note: 4A and 4B exclude switches from the mining and manufacturing sectors, respectively.
Source: Author's own calculation based on data from SCB.

Figure 5. Origin of workers entering the public sector in northern Sweden



Note: Excludes switches from the public sector.
Source: Authors' own calculation based on data from SCB.

botten. Most of the hires are from the region, which can be explained by the fact that a university diploma is often required for these jobs, and that type of competence is often found within the region. Compared to mining and manufacturing, there is a somewhat higher inter-regional recruitment rate (about 12%) from the rest of Sweden. Separating the two counties out (not shown here) reveals that most recruits originate from within the region/county, with only negligible recruitment between the two counties. One notable difference is that Norrbotten has somewhat higher recruitment rates from the rest of Sweden than Västerbotten.

5. Granger causality test

As previously noted, the expected demand shock in mining and manufacturing is projected to cause significant regional multipliers in terms of both income (e.g. Tano et al. 2016) and employment (Ejdemo & Söderholm 2011). Under conditions of inelastic labour supply, however, this expansion may also lead to a regional zero-sum game which simply involves workers being redistributed within the region (Adjei et al. 2023, Blombäck et al. 2024). Whether public sector employment will grow or decline in response to private sector expansion has crucial implications in terms of the regions' overall ability to cater to these

Table 2. Granger causality tests on how shocks in mining and manufacturing predict employment in the public sector (total and in sub-sectors), 1990–2019

	Chi2	*p*-value
Panel 1: Public sector total		
Mining does not Granger cause the total public sector	3.073	0.381
Manufacturing does not Granger cause the total public sector	5.284	0.152
No combined Granger cause on the total public sector	19.328	0.004
Panel 2: Education		
Mining does not Granger cause employment in education	8.847	0.031
Manufacturing does not Granger cause employment in education	4.864	0.182
No combined Granger cause on employment in education	11.791	0.067
Panel 3: Health		
Mining does not Granger cause employment in health	2.709	0.439
Manufacturing does not Granger cause employment in health	6.481	0.090
No combined Granger cause on employment in health	9.094	0.168
Panel 4: Public administration		
Mining does not Granger cause employment in public administration	31.55	0.000
Manufacturing does not Granger cause employment in public administration	128.59	0.000
No combined Granger cause on employment in public administration	158.34	0.000

Note: If p > 0.05, the test statistic indicates that we cannot at the conventional 95% level of significance reject the hypothesis that a change in manufacturing and/or mining does not Granger cause a change in public sector employment.
Source: Authors' own calculation based on data from SCB.

investments and secure long-term welfare provision. For example, public services – such as daycare centres and schools – are essential prerequisites for attracting labour migration from other regions. In Sweden, it is also the municipality that is responsible for overall planning processes, making it a key actor in administrating the response to job-creating investments.

Here, we use Granger causality tests to determine whether a change in public sector employment follows an employment shock in the mining and manufacturing industries (c.f. Granger 1969).[12] It should be noted that this is not a causality test, but rather an indication of change and response.[13] Table A2 in Appendix provides for summary statistics for the variables included in the test.

Table 2 presents the empirical results from four different settings of the Granger causality test, with *p*-values for each chi2-test at three lags. The null hypothesis is the absence of Granger causality – that is, an employment expansion in mining and/or manufacturing *does not* Granger cause a change in public sector employment. Panel 1 shows the test statistics for the single and combined impact of employment expansion in the mining and/or manufacturing sectors on total public sector (public administration, health and education) employment. Following this, panels 2, 3 and 4 show the disaggregated test statistics as applied to public sector employment in, respectively, education, health and public administration.

As shown in Panel 1, the test statistics suggests that we cannot, at the conventional 95% level of significance, reject the hypothesis that an employment shock either in the mining or manufacturing sector does not Granger cause employment changes in the overall public sector (p-values 0.381 and 0.152 respectively). Jointly, however, the test statistics reject the hypothesis that a combined employment shock in mining and manufacturing does not Granger cause an employment shift in the public sector (*p*-value 0.004).

Based on the parameter estimates from the Granger causality test (displayed in Table A3 in the Appendix), Figure 6 shows the dynamic effects of a one standard deviation increase in mining and manufacturing employment. Despite the confidence interval being wide (the grey area surrounding the solid line indicating the average marginal effect), the results suggest a short-term negative effect that ebbs away over the following years. In absolute numbers, the average marginal effect after three years is a loss of 468 employees in the public sector. One potential explanation is that, in light of restricted migration, expansion in one sector comes at another sector's expense – in the longer-run, however, migration and labour redistribution across sectors gradually offsets the expansion effect. This is to be expected given that – as suggested by data on the US by Rajbhandari et al. (2024) – the migration-induced effects of a resource boom take at least three years to materialise.

As mentioned in the introduction, the public sector encompasses several different areas of activity, each requiring

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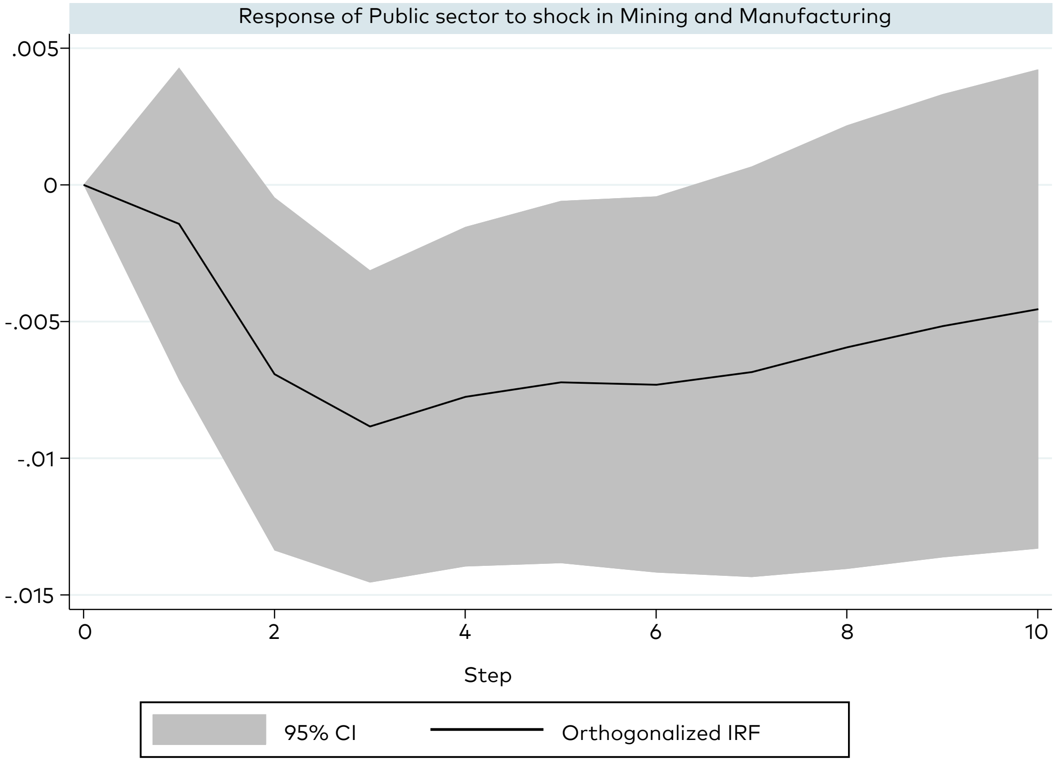
[12] The following example gives an insight into the logic underlying the Granger-causality test: Suppose we have two variables, *Y* and *X*, measured over some time periods, *T*, which we believed to be related – such as a change in one of them at time *t*-1 causing a change in the other (Granger-cause) in the next period, time *t*. To test if *X* Granger-causes *Y*, we regress *Y* on lags of both *X* and *Y*. To be more specific, using two lags, we regress by ordinary least squares $Y_t = \alpha + \beta_{Y1} Y_{t-1} + \beta_{Y2} Y_{t-2} + \beta_{X1} X_{t-1} + \beta_{X2} X_{t-2} + \varepsilon_t$ where α and the β's are parameters to be estimated and ε is the error term. Then we test if $\beta_{X1} + \beta_{X2} = 0$. If $\beta_{X1} + \beta_{X2} = 0$ – which is the null-hypothesis – cannot be rejected, in which case *X* does not Granger-cause *Y*.

[13] For an in-depth description of the Granger causality test see the original article by Granger (1969), as well as standard econometric textbooks such as Green (2017) or Baum et al. (2022) for Stata code.

Figure 6. Directionality of Granger causality (impulse or shock response analysis) on public sector employment

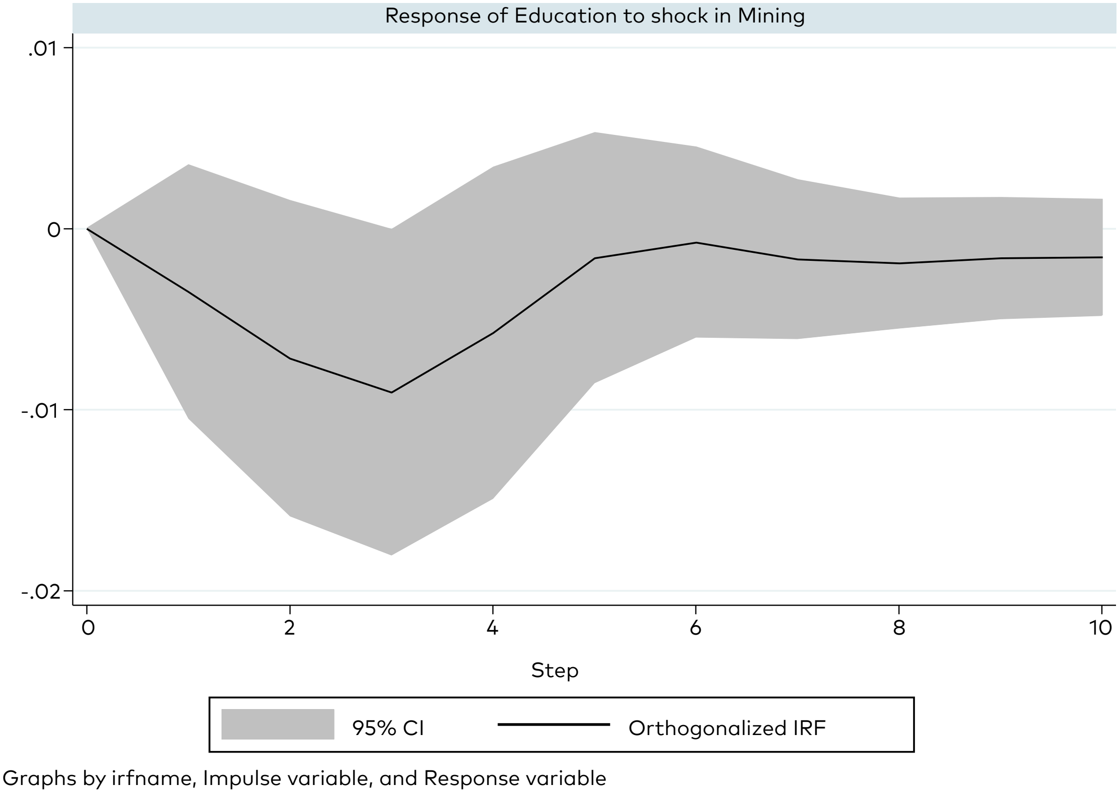


Graphs by irfname, Impulse variable, and Response variable

Note: Impulse response function (IRF) is used to determine the time path and direction of the vector autoregression (VAR) relationships (like Granger causality) between an employment shock in the mining and/or manufacturing sectors and employment in the public sector. The vertical axis employs the variable unit used in the VAR, hence it measures or represents a percentage point change (one stanadrd deviation) to a shock or expansion in mining and/or manufacturinng, while the horizontal axis represents the effects across time (years in the data). The solid line shows the average percentage change in public sector employment Granger caused by a one standard deviation employment increase in mining and/or manufacturing. The shaded area is the 95% confidence interval surrounding the mean effect.

different skills and formal training. As such, employees in different parts of the public sector will have different options when it comes to entering the private labour market. For example, it is reasonable that a nurse's or teacher's ability and propensity to switch to the mining or manufacturing sectors differs from, say, an accountant or a less high-skilled worker such as a janitor. When public sector employment is disaggregated into its constituent sub-sectors, a more distinct pattern emerges. For instance, as displayed in Panel 2 of Table 2, the test statistic rejects the hypothesis that employment expansion in mining does not Granger cause employment changes in education (*p*-value 0.031). Based on the same test statistic, however, we cannot reject the hypothesis that employment

Figure 7. Directionality of Granger causality (impulse or shock response analysis) of mining expansion on employment in education



Note: Impulse response function (IRF) is used to determine the time path and direction of the vector autoregression (VAR) relationships (like Granger causality) between an employment shock in the mining and/or manufacturing sectors and employment in the public sector. The vertical axis employs the variable unit used in the VAR, hence it measures or represents a percentage point change (one stanadrd deviation) to a shock or expansion in mining and/or manufacturinng, while the horizontal axis represents the effects across time (years in the data). The solid line shows the average percentage change in public sector employment Granger caused by a one standard deviation employment increase in mining and/or manufacturing. The shaded area is the 95% confidence interval surrounding the mean effect.

expansion in manufacturing – or a combined effect from employment expansion in both mining and manufacturing – does not Granger cause an expansion in employment in education (p-value 0.182 and 0.067). The latter, though, is only significant at the 10% level.[14] Furthermore, as displayed in Figure 7, our

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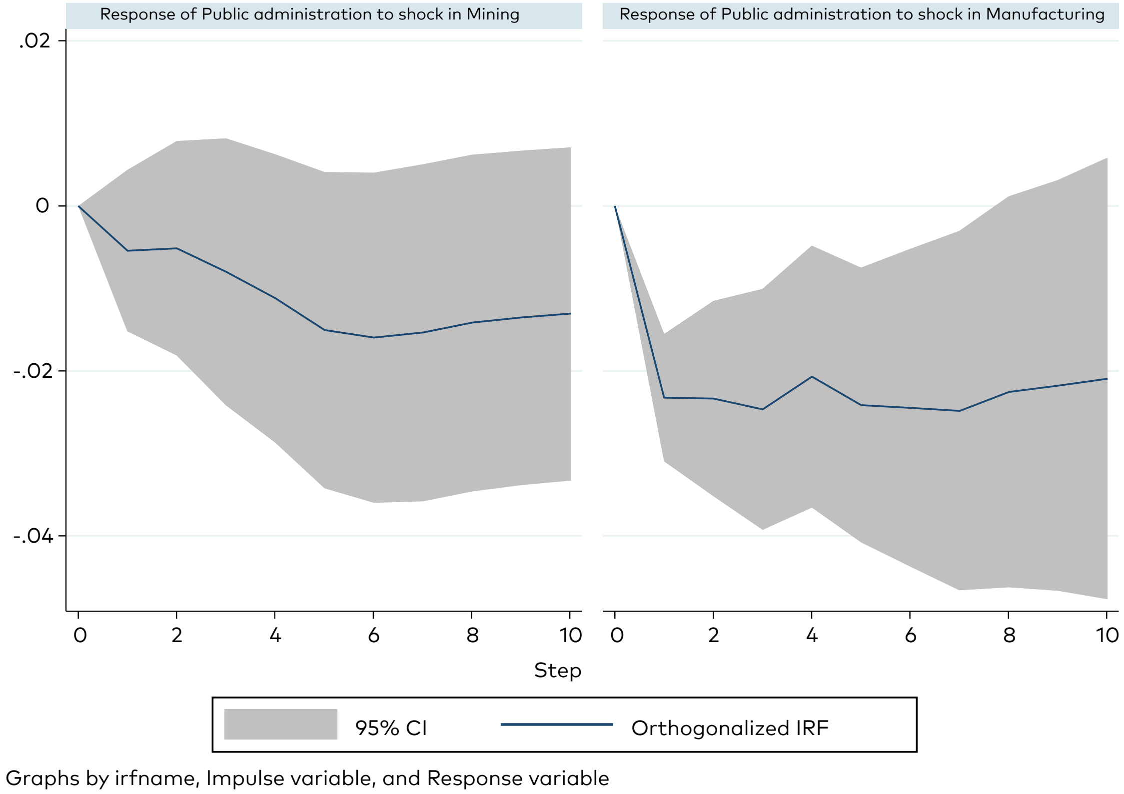
[14] We performed similar analyses for mining regions only (not presented) to find out if the results are influenced by local industrial structure. We found that a combined employment expansion in mining and manufacturing affects employment in the public sector. Further, separately and combined, expansion in mining and manufacturing do not influence employment changes in education and healthcare in mining regions but they do influence employment changes in public administration.

Figure 8. Directionality of Granger causality (impulse or shock response analysis) of mining (left) and manufacturing (right) expansion on employment in public administration



Note: Impulse response function (IRF) is used to determine the time path and direction of the vector autoregression (VAR) relationships (like Granger causality) between an employment shock in the mining and/or manufacturing sectors and employment in the public sector. The vertical axis employs the variable unit used in the VAR, hence it measures or represents a percentage point change (one stanadrd deviation) to a shock or expansion in mining and/or manufacturinng, while the horizontal axis represents the effects across time (years in the data). The solid line shows the average percentage change in public sector employment Granger caused by a one standard deviation employment increase in mining and/or manufacturing. The shaded area is the 95% confidence interval surrounding the mean effect.

results suggest that, on average, a one standard deviation expansion in mining is followed by a short-term decrease in employment in education (95 jobs after three years), which ebbs away over time. Again, the confidence interval is wide and the dynamic effect insignificant.

Further down in Panel 3 (Table 2), we find no support for Granger causality between employment in mining or manufacturing and employment in health (p-values between 0.090 and 0.439). This may reflect a certain professional pride and dedication to work within healthcare, or alternatively, that educational qualifications in healthcare professions (doctors, nurses, etc.) are highly specialised and so may not be as transferable to other sectors.

On the other hand, the test statistics strongly support the hypothesis that employment expansion in either mining or manufacturing Granger causes changes in public administration employment (Panel 4, Table 2). In effect, an employment increase in mining or manufacturing leads to a decrease in public administration employment. As displayed in Figure 8 (building on the parameter estimates displayed in Table A3), a one standard deviation expansion in mining and manufacturing leads on average to, respectively, 145 and 285 jobs losses in public administration within 3–6 years. Following a similar line of reasoning to that given above, this indicates that the educational orientation necessary to qualify for public administration positions is broadly applicable to other sectors. Again, however, these results should be interpreted with caution due to the wide confidence interval.

In summary, our findings suggest that a positive employment shock in mining and manufacturing combined (not when assessed separately) tends to have a general negative effect on public sector employment, thus confirming previous research concerning adverse effects on public sector employment (e.g. Ejdemo & Söderholm 2011). While a one standard deviation increases in mining and manufacturing combined (i.e. 4,300 jobs, as seen in Table A2) implies a loss of 468 jobs across the public sector, this effect is not universal across the public sector's constituent parts. For example, although employment in health is unaffected, employment in education is only moderately (negatively) affected. The most prominent adverse effects can be seen in public administration, where a one standard deviation increase in mining and manufacturing leads to, respectively, 145 and 285 job losses. For the entire period of 1990–2019, this represents an expansion of about 900 jobs in mining and 3,600 jobs in manufacturing (see Table A2). This is far lower than the demand anticipated following future green investments, but if a linear relationship is assumed, a three standard deviation increase (i.e. 2,700 mining jobs and 10,800 manufacturing jobs, totalling 13,500 new jobs across both sectors) implies that fiercer competition for workers could lead to public administration losing about 1,290 workers (435 to mining and 855 to manufacturing). This constitutes almost 8% of the sector's employees in 2019.[15] Given the high future demand anticipated for public sector activities due to ageing, this represents a substantial potential decline. Based on previous flows, it would mainly impact such public administration occupations as civil engineers, cleaners, precision mechanics, accountants and HR staff.

Overall, the results presented thus far provide an indication of how an expansion in mining and manufacturing could impact net employment within the public sector. To conduct a more in-depth analysis, the next section uses multinomial logistic regression to examine which factors influence the likelihood

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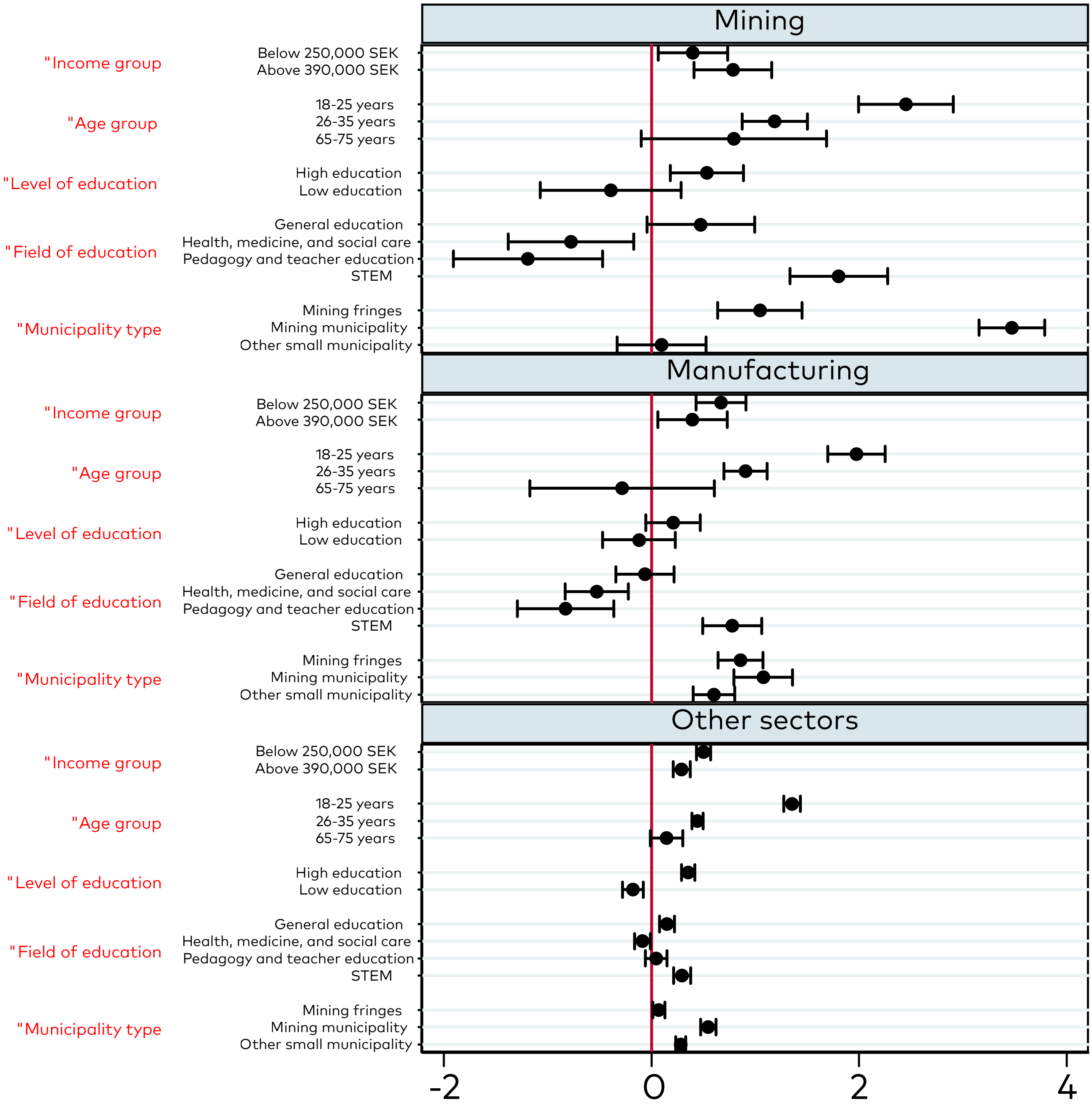
[15] The corresponding combined effect of manufacturing and mining on all public sector activities from a three standard deviation change equates to about 12,900 new manufacturing and mining jobs, with about 1,400 employees poached from the entirety of the public sector. This in turn represents about 4% of public sector employees.

Figure 9. Summary of regression results from multinominal logit model on the likelihood of public sector workers leaving for work in other activities, 2006–2008



Note: The reference dependent category is Stayers. The reference category is set to be a representative public sector worker: A woman aged between 36 and 64, with a medium-high education in social sciences, law, or business, living in the regional centre – Umeå in Västerbotten and Luleå in Norrbotten-, married with children and with an annual gross income between SEK 250,000 and SEK 390,000. The parameter estimates should be interpreted as higher (positive parameter estimates) or lower (negative parameter estimates) probabilities compared to the reference category described above. The point estimate is indicated by the bullet point, while the confidence interval is indicated by the dashed line on both sides of the point estimate. A confidence interval crossing the vertical line indicates that the parameter estimate is not statistically different from zero.

of a public sector employee switching to employment within either the mining, manufacturing or other industrial sectors.

6. Multinomial logistic regression

There are numerous reasons why an individual might terminate their employment in one sector to pursue a position in another part of the economy. For public sector workers, it may, for instance, involve dissatisfaction with the public sector as an employer, working conditions or social influences – factors that are difficult to quantify. In our analysis, we therefore focus on measurable factors, such as income level; education and field of study; family circumstances; and type of municipality.

Here, we use a multinomial logistic regression to estimate the probability of workers leaving the public sector for different alternatives.[16] Figure 9 provides a summary of the main results, with the detailed parameter estimates and standard deviations given in Table A7 in the Appendix. As mentioned previously, we focus on the 2006–2008 period, as this was the most evident period of growth for the mining sector.

The constant is negative and highly significant in all specifications, suggesting that, on average, the reference group[17] is fairly unlikely to move to any other sector (see Table A7 in the Appendix). As shown in Figure 9, however, both low- and high-income earners are more likely to leave the public sector compared to the reference group, although the likely destination varies in each case. Whereas high-income earners in the public sector are more likely to end up in mining, there is a higher likelihood that low-income earners will switch to manufacturing or other sectors.

There is some support for a prediction of brain drain from the public sector to mining in light of the fact that workers making the move are not high-income earners as such, but rather those who are *relatively* well-paid (and therefore presumably more productive or experienced) compared to the workforce in general (see Table A7 in Appendix) (e.g. Cregård & Corin 2019). This result holds true even for those on lower salary levels within the public sector, indicating they may be dissatisfied with their current income and so motivated to seek better-paid jobs or alternative challenges more in line with their potential. It is also striking that, overall, men are more likely to leave the public sector – a highly significant result in both specifications and for all alternative sectors.

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[16] A multinomial logistic regression is an econometric method used to estimate the probability of a specific outcome when there are several possible outcomes that cannot be ordered in any meaningful way. The interested reader is referred to standard econometric textbooks such as Cameron and Trivedi (2005) and Green (2017).

[17] Remember from Section 4, the reference category is set to be a representative public sector worker: A woman aged between 36 and 64, with a medium-high education in social sciences, law, or business, living in the regional centre – Umeå in Västerbotten and Luleå in Norrbotten-, married with children and with an annual gross income between SEK 250,000 and SEK 390,000. The parameter estimates should be interpreted as higher (positive parameter estimates) or lower (negative parameter estimates) probabilities compared to the reference category described above.

If it is assumed that the public sector is regarded as a more reliable employer, this may reflect different levels of risk aversion between men and women. It may also, however, signal a labour market segmented along traditional gender lines in resource-dependent regions (Valestrand 2018). Interestingly, while relative income is not significant when it comes to moves into manufacturing, it is significant and negative for moves into other sectors. The latter finding suggests that less productive and therefore perhaps less well-matched workers find employment in activities other than manufacturing or mining.

The results show that younger workers and workers with a post-secondary education of three years and over are more likely to leave the public sector for mining, manufacturing and other sectors. This indicates that individuals with the potential for high future income development (high education, high salary and young) are more likely to transition from the public sector into the private sector.

When it comes to type of education, the findings suggest individuals with an education in science, technology, engineering and mathematics (STEM) are the most likely to leave public sector employment. Although it is difficult to assess the detailed mechanisms behind this, it could reflect public sector employees with STEM qualifications viewing their job as a stepping stone towards a better-matched position elsewhere. Compared to workers with a social science degree, those with a general education (humanities and art, service and unspecified) are more likely to switch to other sectors, while those with an education in healthcare and teaching (pedagogy and teacher education) are less likely to leave the public sector compared to the reference group.

These results are in line with some of the findings from the Granger causality tests: that is, an employment expansion in mining and/or manufacturing tends to be followed by decreased employment in the public administration. This direct effect also seems to be followed by an indirect effect, in the sense that public sector workers with general qualifications are more likely to find jobs in other parts of the economy when mining expands. The Granger causality tests did not, however, provide any clear evidence that employment expansion in mining and/or manufacturing is likely to be followed by employment changes in health care.

Turning to the type of municipality, the results suggest that during a period of rapid mining expansion, it is primarily in mining municipalities and mining fringes that moves away from the public sector occur. This trend occurs in conjunction with higher likelihoods of public sector workers in mining regions leaving for manufacturing and other sectors. This combined effect may prove a challenge when trying to sustain welfare provision in mining regions and their functionally integrated vicinities.[18] While the likelihood of public sector workers in other small municipalities entering employment in mining is not statistically different from large regional centres, there is a higher likelihood that workers

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[18] Welfare provision in this context means general service provision in the public sector (i.e. administration services, etc.), rather than necessarily essential services such as healthcare and social care.

in other small municipalities leave for either manufacturing or other sectors. Thus, the public sector effects of mining expansion are primarily confined to areas in or close to the mining jobs.

7. Concluding remarks

Large green transition-connected investments in northern Sweden – both those realised in recent years and those anticipated for the future – have prompted expectations of a substantial increase in local demand for labour. At least in the short run, assuming limited migration across regions, the projected labour demand increases in mining and manufacturing may negatively impact incumbent employers. This especially so for the public sector, which is not only a substantial employer in the territory but plays a key role in providing the welfare necessary for place-based development. Against the above backdrop, this study set out to analyse how labour demand in the mining and manufacturing industries influenced employment in across both the public sector as a whole and its constituent parts.

The findings show that a positive employment shock in both mining and manufacturing is more likely to induce negative general public sector employment changes in the short and medium term. Assuming a linear relationship based on past labour market interdependencies, this would mean that a three standard deviation increase in mining and employment (approximately 12,900 new jobs) could lead to about 1,400 public sector job losses (about 4% of public sector employees).

At the same time, these interdependencies are not universal. In fact, employment in health remains unaffected by employment expansions in mining and/or manufacturing, while education is only moderately affected. Thus, the adverse public sector impacts caused by a mining and/or manufacturing expansion are largely attributable to poaching from public administration, with almost 8% of such employees potentially leaving their positions to enter the mining and/or manufacturing sectors in the event of these activities increasing by three standard deviations (approx. 13,500 jobs). It should be noted, however, that only a small share of workers entering mining and/or manufacturing originate from the public sector. Instead, they tend to originate either from other sectors locally, or – in the case of mining – from manufacturing. Nevertheless, given the anticipated high labour demand in public administration arising from the local institutional capacity needed to absorb investments and cater to a growing population, any increase in the level of labour demand in mining and manufacturing could pose challenges when it comes to sustaining public administration in the focal communities.

Our micro-level findings suggest that younger individuals (18–25 and 26–35 years), higher income earners (annual income above SEK 390,000), and highly educated individuals (post-secondary education of three years or more) are more likely to leave the public sector. Surprisingly, the public sector tends to replace poached workers with highly educated (but inexperienced in terms of prior employment) individuals qualified for advanced positions. Moreover, the results do indeed point to a leakage from the public sector to *mining*, as well as to *other activities*, during periods of mining expansion. This indicates an indirect adverse effect of a mining boom, given that labour demand also increases in sectors other than mining and manufacturing.

It is, however, not predominantly certified workers with – among other backgrounds – a pedagogic or health-related education that leave the public sector, but rather workers with a social science background working in public administration. A plausible explanation for this is that the education and expertise necessary for public administration is more easily transferable to private sector industries, in contrast to the more profession-specific training required for healthcare and education. Furthermore, the public sector serves as the predominant employer in healthcare and education, thereby restricting mobility. Finally, the results suggest a highly localised interdependence between mining and public sector employment, in the sense that it is more likely that a public sector employee in a mining municipality will move into the mining sector compared to a counterpart working in a non-mining municipality.

A number of policy implications arise from these findings. While great emphasis is put on skills supply to the green industries, the predominantly intra-regional supply of workers identified in this chapter and elsewhere (e.g. Blomback et al. 2024) suggests policy-makers also should consider the consequences and effects for surrounding and neighbouring municipalities when tailoring regional policies. In fact, despite relatively moderate outflows from the public sector to mining and manufacturing during the study period, our results do indicate there is a risk of poaching in response to a demand shock.

As discussed by Valestrand (2018) in the case of Norway, policy-makers typically privilege expansions in productive sectors, thereby rendering work practices in the public sector – including health – invisible. Having interviewed young adults in northern Sweden, Rönnlund and Tollefsen (2023) show that the narrative of industrialisation strongly influences how youth perceive their future, including which high-school educations and career-tracks are articulated as more successful. Their findings suggest a striking lack of interest in health and care sector jobs compared to jobs in the transport sector and manufacturing. Hence, although workers with training in health and education appear less likely to move into mining or manufacturing, the major shift may instead be connected to a changing labour supply based on new narratives around successful labour market trajectories.

The question, then, is how to re-value such jobs in such a way as to give them the status of viable career opportunities amid the expansion in mining and manufacturing. As discussed by, for example, Grip and Jansson (2022) and Calmfors and Sánchez Gassen (2024), this could include bolstering the status of public sector employment by raising salaries and improving working conditions (see also Parding et al. 2023). Moreover, given that public sector workers are over-represented among migrants moving from larger to smaller cities, such policy actions could potentially make a migration decision look more attractive (Hansen & Eriksson 2023).

Our micro-analyses also show that public sector workers in mining areas are more likely to leave public sector employment compared to those residing in large regional centres. While this is hardly surprising, it does highlight the local dimensions of labour market realignments. Looking at the two counties that formed the basis of our research, it can be seen that there is significant intra-regional variation, which any policy intervention must take into consideration. Rather than rely on the spatially blind transition study support[19] that overlooks local needs (e.g. Berström et al. 2023), interventions should make greater use of bottom-up knowledge and support the continuous mapping of skills and demand.

As exemplified by the situation in Skellefteå, current policy arrangements make it difficult to attract unemployed people from southern Sweden due to a lack of coordinating bodies or incentives supporting migration (Eriksson forthcoming). Local forecasts of labour demand, especially in rural and peripheral regions, are often associated with a high degree of uncertainty as the figures available for many occupations may be too low for the Employment Agency to make accurate local predictions. Even so, given the functional specialisation and strong path dependence of regional labour markets (Hane-Weijman et al. 2022), having detailed knowledge and support schemes for migration in order to smooth out adjustment costs related to structural change has for long been argued to be imperative for a successful structural change (Aghion et al. 2009).

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[19] Student finance for transition and retraining is a Swedish publicly funded scheme for adults in the labour market who need to broaden their skills to improve their employability. It is possible to use the finance scheme for courses in Sweden that are currently eligible for student finance, as well as for courses financed by a transition organisation, if they strengthen the applicant's position in the labour market. A prerequisite for receiving support through the scheme is that the applicant must have worked an average of at least 40 per cent per week during each calendar month for at least eight years during a framework period of 14 years. The scheme can be provided for a period corresponding to a total of 44 weeks of full-time studies. It supports both full-time and part time studies, including 20, 40, 50, 60 and 75 per cent of full-time.

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