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The economy-wide impact of Arctic energy supply

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Summary of Results

A significant share of the world's undiscovered oil and natural gas resources are assumed to lie under the seabed of the Arctic Ocean. Due to the technological challenges posed by the harsh climate and the fields' remoteness, however, the extraction of Arctic hydrocarbons is relatively costly. At the same time, Arctic hydrocarbons need to compete with less expensive supply options on the world market, including oil and gas from unconventional sources. In light of the above, we assess the future competitiveness of Arctic offshore gas and oil, its possible recipients as well as its effects on economies and markets in Europe and beyond. For this purpose, we conduct a scenario-based analysis and employ economic modelling techniques to determine the economy-wide implications until 2040.

Natural gas

In general, the effects of additional natural gas production are very moderate. This is due not only to the small existing production capacities which, taken together, will amount only to 28.6 bcm in 2018. It is also due to the fact that only few locations in the European Arctic are actually economically viable in the current gas market environment. We study additional production in the Norwegian and Russian Barents Sea, existing Kara Sea Facilities and off the West coast of Greenland. Of these locations, only production in Greenland and the expansion of existing production facilities in Norway (Snøhvit) and Russia (Yamal) are actually economically viable at present. More challenging environments in the Barents Sea, e.g. offshore locations with higher step-out distances, are not economic in the current environment. This highlights the importance of existing infrastructure for economic development in the High North, which serves as a catalyst for future development.

With Asian demand steadily increasing, the vast majority of Arctic production will be shipped to Asia in the long run. Hence, the European supply portfolio is not going to be significantly altered by Arctic production from existing facilities, even if production volumes increase significantly. Only hypothetical LNG production in Greenland will be shipped to Europe where it partly replaces US LNG.

We also find that accelerating climate change in the Arctic does not have a significant effect on deliveries via the Northern Sea Route, since even in the case of limited availability of the route in the reference scenario (we assume availability of the NSR from June to September), almost all gas is shipped to Asia.

Still, additional Arctic gas production has some small indirect impacts on Europe and beyond. Naturally, the producing countries are most affected. This is especially true for Greenland/Denmark, where we find an increase in Gross Domestic Product (GDP) of 1.3-1.4 % and spillovers to some manufacturing sectors in 2040 if natural gas is produced in the Arctic. Overall economic impacts on Norway and Russia are even smaller, although we find significant reactions in downstream sectors in both countries. The Norwegian downstream economy is mostly negatively hit, with output decreasing especially in the chemicals and energy intensive industry sectors. These sectors suffer twice from additional production, once because of increased competition about qualified labour and once because of Dutch Disease effects, i.e. the disadvantageous appreciation of the producing country's real exchange rate. The Russian downstream economy, especially the chemicals and electricity sectors, partly profits from lower prices for natural gas and realizes production increases. Furthermore, increased competition about qualified labour can be seen also in Denmark and Russia, and to a smaller effect also in other natural gas producing economies, including The Netherlands and countries in North Africa.

Even though overall effects outside the Arctic may be small, we do find some effects in selected non-Arctic countries. Especially Eastern Europe (both Eastern European Union and beyond) and other states of the Former Soviet Union, both in relatively close proximity to Russia, are affected. GDP increases in the gas importing countries of Eastern Europe, due to lower gas prices, but decreases in gas producing countries of the Former Soviet Union. Again, the chemicals and energy intensive industry sectors profit most from reduced natural gas prices.

On global goods and services markets, effects are mostly limited to the producing countries. Terms-of-trade decline by around 1 % in 2040 for Denmark and Norway, as are exports in the Norwegian manufacturing sectors. Potential reasons for these losses are Dutch Disease effects as well as increased competition on factor markets, including labour. Despite reduced terms of trade, some Danish manufacturing sectors increase their exports as they profit from reduced natural gas prices. The same is true for the Russian chemicals and electricity sectors.

Also, the production of other fuels is not significantly affected, apart from some special cases, such as Russian electricity and non-Arctic natural gas. Offshore production of Arctic natural gas is, however, detrimental to reaching European and global climate protection goals. As global CO_2 emissions from burning coal, gas and oil increase in the order of magnitude of several dozen megatons, the hope that natural gas might replace even more carbon intensive fuels such as coal or oil does not realize.

As a general conclusion, offshore production of natural gas in the Arctic, while having some modest regional effects, is certainly not a game changer for Europe. The effects on import diversification are miniscule as economic possibilities on competing markets, especially Asia, are more tempting for natural gas producers. Also, the impulses for economic development remain small and confined to the producing countries or selected energy intensive sectors.

Crude Oil

Regarding Arctic offshore oil, we find that additional production has a number of consequences for European economies, not all of which are in line with European policy goals. The most impactful effect of Arctic oil – and presumably any additional oil production for that matter – would be a decrease in oil price of significant order of magnitude, both in producing and importing countries. As oil is one of the, if not the single most important input factor for any economy, the price reduction acts as a stimulus program. GDP increases significantly in producing countries, especially in comparably small Norway and Greenland/Denmark where we see an increase of up to 1.7 %. GDP increases, however, are not restricted to the producing country. We find an expansion of economic activity also for all European countries. Only competing oil exporters are negatively hit, such as countries in the Middle East, North and Sub-Saharan Africa and of the Former Soviet Union.

The price changes and the economic expansion in many parts of the world have important implications for world trade. The terms-of-trade, i.e. the ratio of export prices in terms of import prices, decrease substantially for Arctic producers, even though each individual non-Arctic region is not much affected. Consequently, exports especially in manufacturing decrease in the producing countries. As an extreme example, overall, Danish exports decrease with oil production in Greenland, and Russian exports remain constant, with significant inter-sector shifts among exporting sectors in both countries. Dutch Disease effects, i.e. the disadvantageous appreciation of the producing country's real exchange rate and increased competition on domestic input markets are among the reasons. Only Norway profits overall in terms of exporting activity. The rest of the world increases exporting activity as the overall economic expansion spurs global demand. Nevertheless, this economic expansion is not enough to produce significant changes on the labour markets outside the producing countries. In the producing countries, however, we find significant labour market effects, including shifts from manufacturing sectors towards the oil and oil processing industry. While we do not find significant shifts on the markets for primary fuels, we do find a significant increase of CO_2-emissions as a consequence of additional oil production. Globally, CO_2-emissions increase by over 10 mt (0.02 %) even for the smallest production unit studied here.

The conclusion we draw regarding the offshore production of natural gas in the Arctic is also true as a general conclusion for European Arctic offshore oil: while having some modest regional effects, Artic offshore oil production is certainly not a game changer for Europe. Even though oil production and the accompanying price decrease acts as a small stimulus program for European economies, this effect is not confined to Arctic oil, where it is nevertheless connected with especially detrimental environmental risks.

General conclusion

Both offshore oil and gas production from the Arctic Ocean are being discussed currently as a solution to diminishing fossil fuel supply and energy security worries in Europe. We conclude that neither European Arctic offshore natural gas, nor European Arctic offshore oil are a game changer for Europe. While production in the European Arctic might in the long term alleviate some effects of severe supply disruptions, attractive markets especially in Asia attract what small realistic production we might witness in Greenland, the Norwegian Barents Sea, or even the Russian Arctic.

Nevertheless, we do find some effects of increased offshore production of hydrocarbons in the European Arctic. We find that under certain conditions, oil and gas projects are viable in existing natural gas locations in Norway and Russia, in Greenland, and in the case of oil production, should the necessary discoveries be made. Nevertheless, most natural gas would be shipped to Asian markets. The economic unviability of new production sites with large step-out distances in Norway and Russia highlights the importance of existing infrastructure for economic development in the High North, which serves as a catalyst for future development.

Given additional Arctic gas or oil production, we find a positive effect on GDP in the producing countries, even larger in the case of oil compared to gas in Norway and about the same for Greenland/Denmark and Russia, with some modest second-round effects for downstream sectors. Regarding countries outside the Arctic, we find by comparing regions that are active on both the gas and the oil market, such as the Middle East or North Africa, and comparable oil and gas scenarios, that the effects of oil production in the Arctic are considerably larger than those of natural gas production. This reflects the higher integration of the corresponding global or, respectively, regional markets. The same integration also leads to smaller price decreases in Russia and Denmark/Greenland for oil compared to natural gas. Any expectations that additional natural gas production might lead to reductions in CO_2-emissions do not realize. We find an increase in emissions for both fuels and all scenarios.

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Part I: Assessment of the economy-wide impacts of Arctic energy supply – introduction and methodology

1. Motivation and research questions

With ongoing climate change the Arctic Ocean changes, as rising temperatures lead to receding sea ice. This has not only severe implications for the ecosystem itself, but also sparks worries that accessibility increases human activity since, for example, large reserves of natural gas and oil lie below the Arctic sea floor. The USGS estimates in their Circum-Arctic Resource Appraisal (USGS-CARA) that the area north of the Arctic Circle holds "about 30% of the world's undiscovered gas and 13% of the world's undiscovered oil" (Gautier et al. 2009).

Progressive climate change, recent discoveries, new production technologies, and business's interest in a diversification of sources make exploitation of Arctic offshore hydrocarbons more probable. Also governments worldwide have an interest in a diversified and large fossil fuel resource stock that may include Arctic sources. Reasons are manifold, but in particular include energy security issues and worries about decreasing production paths for example in Northern and Western Europe ("peak oil"). Still, technological challenges remain, posed e.g. by the harsh climate, darkness, weather conditions, as well as the area's remoteness. Together with the uncertain outlook on price developments in international energy markets, these technological challenges make Arctic offshore hydrocarbons far from a surefire success. Furthermore, Arctic gas, for example, competes with less expensive supply options on the world market such as unconventionally produced gas.

In light of the above, the ACCESS project attempts to provide an assessment of the implications of human activity in and at the Arctic Ocean. This report contributes by analysing the economic viability of Arctic offshore production of hydrocarbons from different locations as well as the implications of additional production of hydrocarbons from the Arctic on the global gas and oil markets and beyond. We focus not only on the direct effects of production, but show economy-wide effects too, both in other sectors and in other countries. We investigate future competitiveness of Arctic oil and gas, its possible customers as well as its effects on welfare and other economic indicators including prices, trade and employment. For this purpose, a scenario-based analysis is conducted by employing economic modelling techniques up to the year 2040. In a first step, a Reference Scenario is specified which reflects the "most likely development" of Arctic gas production. The Reference Scenario assumes, among other things, that current economic conditions and dynamics are perpetuated. This Reference Scenario is then compared to several alternative scenarios. These alternative scenarios differ from the Reference Scenario with respect to assumptions on Arctic offshore production of oil and natural gas, with respect to quantity, production costs, and location. Given the current political situation we add in an excursus a scenario modelling an EU embargo for natural gas from Russia.

This report aims at addressing the following aspects:

1. Identification of offshore fields likely to deliver oil and gas from the Arctic in the medium term,
2. Assessment of the economic viability of these fields,

3. Assessment of the impacts of Arctic oil and gas on global and European energy markets (e.g. effect on energy prices),
4. Assessment of the economy-wide impacts of oil and natural gas extraction from the Arctic (e.g. effect on international trade, sector composition).

This respport is structured as follows. The methodological foundations of this report are presented in Sections 2 and 3. Part II of the report describe the scenarios and results for additional production of natural gas from the Arctic, including an excursus on a Russian embargo or boycott and Arctic energy production. In Part III, we present the scenarios and results for Arctic oil, before we conclude in Part IV.

2. Locations and the impact of ice conditions for oil and gas exploitation in the Arctic Ocean

For the assessment of the economic viability of a new production site, information on the location, size, and environmental conditions, such as bathymetry and ice conditions of that site is vital. The location of sites depends on the probability of successful exploration, which in turn depends on the geological conditions as well as the size of potential fields in the area, since exploring firms are more likely to invest in drilling in areas with high potential. The USGS-CARA (USGS 2008, Gautier et al. 2009) publishes information on both the probability of the presence of at least one undiscovered oil and/or gas field[1], as well as the oil and gas potential by a relatively narrowly defined area (see Figure 1 and Figure 2).

[1] The probability of the presence of at least one undiscovered oil and/or gas field with recoverable resources greater than 50 million barrels of oil equivalent (MMBOE).

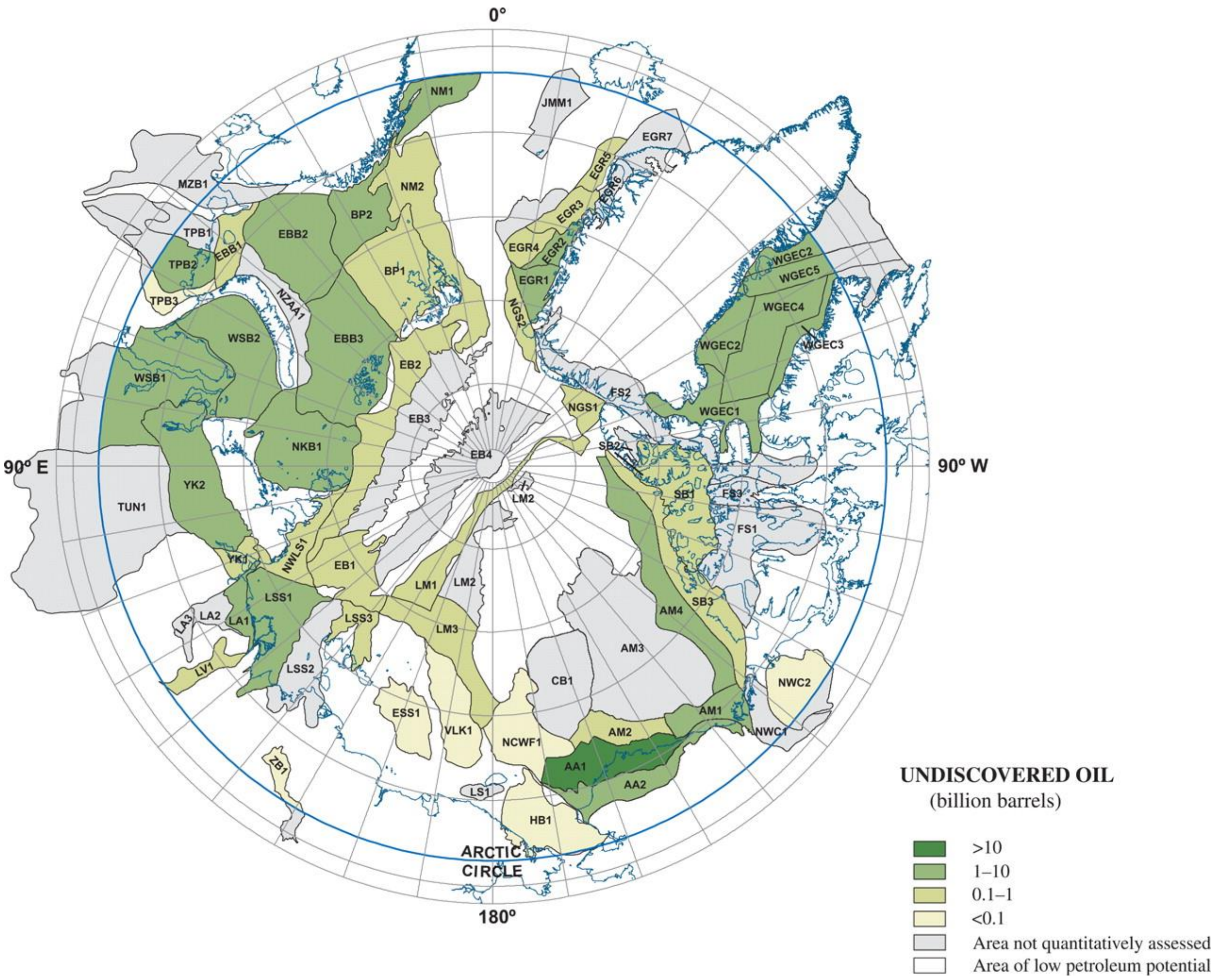


Figure 1: Map showing the Assessment Units of the USGS-CARA, color-coded for mean estimated undiscovered oil. Only areas north of the Arctic Circle are included in the estimates. Source: Gautier et al. 2009.

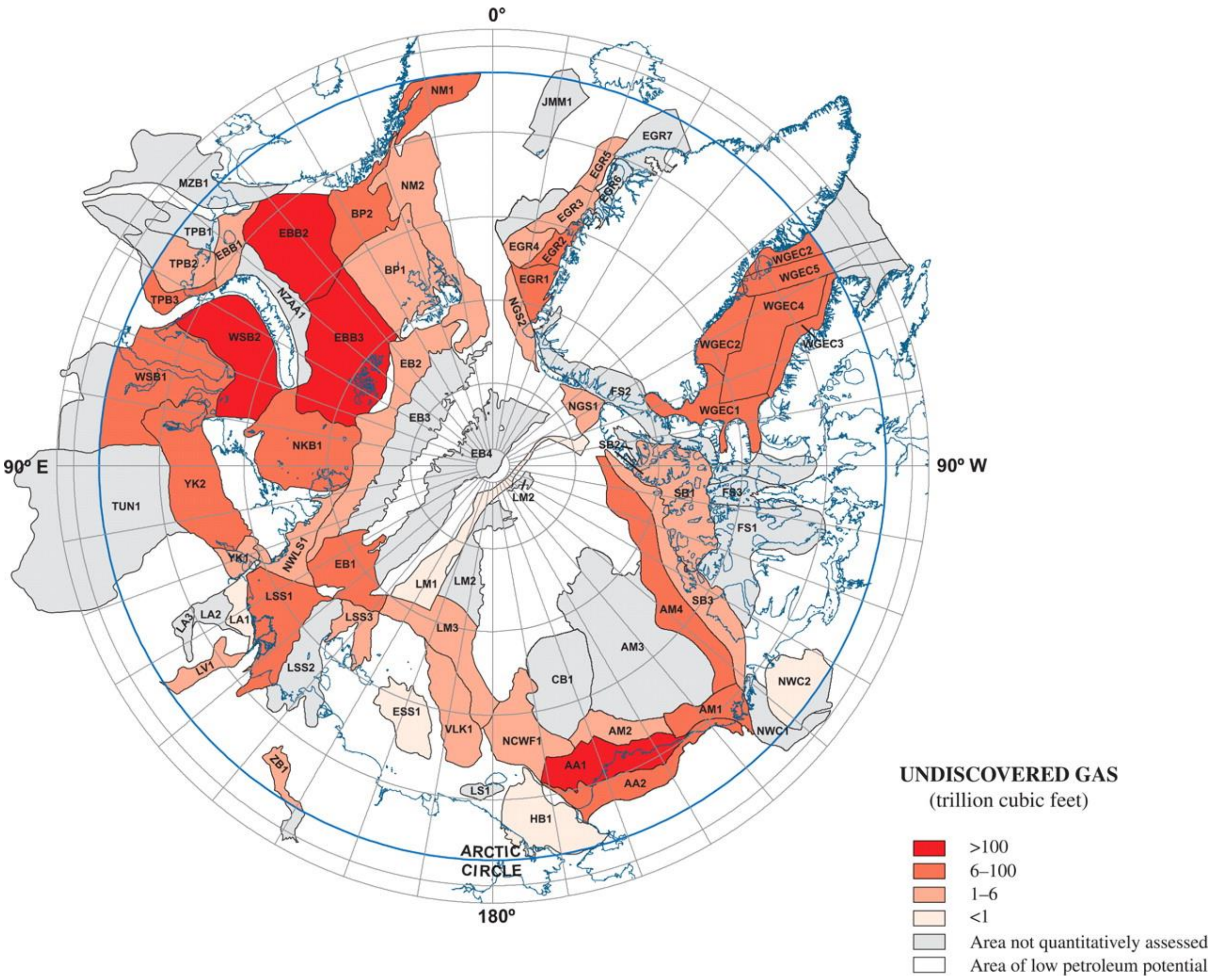


Figure 2: Map showing the Assessment Units of the USGS-CARA, color-coded for mean estimated undiscovered gas. Only areas north of the Arctic Circle are included in the estimates. Source: Gautier et al. 2009.

Building on information from the USGS-CARA, we determine locations for Arctic offshore oil and gas production used for the scenario analysis. Since our focus is on the European Arctic, we concentrate on European Assessment Units, covering a variety of Exclusive Economic Zones (EEZs), step-out distances, and ice conditions as determinants. Given the high potential and probability of the areas, and the fact that these Assessment Units provide the aforementioned variety in characteristics, we cover the Barents Sea (EBB2 and EBB3 in Figure 1 and Figure 2), Kara Sea (WSB2) and the area off West Greenland (WGEC2).

Ice conditions are a major worry and technological driver of offshore developments in the Arctic. Ice conditions include mainly ice concentration and thickness, but also prevalence of icebergs. There are indirect effects of the ice conditions on other environmental factors such as waves, but also on how infrastructure can be deployed, e.g. on icing of structures as well as SAR and oilspill response capabilities. We take into account future ice developments by retrieving information until 2040 from climate models from Phase 5 of the Climate Model Intercomparison Project (CMIP5), based on data used for the IPCC's fifth Assessment Report.[2] To assess the impact of climate change on our results, we analyze two

[2] The analysis and data on climate models were provided by a project partner from ACCESS WP1 (AWI Bremerhaven). For details see (Riemann-Campe et al., mimeo).

Representative Concentration Pathways (RCPs), assuming two different CO_2 concentrations. RCP4.5 describes a concentration of CO_2 equivalents of 650pmm in 2100, RCP8.5 describes a concentration of more than 2100pmm in 2100. For these two carbon concentrations, we calculate the average summer (September) and winter (April) ice concentration and ice thickness in the areas in question for a reduced set of especially well-fitting climate models. Model selection is done by a cost function approach that filters models that are especially good at predicting ice conditions in the locations in questions relative to historical satellite data.

Depending on the potential, step-out distance, bathymetry, and ice conditions of an area, we determine the applicability of two production technologies and oil or LNG shipping via ice-strengthened tankers. Regarding technology choice, we consider autonomous subsea systems as well as Floating Production, Storage, and Offloading (FPSO) units.[3] As it turns out (see Riemann-Campe et al., mimeo), climate change, i.e. the difference between RCP4.5 and RCP8.5 makes largely no difference for the production decision and technology choice in the regions in question.

3. Methodological approach to assess economy-wide impacts

Economic models can help assessing the potential economic impact of future Arctic energy supply. However, existing models of energy markets often have a national focus with a limited representation of international markets. A full understanding of energy supply and demand and the effect of changes is impossible without understanding the international market for energy. In order to obtain insights on global economic impacts, partial and general equilibrium models can be used. Partial equilibrium analysis focuses on the sector directly affected by changes, for example a policy measure or new sources of production previously unaccounted for, assuming that the rest of the economy is not affected. General equilibrium models consider other sectors and regions as well to determine the economy-wide effect. Partial equilibrium models tend to have more detail regarding the market in question, while general equilibrium models tend to be more comprehensive, both spatially and in terms of economic sectors.

We use two models to assess the economy-wide impact of Arctic energy supply, namely the partial equilibrium model COLUMBUS and the computable general equilibrium (CGE) model DART.

For our analysis on the economy-wide impacts of Arctic gas, we link both models to be able to combine the respective strengths of both the partial equilibrium approach of COLUMBUS and the general equilibrium approach of DART. We use COLUMBUS in order to model natural gas production and trade in great detail, including location-specific production and mode-specific trade, i.e. differentiating between pipeline and LNG trade. Also endogenous investment can be modelled more realistically in COLUMBUS, which is especially important in the Arctic Ocean, where most conceivable projects are still at most in the exploration phase. We use DART to model, among other things, overall economic activity and repercussions on up- and downstream sectors, substitute fuels, international linkages

[3] We rely on information from ACCESS partner IMPaC, an independent engineering and consultancy company, for an analysis of the suitability and cost structure for the two technologies (see IMPaC 2012). The cost structure estimates used as an input here for new facilities in the Arctic can be found in Table 6 and Table 8.

through factor movements and trade in goods other than natural gas as well as CO_2 emissions. For our analysis on the economy-wide impacts of Arctic oil we use the DART model only. This is, on the one hand, dictated by data restrictions regarding detailed and comprehensive oil market data. On the other hand, the oil market is less complex to model, since it is, contrary to natural gas, a global market with one global price as opposed to regionalized natural gas markets with price differences across regions. For that reason, the depiction of the oil market in DART is sufficient to analyse also intra-market developments.

The following two sections provide more detailed descriptions of both models and the modifications made for the analysis of the economy-wide impacts of Arctic energy.

3.1. Model description COLUMBUS

The COLUMBUS model of the Cologne Institute for Energy Economics (EWI) is a long-run, partial equilibrium model that allows the simulation of different scenarios of the global natural gas market up to 2040, while taking into account global interdependencies. COLUMBUS is designed as a dynamic, spatial, and intertemporal model. The model is supply-based and the basic version aims to meet demand for natural gas at the lowest possible cost. Consequently, the existence of a perfectly competitive natural gas market is initially assumed. Due to the flexibility of mixed-complementary programming, COLUMBUS also allows the strategic behaviour of individual players in the global natural gas markets to be analyzed. Although the model is not a prognoses tool, it enables the analysis of interdependencies within the global natural gas market under consistent modelling conditions.

COLUMBUS maps the spatial structure of the global natural gas market as a network-flow model. Nodes represent production and demand regions, as well as turnover points such as regasification or liquefaction terminals. These nodes are connected by arcs which represent transport routes, e.g. pipelines or naval routes.

On the supply side, the model includes all key gas-producing countries (accounting for more than 95 % of global natural gas production) as well as their specific supply characteristics (e.g. production costs of various extraction sites, reserves, connection to infrastructure, etc.). COLUMBUS also endogenously optimizes investments in natural gas infrastructure capacities, i.e. investments in additional production, transport and storage capacities.

The demand-side modelling includes all key demand countries. In some countries, fixed demand levels are replaced by a price-elastic demand function. For this study, a semi-annual resolution has been used. The model can alternatively be run using a monthly resolution in order to account for seasonal fluctuations in natural gas demand.

The so-called ‘exporters’ establish a trading relationship between the production and demand regions. Apart from the global gas trade, the exporters must also identify the efficient physical transport path while competing with other exporters for transport infrastructure. Exporters are either modelled as competitive or strategic player.

Model results include trade flows (pipeline or LNG), marginal supply costs (price estimates assuming perfect competition) or prices determined by strategic behaviour (assuming market power). The levels of investment in production sites transport and storage infrastructures are calculated, and a geographic distribution of investments is also generated. Furthermore, options for the future utilization of the natural gas market infrastructure (e.g. storage, pipelines, LNG-terminals) can be evaluated. More detailed information about the COLUMBUS model can be found in Growitsch et al. (2013).

For the ACCESS project, the COLUMBUS model was fed with investment and production cost data from IMPaC (IMPaC 2012). This data gives detailed information for several types of production technologies as well as for different liquefaction terminals. Also, the opportunity to ship LNG via the Northern Sea Route during four ice-free months a year has been included in the model. In the model infrastructure capacity is exogenously specified until 2018 to reflect a realistic development of production, transportation, storage, and LNG-related assets based on existing information. For this purpose, information on the year of commissioning as well as on capacity of gas infrastructure assets is taken from the International Energy Agency (IEA), the International Group of Liquefied Gas Importers, and other sources (more details are provided in the next sectio). After 2018, COLUMBUS endogenously invests in infrastructure assets (production facilities, pipelines, LNG terminals, storages) whenever this is economically rational given capacity restrictions.[4] The endogenous investment calculus is incorporated into the modelling framework to compensate for the lack of reliable information on infrastructure development from 2018 onwards.

3.2. Model description DART

The Dynamic Applied Regional Trade (DART) Model of the Kiel Institute for World Economics (IfW) is a recursive-dynamic computable general equilibrium (CGE) model of the world economy that was originally designed for the analysis of international climate policies[5]. The first version of DART was developed in the late 90's and has since then been applied to analyse international climate policies (e.g. Springer 1998; Klepper and Peterson 2006a; Weitzel et al. forthcoming), environmental policies (e.g. Weitzel et al. 2012), energy policies (e.g. Klepper and Peterson 2006b), technology transfer (Hübler 2011) and agricultural and biofuel policies (e.g. Kretschmer et al. 2009) among others. In the following we shortly present the current version of the DART model used for this analysis. For a more detailed description of the basic core of the DART model see Klepper et al. (2003).

The DART model is written in the mathematical programming language GAMS/MPSGE (Rutherford, 1999) and it is based on the GTAP8.1 data from the Global Trade Analysis Project (Narayanan et al. 2012) which represents the global economy in 2007 and covers 57 sectors and 134 regions. Sectors and regions are aggregated/extended depending on the question at hand. The version of the DART model used here has 23 regions, 15 sectors and 4 factors of production (see below for more details).

The economy in each region is modelled as a competitive economy with flexible prices and market clearing conditions. The dynamic framework is recursively-dynamic meaning that the evolution of the economies over time is described by a sequence of single-period static equilibria connected through capital accumulation and changes in labour supply. The economic structure of DART is fully specified for each region and covers production, investment and final consumption by consumers and the government. Primary factors are labour, capital natural resources and land.

[4] Investment in infrastructure takes place if the investment costs for the respective infrastructure asset are smaller than the expected economic benefits gained by the investment during the asset's economic lifetime.

[5] For a detailed description of the DART model see www.ifw-kiel.de/academy/data-bases/dart_e

Production

Producer behaviour is characterized by cost minimization for a given output. All industry sectors are assumed to operate at constant returns to scale. The nesting structure is differentiated for non-fossil fuel industry sectors and fossil fuel generating sectors. For the non-fossil fuel industries, a multi-level nested separable constant elasticity of substitution (CES) function describes the technological possibilities in domestic production between intermediate inputs on the one side and a primary-factors-energy aggregate on the other side (see Figure 3). The intermediate inputs are combined of non-energy domestic and imported inputs that have fixed input coefficients. The primary-factors-energy aggregate combines land (only for the agricultural sectors) with a capital-labour-energy (KLE) aggregate through a CES function. The KLE aggregate is a CES function of an energy aggregate and the capital and labour (VA) that are also combined in a CES function. Inside the energy aggregate, substitution is possible between electricity and fossil fuels.

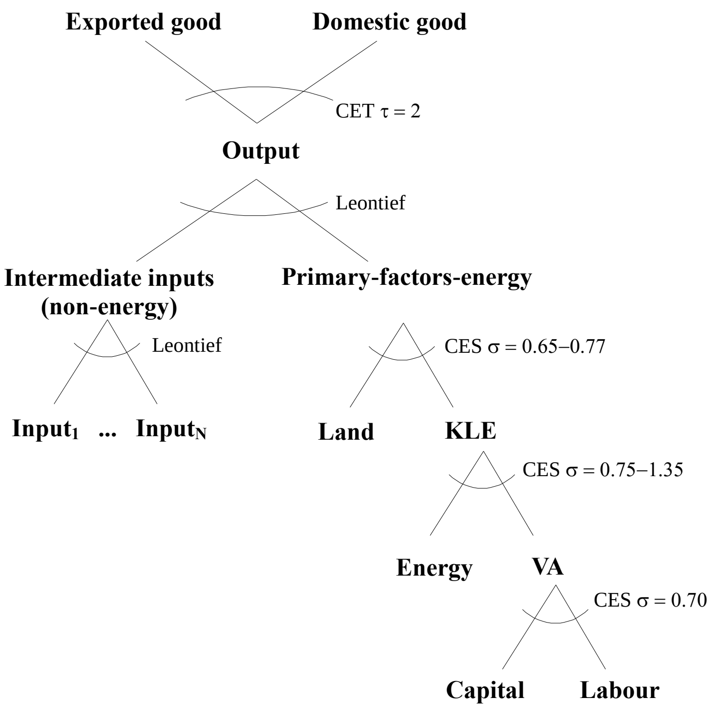


Figure 3: Production structure of non-fossil fuel industries

The fossil fuels gas, coal and crude oil are each produced of specific, fixed natural resources, and a macro aggregate of all other intermediate inputs and primary factors (see Figure 4). The elasticity of substitution between the specific natural resource and the macro aggregate of other inputs determines the elasticity of supply (see e.g. Boeters and Bollen 2012 for the relationship between the elasticity of supply and the elasticity in the CES production function). These elasticites are chosen in such a way that the carbon emissions in 2035 resulting from the model in the business as usual scenario meet the latest projections of the World Energy Outlook (IEA 2013a).

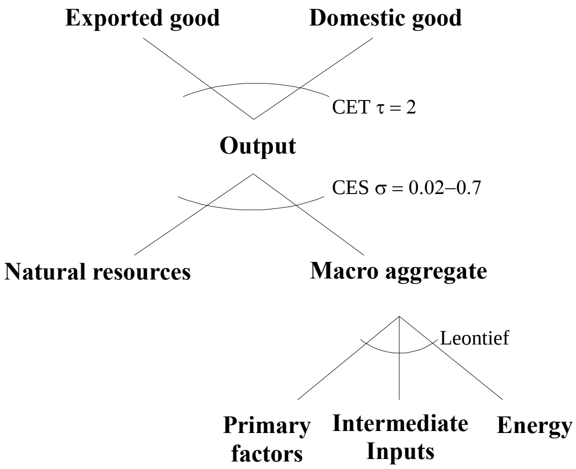


Figure 4: Production structure of fossil fuels (gas, coal, oil)

The electricity sector consists of several technologies that are modelled as perfect substitutes. Besides the traditional electricity generation from fossil fuels (coal, gas, oil) and nuclear power, there are four renewable technologies (wind, solar, hydro and solid biomass). The renewable technologies provide electricity that is perfect substitute to (traditional) fossil fuel electricity, but at a higher cost. Therefore, in the short run subsidies are needed to make renewable electricity generation competitive with fossil fuel electricity. The subsidy rates are calculated such that the share of renewable energy production in the base year is reached. For more details see Weitzel (2010).

A graphical representation of the production function of renewable electricity is shown in Figure 5. Similar as in the sectors for fossil fuels, a fixed factor (interpreted as a capacity constraint in natural resources or knowledge needed as input) enters the production function. In any given year, there are hence decreasing returns to scale in the renewable energy sectors as the fixed factor is becoming scarcer and substitution away from the fixed factor requires additional other inputs Weitzel (2010). Learning by doing however reduces the cost of renewable electricity relative to conventional electricity over time.

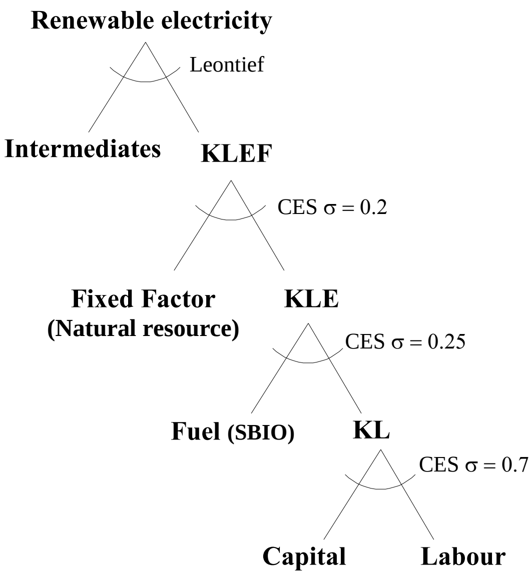


Figure 5: Production structure of renewable electricity

To model the economic impacts of future Arctic energy supply, two new sectors have been added to the standard DART model and database: Arctic gas and Arctic oil. These sectors are produced exclusively by Norway, Denmark and Russia. The gas and oil produced in the Arctic are perfect substitutes of the gas and oil produced by conventional technologies and have identical nested CES production structure. However, there are differences in their cost structures (see Table 6 and Table 8 in Sections 6 and 11 below). The extraction of gas and oil from the Arctic is relatively more expensive and depends on the technology used, the expected stock of the specific natural resource and regulations on the production process. To overcome part of the uncertainty on the future Arctic energy supply, we run several scenarios assuming different extraction technologies and production levels. Based on IMPaC 2012 we assume two different technologies, which differ mainly on the weights assigned to capital and variable costs: FPSO technology (Floating Production, Storage, and Offloading Facility) and subsea technology (see Section 2). Similar to conventional fossil fuels, the elasticities of supply of Arctic gas and oil are adjusted during the calibration process to match the expected regional production in accordance with the COLUMBUS model (see Section 3.3).

With the exception of Snøhvit, gas and oil production from the Arctic is not observable. In fact, even though the technology to produce Arctic gas and oil exists, these technologies are inactive in the calibration year (2007) because their production costs are higher than the market price. In DART, this is reflected in the fact that a production function for these activities is specified, yet the level of activity is zero as the activity would generate negative profits (Böhringer and Rutherford, 2008). Such technologies are called latent technologies and could become active at a later stage through changes in relative input or output prices, as well as through policy incentives. We use this approach that clearly fits to the Arctic energy production. Thus, we define a mark-up between the production costs Arctic gas/oil relative to the conventional cost of producing gas/oil. This mark-up factor has a central role determining the level of Arctic gas and oil production.

An investment good is produced in each region using fixed shares of the different intermediate inputs. The investment good is not sector specific and does not require primary factors. Produced goods are directly demanded by final consumers (comprising regional households and governments), other industries, the export sector and the investment sector.

Consumption

In each region, a representative household, that comprises private households and the government sector, receives all income generated by providing primary factors to the production process. After deducting taxes and savings, the disposable income is used for maximizing utility by purchasing goods. The final consumer decides between different primary energy inputs and non-energy inputs depending on their relative price in order to receive its consumption (utility) with the lowest expenditures. Consumption is modelled as a linear expenditure system (LES) with Stone-Geary preferences. First, consumption covers a subsistence share, which is determined by the relative income elasticities (taken from GTAP data) for the demand of the various goods. The expenditure function for the remaining consumption is a Cobb-Douglas function of energy and non-energy inputs. In each period, a fixed share of income is saved; the savings rate is held constant at the observed 2007 rate except for China where we assume a decreasing rate over time.

Factor markets

Factor markets are perfectly competitive and full employment of all factors is assumed. Labour is assumed to be a homogenous good, mobile across industries within regions but internationally immobile. Similarly, capital is also inter-sectorally but not internationally mobile. Regional capital stocks are given at the beginning of each time period and results from the capital accumulation equation. In every time period they earn a correspondent amount of income measured as physical units in terms of capital services. Specific natural resources are used for the production of coal, gas (conventional and Arctic) and oil (conventional and Arctic) as well as for renewable electricity generation.

Foreign trade

The world is divided into 23 economic regions (see Section 14.2), which are linked by bilateral trade flows. All goods are traded among regions, except for the investment good. Following the proposition of Armington (1969), domestic and foreign goods are imperfect substitutes, and distinguished by country of origin. Import demand is derived from a three stage, nested, separable CES cost of expenditure function respectively and distinguishes between imported and domestically produced goods as well as between the country of origin. On the first level domestic goods substitute with imports. On the second level the imports of different regions are aggregated. The imports of one region r are equivalent to the exports of all other regions into that region r including transport. Transport costs, distinguished by commodity and bilateral flow, apply to international trade but not to domestic sales. The exports are connected to transport costs by a Leontief function on the third level. International transports are treated as a world-wide activity which is financed by domestic production proportional to the trade flows of each commodity. There is no special sector for transports related to international trade.

On the export side, the Armington assumption applies to final output of the industry sectors destined for domestic and international markets. Here, produced commodities for the domestic and for the international market are no perfect substitutes. Exports are not differentiated by country of destination.

CO2 emissions

The use of energy in production and consumption leads, depending on the energy source, to different amounts of carbon dioxide emissions. The release of large amounts of CO_2 to the atmosphere increases the CO_2 concentrations in the atmosphere and plays the main role in the greenhouse gas effect. Carbon dioxide emissions are modelled in DART. However, other greenhouse gas emissions and sinks are not accounted for. The CO_2 data for the base year is taken from the GTAP database.

In the business as usual scenario, the DART model is calibrated in such a way that the carbon dioxide emissions in 2035 resulting from the model match the latest projections of the World Energy Outlook (IEA 2013a).

Dynamics

The DART model is recursive-dynamic, meaning that it solves for a sequence of static one period equilibria for future time periods connected through capital accumulation and changes in labour supply. The dynamics of the DART model are defined by equations which describe how the endowments of the primary factors capital and labour evolve over time. The major driving exogenous factors are changes in the labour and capital supply. In addition, there is autonomous energy efficiency improvement (AEEI), which is assumed to be 1% per year (except for the electricity sector, where it is 0.1%). The DART model is recursive in the sense that it is solved stepwise in time without any ability to anticipate possible future changes in relative prices or constraints.

Labor supply

The main factors influencing the development of labour supply are population and productivity growth and human capital accumulation. Labour is thus measured in efficiency units which are adjusted in order to match future GDP growth as projected in the OECD Environmental Outlook (OECD 2012). Population growth is taken from United Nations, Department of Economic and Social Affairs, Population Division, Population Estimates and Projections Section (2010).

Capital formation

Current period's investment augments the capital stock in the next period. The aggregated regional capital stock, Kst at period t is updated by an accumulation function equating the next-period capital stock, Kst at t+1 to the sum of the depreciated capital stock of the current period and the current period's physical quantity of investment, Iq(r, t). The equation of motion for capital stock Kst(r, t+1) in region r is given by:

$$Kst(r, t+1) = (1-d) * Kst(r, t) + Iq(r, t)$$

where d denotes the exogenously given constant depreciation rate. According to the GTAP data we set d = 0.04, and we use the same value for all time periods. The allocation of capital among sectors follows endogenously from the intra-period optimization of the firms. The savings behaviour of regional households is characterized by a constant savings rate over time. This rather ad-hoc assumption seems consistent with empirical observable, regional different, but nearly constant savings rates of economies, which adjust according to income developments over very long time periods. Additionally, a wide range of empirical evidence in macroeconomic literature rejects the theoretically elegant permanent income hypothesis and shows that a huge fraction of the consumption decisions are based entirely on current after tax income.

Regional aggregation

The 134 regions in the original GTAP database have been aggregated to 23 regions shown in Section 14.2. As the focus of the model is to assess the economic impacts of the future Arctic energy supply, the main gas and oil producers in the region are clearly identified: Norway, Denmark and Russia. Some European countries are also modelled in more detail in order to analyse the impact of the Arctic resources on their economies and consumption decisions. The remaining regions are selected according to common economic and geographic structures.

Sectoral Aggregation

For the ACCESS project, the energy sector is modelled with great detail. Besides the production of conventional fossil fuels (coal, gas, oil), two new sectors are introduced in the model: Arctic gas and Arctic oil. Different technologies regarding the future production Arctic gas and oil are assessed through scenario analysis as explained above. In addition, we have chosen a model version with a relatively detailed electricity sector. Besides the traditional electricity generation from fossil fuels (coal, gas, oil) and nuclear power, there are four renewable technologies (wind, solar, hydro and solid biomass). The main industries related to the energy sector are also modelled in more detail: refined oil products, chemical products and energy intensive industries. The remaining sectors comprise agriculture, transport, manufacturing and services (see Table 1).

Table 1: Sector aggregation in DART

Sectors
Coal
Gas

Arctic gas
Oil
Arctic oil
Electricity
Refined oil products
Chemical products
Energy intensive industries
Agriculture
Mobility/Transport sector
Other light industries
Other heavy industries
Services
(Savings good)

Note: New sectors are highlighted in blue.

3.3. Soft-coupling of COLUMBUS and DART for assessment of the economy-wide impact of Arctic gas supply

In this section we describe how we combine the respective strengths of the two models for the assessment of the economy-wide impact of Arctic gas supply. As mentioned above, the assessment is based a comparison between a reference scenario (up to the year 2040) and several alternative scenarios. These scenarios are driven by assumptions on Arctic production of natural gas, with respect to quantity, production costs, and location (see Sections 5 and 10).

Production capacities of standard FPSO or subsea production units are taken from IMPaC (2012) and directly fed as an exogenous input into COLUMBUS, where data on existing natural gas production is more precise. In COLUMBUS, we assess the general economic viability, i.e. whether fields at our predefined locations can break even in the gas market environment described in COLUMBUS, and project the actual produced quantities for each scenario including the reference scenario. We also analyse gas market-specific outcomes, such as destinations for LNG. To get an assessment of the economy-wide impacts, the produced quantities are fed into DART. In the case of economic unviability, produced quantities are zero and the state of play is described by the reference scenario. Since the data bases of COLUMBUS and DART are different, we chose to convert production quantities into shares in an Arctic country's total natural gas production before feeding them into DART. This way, we ensure that production quantities have the same relevance relative to the rest of the model economy over the two models. Still, some differences between the two models remain, due to the different data bases of the models. The differences are mainly in the adaption path towards the new situation at the end of the modelling period in 2040 and not so much in the final result in the last year of modelling. We describe those differences when describing the scenario outcomes in the sections below.

Part II: The economy-wide impact of natural gas from the Arctic

4. Status quo on Arctic gas production

A decade ago Arctic gas was seen as resource with great market potential. This view has meanwhile changed fundamentally. The occurrence of less expensive and less risky supply sources such as unconventional gas, i.e. shale gas from the United States, have decreased prospects of Arctic gas. Furthermore, the rise in expected Asian demand has urged producers of natural gas to develop or extend facilities closer to these emerging regions. In particular, Russia is currently putting its focus on the construction of (ice-free) LNG-export facilities in Sakhalin and Vladivostok. Gazprom's initial plans in the Arctic (i.e the Shtokman field), in turn, have been declared to remain a project for "future generations".

At present, Arctic gas exclusively comes from the Norwegian Snøhvit production plant and its associated Hammerfest LNG-export facility. In 2016 additional natural gas from the Yamal peninsula (Novatek, Total) will enter the world market via LNG-shipments from Sabetta port. These two production facilities are included in the Reference Scenario. A more detailed description of the Reference Scenario including technical and economic details provided Section 5.

5. The natural gas Reference Scenario

This section gives an overview of the scenarios conducted for this study, describes the most relevant exogenous parameters and summarizes the input data used. After presenting the basic parameters of the Reference Scenario, parameter variations in alternative scenarios are motivated and outlined in detail.

5.1. Assumptions on Arctic natural gas production

The Reference Scenario is a scenario reflecting conservative estimates of Arctic gas production. Hence, we only consider production fields in the Arctic which are supposed to be "certain". By certain, we mean that either the Final Investment Decision (FID) has already been made or the facility is already being used. We thus consider the Norwegian Snøhvit plant and the Russian Yamal LNG-project. The Reference Scenario does not allow for model-endogenous investment for the Arctic fields Yamal and Snøhvit.

Production from the Snøhvit field is transported via a 140 km subsea pipeline to Melkoya Island where the Hammerfest LNG terminal has been constructed to liquefy and export LNG. On Yamal peninsula, in constrast, natural gas from the onshore South-Tambeyskoye field is exported from the nearby Sabetta LNG export terminal.

Table 2 gives an overview of the technical details as well as on commissioning dates for the two projects. While natural gas from Snøhvit has been produced for more than seven years, large-scale gas deliveries from Yamal peninsula are yet to come. Production capacities for both projects have been scaled to LNG-liquefaction capacity since natural gas from both facilities can exclusively be transported via LNG-vessels. To put the liquefaction capacities at the two sites into perspective, total natural gas production in Europe and Eurasia was in

2013 1032.9 bcm, so Snøhvit and Yamal make up less then 3 % of the Europe and Eurasia total in 2013 if producing at full capacity (BP 2014).

We include the production capacity of both facilities exogenously in and assume that investment costs are already paid off. Hence, production at any of these two plants occurs in COLUMBUS as soon as the market price in a connected consumption region exceeds the sum of variable production and transport costs. Corresponding production is then also fed into DART (see Section 3.3).

Table 2: Technology, Capacity and Year of Commissioning

	Technology	Liquefaction Capacity	Year of Commissioning
Snøhvit, Barents Sea, Norway	Subsea Production, LNG-onshore	5.9 (bcm/a)	2007[6]
Yamal, Kara Sea, Russia	Onshore Production, LNG-onshore	22.3 (bcm/a)	2016-2018

Source: COLUMBUS

LNG-tankers departing from the liquefaction terminals can access the same set of regasification terminals in Europe and Asia. In the Reference Scenario we assume that LNG-tankers are able to pass the Northern-Sea Route during four ice-free months a year, based on personal communication with experts from the ACCESS consortium. During this period, for destinations Asia transport costs are lowered by about one third compared to passing the Suez Canal.

Production shares from both plants are bound to specific destinations via long-term contracts (LTCs). Yamal volumes are partly shipped to China (4 bcm/a until 2045) and Spain (3.4 bcm/a) (Novatek 2013 and Gas Natural Fenosa 2013). Since information on the contract period for volumes to Spain is, to our knowledge, not publicly available, a yearly reduction in volumes of 5 % is assumed. Volumes from Snøhvit are bound via long-term contracts to Spain (<2.4 bcm) and the U.S. (<0.5bcm). Taking the 5 % reduction factor into account, by 2020 these volumes will be reduced to 0.38 bcm and 0.05 bcm respectively.

Despite rumours about possible production expansions (e.g. the development of the Askeladd field adjacent to Snøhvit) the COLUMBUS model is not allowed to invest in additional production or infrastructure in any of the two fields in the Reference Scenario. Thus, within the model horizon, production from those fields cannot exceed the quantities bound by the liquefaction capacities presented in Table 2. Likewise, the COLUMBUS model is in the Reference Scenario not allowed to invest in any other Arctic production region such as Shtokman, Greenland, etc. This restriction is based on the assumption that today's gas market offers cheaper and less risky supply options elsewhere, e.g. shale gas in the US.

The following Table 3 contains an overview of the cost structures of the two Arctic facilities included in the Reference Scenario. Yamal development costs are assumed to average Russian production costs in Western Sibiria, Irkutsk, and Sachalin. Production costs are

[6] Note that production of the Snøhvit field did not exceed 0.27 bcm in 2007 (Norwegian Petroleum Directorate 2014).

assumed to amount to 2.5% of development costs. Subsea development and production costs for Snøhvit are taken from the IMPaC cost analysis (IMPaC 2012).

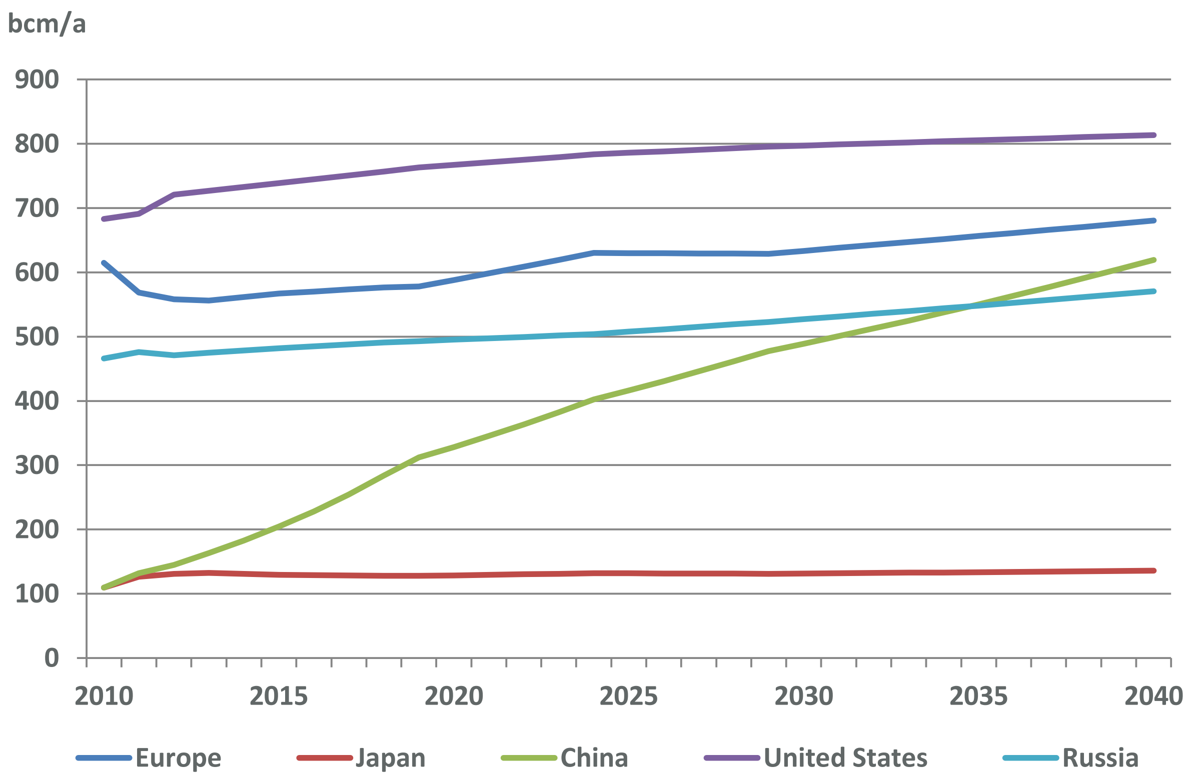
Table 3: Cost Assumptions for Production Plants Snøhvit and Yamal (EUR/kcm/a)

	Development Cost	Production Cost
Snøhvit (Subsea)	1076	8.5
Yamal (Onshore)	498	12.45

Source: Own calculations based on IMPaC 2012.

5.2. Assumptions on future demand for natural gas for some world regions

While demand is endogenously determined in the DART model, the COLUMBUS model determines demand exogenously. Figure 6 depicts expected demand developments in selected countries for the period 2010 to 20140 derived from the World Energy Outlook 2013 ("New Policies Scenario"). China is supposed to experience the strongest increase, namely a fourfold rise from about 160 bcm in 2013 to 620 bcm in 2040. Russia, the United States and Europe all increase their demand by about 100 bcm while Japanese demand remains constant during the period covered.



Source: IEA (2012).

Figure 6: Demand Developments in Selected Countries (bcm): 2010-2040.

5.3. Assumptions on LNG-infrastructure

This section gives an overview over medium-term infrastructure projects which are exogenously fed into the COLUMBUS model. The information is taken from the Medium-term gas market report 2013 (MTGMR, IEA 2013b) as well as from selected company websites.

Figure 6 reports planned (non-Arctic) LNG-infrastructure projects for selected world regions and countries. Within the next years, Australia and the United States are supposed to undertake the most significant investments in LNG-infrastructure with an increase of liquefaction capacity of 48.7 bcm/a and 64.6 bcm/a respectively. Although a number of Russian liquefaction terminals are currently being discussed only the first terminal of the Gazprom Vladivostok project seems to be at a stage that is mature enough in order to be included in the list of terminals. More information on the LNG-terminals in the USA are provided in Table 5.

Table 4: Assumptions on Current and Planned LNG-Liquefaction and Regasification Terminals

	Type	Current (bcm/a)	Planned by 2018 (bcm/a)
Australia	Liquefaction	33.5	+ 48.7
China	Regasification	46.3	+ 22.5
Europe	Regasification	205.5	+ 14.0
India	Regasification	33.5	+ 0
Russia	Liquefaction	13.2	+ 6.8
United States	Liquefaction	0	+ 64.6

Source: COLUMBUS

Since LNG-flows from the USA are expected to considerably affect international trade flows, the subsequent table (Figure 6) reports commissioning data as well as granted annual export quantities for the plants considered. All four LNG-terminals in the USA have been granted to export LNG to non-FTA countries (as of January 2014).

Table 5: Assumptions on Planned LNG-Liquefaction Terminals in the United States

	Approved LNG-Liquefaction Capacity (bcm/a)	Year of Commissioning
Sabine Pass, LA	22.7	2015-2017
Freeport LNG, TX	14	2018
Lake Charles, LA	20	2018
Dominion Cove Point, MD	7.9	2017
USA (total)	64.6	

Source: COLUMBUS

6. Motivation and description of alternative scenarios

In order to test the sensitivity of the results of the Reference Scenario we specify a set of alternative scenarios. This generates a more robust corridor for an assessment of the economy-wide impact of Arctic gas.

For the alternative scenarios, we assume that up to two standard production units with 5bcm capacity (taken from IMPaC 2012) are a realistic development size for a non-developed region. Whether this potential is actually realized, i.e. whether it is economical to invest, is determined by COLUMBUS. In addition, we analyse the effects of additional capacity at existing sites in the Barents and Kara Sea (see section 6.1).

6.1. Scenario 1: "Model-driven investment in existing Arctic locations"

The first alternative scenario allows endogenous model investment in the COLUMBUS model at the Yamal and Snøhvit sites beyond 2018, i.e. the level of additional investment is determined by the model. All other parameters are those of the Reference Scenario.

This scenario not only accounts for published information according to which additional investments at these two sites are intended to take place in the long run. The chosen plants can also be seen as representative for any other investment initiative in the Norwegian Barents Sea and at the Kara Sea. Other than for alternative Arctic locations (as studied in the following scenarios), development costs for additional capacity in the Norwegian Barents Sea and the Kara Sea can be assessed relatively realistically from information already in COLUMBUS. The related development costs are presented in Table 3 above.

The overall aim of this scenario is to analyse the economical rational to expand the already existing plants in the Arctic and to determine the related economy-wide implications of such an investment. We also run a scenario with the more demanding cost assumptions based on IMPaC (2012) for new production sites in the Norwegian or Russian Barents Sea that cannot take full advantage of existing experience with the Yamal and Snøhvit sites. See section 6.3 for details.

While development and production costs can be readily implemented in COLUMBUS, implementation is not as straightforward for DART. Due to the nature of DART being a CGE model, production costs are not expressed in monetary terms, but as inputs from other sectors (in value terms). To express Arctic production costs in DART, we calculate mark-ups on conventional gas production. Production costs in monetary terms for conventional gas production are taken from the COLUMBUS model. Using these mark-ups, we can calculate costs for Arctic gas production by using the input structure of conventional production.

6.2. Scenario 2: "Model-driven investment in Greenland"

This scenario allows for offshore investment in Arctic gas off the Greenlandic coast. It is divided into two sub-scenarios. While Scenario 2a tests the economic viability of FPSO technology (Floating Production, Storage, and Offloading Facility), i.e. a floating production unit with a floating LNG-terminal, Scenario 2b tests the economic viability of an autonomous subsea production facility with onshore liquefaction. In both cases, a standard train of 5 bcm can be added in 2020. This train can then be complemented by a second train of the same size two years later. In both sub-scenarios, the production site is by assumption 100 km off the coast (step-out distance). The following table contains the cost structure for these two technologies. Cost data is taken from IMPaC (2012) and adapted to model conditions. While the subsea technology is characterized by very high upfront costs and relatively low variable costs, the case is reversed for a floating production unit with floating LNG. In addition to the assessment of economic viability we determine the economy-wide implications of this investment scenario.

Table 6: Cost Assumptions for Arctic Offshore Natural Gas

	Development cost (mio. EUR, 20 years lifetime)	Production Cost (mio. EUR/a)
Floating Production and Offloading Unit	5530	490
Subsea Production Facility and onshore LNG plant	7750	528

Note: Numbers assume annual production of 3.6 mt/a. Numbers include shipping and receiving terminal. Numbers are adapted to model conditions before implementation. Source: IMPaC (2012).

As in the case of the “existing locations” scenario, we use the mark-up-based approach described in Section 6.1 to estimate production costs in DART. In order to account for the differing composition of inputs between FPSO, subsea, and average conventional technology, we calculate the mark-ups distinguishing between capital (mark-up calculated based on fixed development costs), labour (mark-up based on variable production costs), and intermediates (mark-up based on a mixed calculation between the two reflecting total cost). Given the different cost-structures between different countries, the mark-ups differ between Norway, Russia, and Greenland.

6.3. Scenario 3: “Model-driven investment in the Russian Barents Sea”

Similar to Scenario 2, this scenario tests first of all whether it is economically reasonable to invest in the Russian Barents Sea and subsequently determines the economy-wide impacts. Like Scenario 2, two production technologies are being tested (floating production with floating LNG as well as subsea production with onshore LNG). The cost structure for each of them is equivalent to those shown in Table 6.

Unlike Scenario 2 the step-out distance is increased to 700 km since gas fields in the Russian Barents Sea (such as the Shtokman field) are farther away from the coast than it is the case for the Norwegian Barents Sea.

6.4. Scenario 4: “Year-round availability of the Northern Sea Route”

In this scenario, we assume that the Northern Sea Route can be used year-around in order to depict lower transportation costs. While in the Reference Scenario, LNG tankers can ship along the Northern Sea route from June to September, this scenario explicitly models enhanced climate change with year-around utilization of the passage. Although such a large change in ice coverage is unlikely in the mid-term, this scenario helps to understand the extent of such drastic Arctic change for world markets. The scenario further assumes endogenous investment opportunity in Greenland.

We concentrate our analysis of this particular scenario solely on the implications for shipping.

6.5. Scenario 5: "Russian embargo"

In this scenario, a Russian embargo is assumed, i.e. gas exports from Russia to countries of the EU are stopped. This includes both pipeline and LNG-exports. In this scenario the Norwegian Barents Sea is added as a possible production site for European LNG in order to provide additional investment options. It is assumed that the facility in the Norwegian Barents Sea is located close to the Snøhvit facility. In total, there are three European gas fields the model can invest in: Greenland, Snøhvit and the Norwegian Barents Sea. Whereas the Snøhvit plant already exists (subsea technology), Greenland and the Norwegian Barents Sea represent greenfield investments (FLNG).

This scenario intends to show whether, under extreme supply shortages, European Arctic natural gas fields are developed or whether European countries will be supplied with LNG from overseas. In addition, we determine the economy-wide implications of this scenario.

6.6. Summary of the Scenario Outline

The following table contains a summary of the scenario outline.

Table 7: Scenario Overview Arctic natural gas

<table>
<tr><th>Scenario</th><th colspan="3">Description</th></tr>
<tr><td>Reference Scenario</td><td colspan="3">Until 2018, infrastructure capacity (production facilities, pipelines, LNG-terminals, storages) is exogenously specified. Investment costs for these capacities are assumed to be already paid off. Beyond 2018, endogenous (i.e. “model-driven”) investments in infrastructure assets are possible except for the production sites Yamal and Snøhvit. It is also assumed that LNG-tankers with destination Asia are able to pass the Northern-Sea Route during four ice-free months a year which is about one third cheaper than passing the Suez Canal. Demand developments in the model are derived from the World Energy Outlook 2013 (“New Policies Scenario”).</td></tr>
<tr><td>Scenario 1</td><td colspan="3">This scenario allows endogenous model investment at the Yamal and Snøhvit sites beyond 2018. All other parameters are those of the Reference Scenario.</td></tr>
<tr><td rowspan="2">Scenario 2</td><td>a</td><td>Floating LNG</td><td rowspan="2">This scenario allows for offshore investment in Arctic gas off the Greenlandic coast. It is divided in two sub-scenarios. In both cases, a standard train of 5 bcm can be added in 2020. This train can then be complemented by a second train of the same size two years later. In both sub-scenarios, the production site is 100 km off the coast. All other parameters are those of the Reference Scenario.</td></tr>
<tr><td>b</td><td>Subsea production facility</td></tr>
<tr><td rowspan="2">Scenario 3</td><td>a</td><td>Floating LNG</td><td rowspan="2">This scenario allows investments in the Russian Barents Sea. Equivalently to Scenario 2, two production technologies are being tested, but step-out distance is increased to 700 km. All other parameters are those of the Reference Scenario.</td></tr>
<tr><td>b</td><td>Subsea production facility</td></tr>
<tr><td>Scenario 4</td><td colspan="3">This scenario models a year-round availability of the Northern Sea Route and an endogenous investment opportunity in Greenland. All other parameters are those of the Reference Scenario.</td></tr>
<tr><td>Scenario 5</td><td colspan="3">This scenario models a Russian embargo, i.e. gas exports from Russia to countries in the EU are stopped. Model-driven investment opportunities include: extension of Snøhvit and the greenfield investments in the Norwegian Barents Sea and Greenland. All other parameters are those of the Reference Scenario.</td></tr>
</table>

7. Economy-wide impact of Arctic gas supply: Results

This section reports the results from our scenario analysis. We start by presenting changes in Arctic gas production between 2015 and 2040, comparing results from the COLUMBUS and the DART model. Next, we study the relevance of changes in Arctic natural gas supply for LNG shipments and the EU's import portfolio based on COLUMBUS model output (Sections 7.2 and 7.3). Finally, we present the economy-wide effects of Arctic natural gas on the EU's economies and beyond, focusing on the impact on GDP and welfare, prices, trade, energy production, other economic sectors, the labour market, and emissions (Sections 0 to 7.11). These findings are based on DART results. In the following we first focus on a comparison between the Reference Scenario and scenarios 1 to 4 before we discuss the results of scenario 5, the Russian embargo (Section 7.12).

For reasons of clarity and in the interest of inter-model consistency, we concentrate on the effects in 2040 when analysing the effect on European economies and beyond. However, in the case of natural gas production results, results for the period 2015 to 2040 are displayed every five years starting with 2015.

7.1. Arctic gas production

7.1.1. Reference scenario ("most likely development")

For a number of reasons and because of the different model philosophies, model setups, and databases, results for COLUMBUS and DART differ. We couple the two models in order to find a compromise between harmonizing production volumes and providing a consistent shock relative to the conditions of each model. For this reason we adapt production numbers in DART attempt to minimize differences in total production volumes and in the shares of Arctic natural gas in total gas production between the two models. Figure 7 and Figure 8 show the produced Arctic natural gas volumes and shares for Norway and Russia from COLUMBUS vis-à-vis DART for the "most likely development" scenario, which we use as the reference we compare any other scenario to. As mentioned in Section 3.3, production capacities in COLUMBUS are exogenously given. For DART, production volumes are converted into shares in total gas production, since the focus is on the interconnection with the rest of the economy. This way, we ensure that production quantities have the same relevance relative to the rest of the model economy across the two models. Still, some differences between the two models remain, due to the different data bases of the models. As Figure 7 and Figure 8 show, the differences are mainly in the adaption path towards the new equilibrium at the end of the modelling period and not in the final result in the last year of modelling. Contrary to COLUMBUS, production in DART does not increase discretely, even though this is the more realistic consumption, as operators try to exhaust the maximum capacity of production units as quickly as possible. DART assumes that production units can be arbitrarily small, leading to a smooth and monotonic development path until roughly the same amount as in COLUMBUS is reached towards the end of the modelling period.

Comparing Figure 7 and Figure 7, Russia has a relatively small share of about 3 % of Arctic gas production compared to the countries' total gas production, where the majority is produced in other regions of the country. Arctic gas production in Norway amounts to around 10 % (Figure 7), but overall gas production is much smaller compared to Russia (Figure 8). As mentioned above, the Snøhvit production facility went online already in 2007, while Yamal start producing only after 2016. This is reflected in the output of the two models.

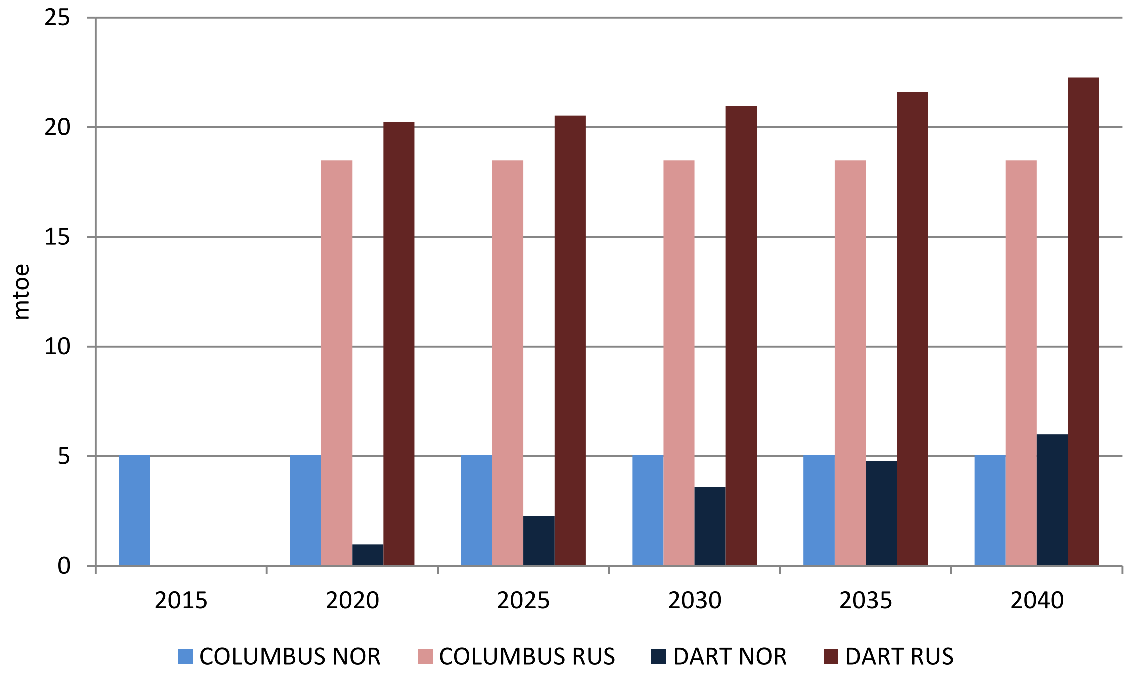


Figure 7: Arctic gas production in Russia and Norway (Reference Scenario) (mtoe). Source: Own presentation based on model results.

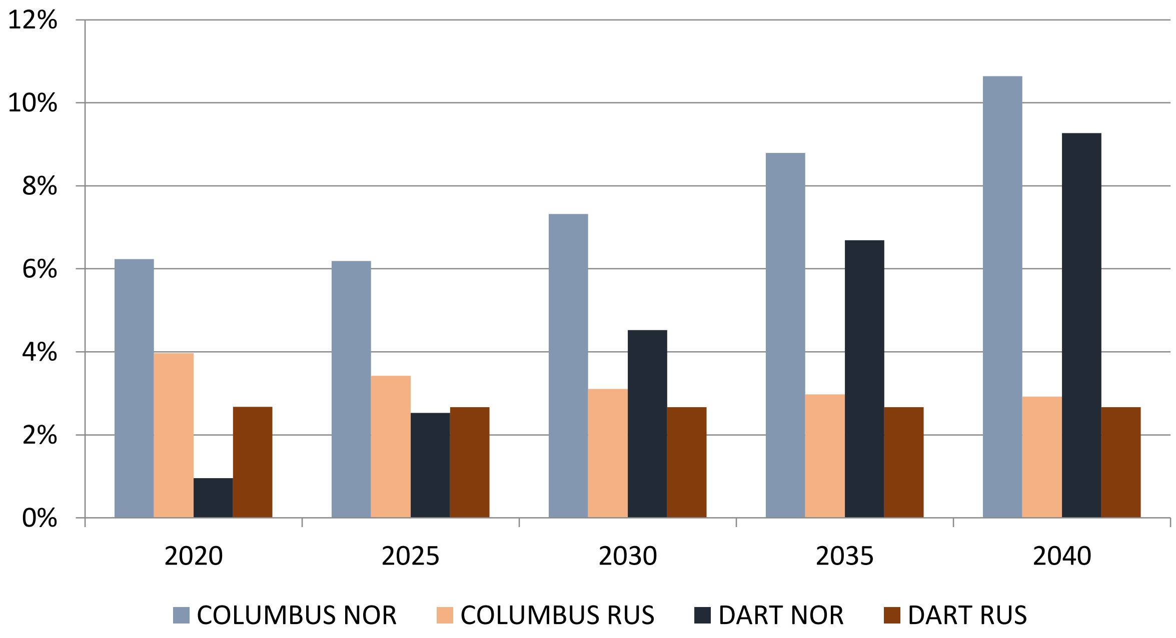


Figure 8: Share of Arctic natural gas in a country's total gas production for Norway and Russia (Reference Scenario). Source: Own presentation based on model results.

7.1.2. Scenario 1 ("Model-driven investment in existing locations")

Allowing model-endogenous investment to expand production units at Snøhvit (NOR) and Yamal (RUS) increases gas production as presented in Figure 9. Production at Snøhvit increases steadily, until in 2040 production has increased by more than 5 mtoe compared to the Reference Scenario (COLUMBUS numbers). Production at Yamal increases even further by more than 20.1 mtoe compared to the Reference Scenario in 2040.

The two models show differences in the adaptation path. In general, changes in production from the COLUMBUS model which provides a more detailed representation of the natural gas market are smaller compared to the results of the DART model.

The model results suggest that it is economically rational to expand the two existing production plants in the Arctic. This is in line with announcements from Novatek according to which production capacities are planned to be considerably enlarged in the next decade (Hodyakova, 2013).

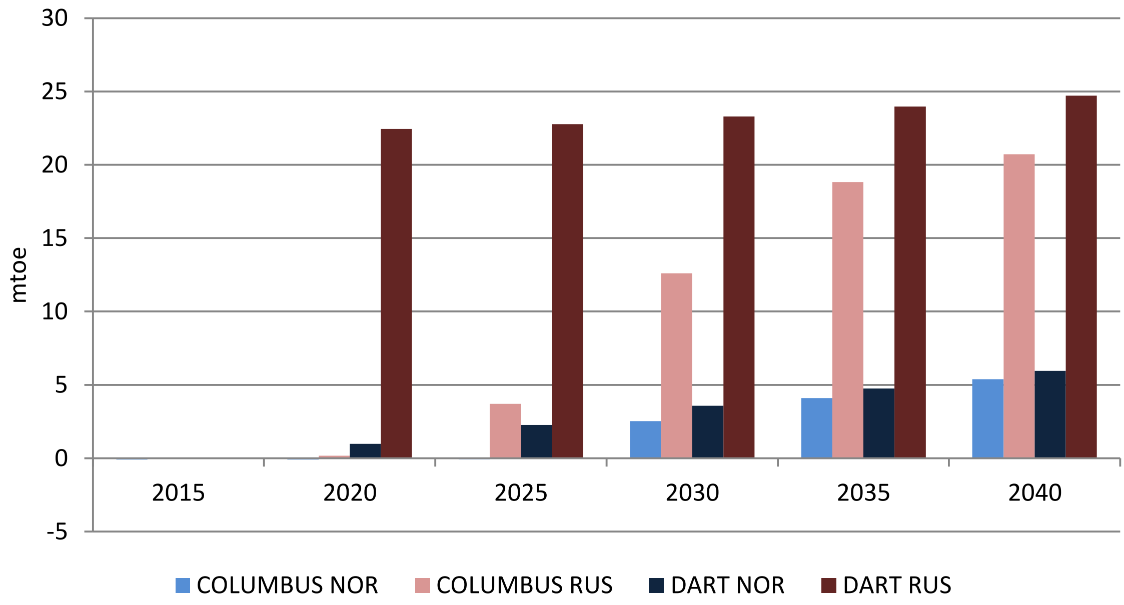


Figure 9: Change in Arctic production at existing locations (Scenario 1) compared to Reference Scenario (mtoe). Source: Own presentation based on model results.

7.1.3. Scenario 2 ("Model-driven investment in Greenland")

Allowing investments in Greenland the facility would be going into production, irrespective of the production technology (Figure 10 and Figure 11). Comparing Figure 10 and Figure 11, production numbers do not differ between subsea and FPSO technology.

Assuming a discovery of natural gas off the coast of Greenland that would allow a start of production in 2020 both models project a relatively quick increase in production in the first years of operation to full capacity; the second train is installed already in 2022. Here, the two models agree more or less on the production path. Arctic gas production in Norway and Russia is not significantly affected.

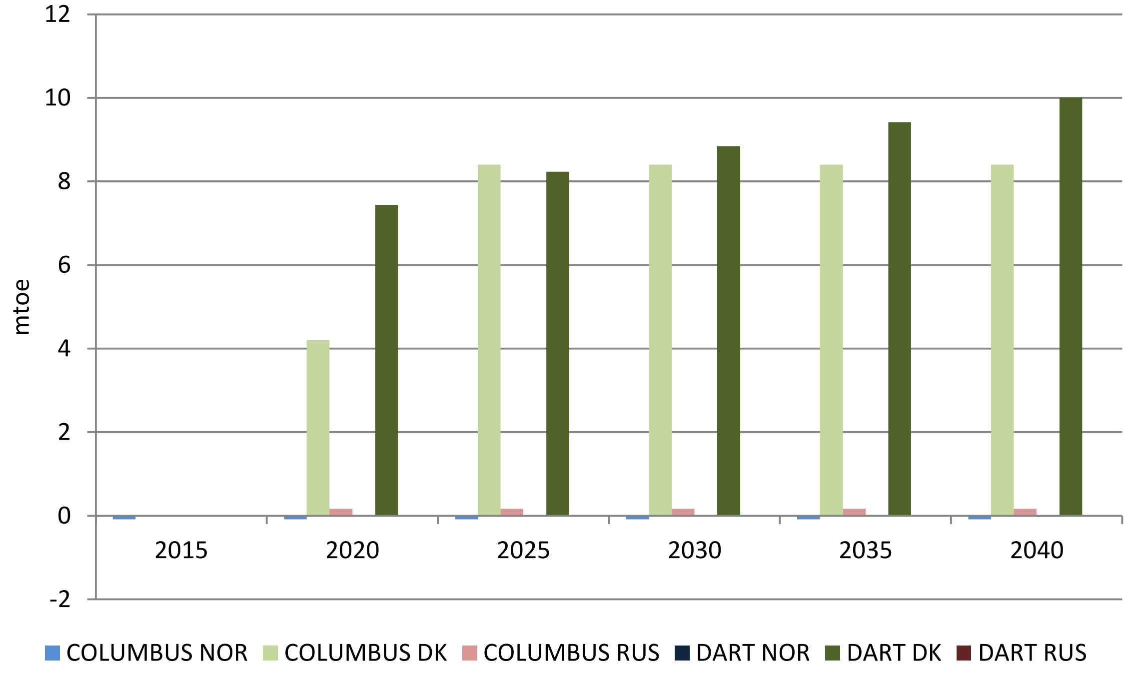


Figure 10: Change in Arctic gas production at existing locations and Greenland (Scenario 2a; subsea) compared to Reference Scenario (mtoe).
Source: Own presentation based on model results.

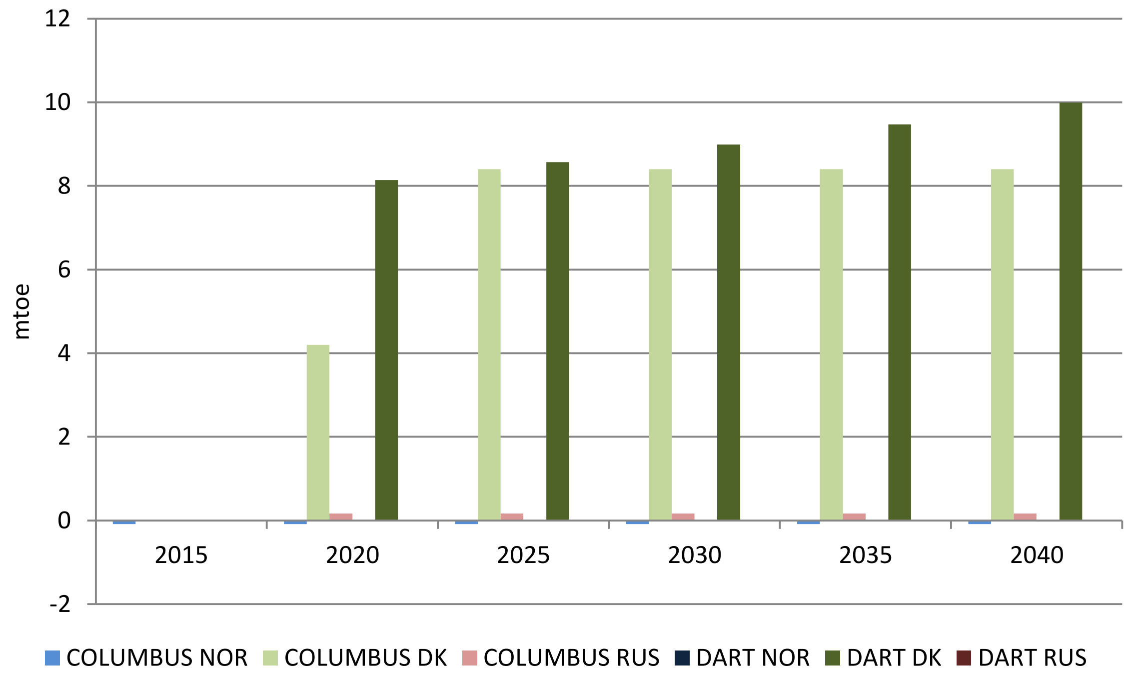


Figure 11: Change in Arctic gas production at existing locations and Greenland (Scenario 2b; FPSO) compared to Reference Scenario (mtoe).
Source: Own presentation based on model results.

7.1.4. Scenario 3 ("Model-driven investment in the Russian Barents Sea")

Similar to Scenario 2, this scenario intends to test the economic viability of production facilities for Artic natural gas in the Russian Barents Sea, again differentiating between two production technologies to invest in. Unlike for Greenland, however, no model-driven investment takes place. According to results of the COLUMBUS model, it is economically not rational to invest in production facilities in the Russian Barents Sea. This can be explained by two facts. First of all, the assumed step-out distance is a lot larger (700 km), hence investment costs are higher compared to production facilities in Greenland. Second, the assumed shipping distances to European LNG-terminals exceed those assumed for Greenland. In the following, we will, therefore, omit this scenario from further analyses on the economy-wide impact of Arctic natural gas supply.

Overall, our results confirm the missing business case for projects like "Shtokman".

7.1.5. Scenario 4 ("Year-round availability of the Northern Sea Route")

In this scenario, a year-round availability of the Northern Sea Route (NSR) is modelled as one consequence of accelerated climate change. Our results show that the permanent navigability of the sea passage does not significantly increase traffic on this route. Volumes shipped from Snøhvit and Yamal to Asia increase by 1.4 % in 2025 compared to the Reference Scenario. Numbers for the other years are even lower. This can be mainly explained by the fact that nearly all volumes which are not bound by LTC to Europe are already shipped to Asia in the Reference Scenario. Thus, a shorter transport route does not lead to an increase of these volumes. Also production from Greenland is unaffected, as volumes and destinations from Greenland do not significantly differ from Scenario 2. Year-round availability of the NSR has, according to our results, no effect on the economic viability of additional natural gas projects in the Norwegian or Russian Barents Sea. For this reason we omit this scenario from further analyses on the economy-wide impact of Arctic natural gas supply.

7.2. Destinations of Arctic LNG

7.2.1. Reference scenario ("most likely development")

Figure 12 reports production volumes and the recipient pool of Arctic gas from Yamal and Snøhvit for the years 2015 to 2040, as modelled in COLUMBUS. The coloured bars indicate the share each destination receives. The total volume amounts to 6 bcm for Snøhvit and 22 bcm for Yamal.[7] These numbers correspond to the liquefaction capacities outlined in Table 2 (Section 5.1), indicating that COLUMBUS assumes both plants to be operating at full capacity during the entire time period analysed (i.e. an utilization rate of 100 %). The volumes do not increase beyond the predefined LNG-liquefaction capacities since the model is not allowed to invest endogenously (for the impact of endogenous investment, see Scenario 1, "existing locations", Section 7.2.2).

Compared to non-Arctic LNG-liquefaction terminals, the portfolio of receiving countries of Arctic LNG is relatively small. While in 2020, 69 % of all Artic volumes are shipped to Europe, volumes beyond 2030 are exclusively transported to Asia. This can be explained by changes in the profitability of selling natural gas to Asia. Due to the strong increase in demand, natural gas is becoming an even scarcer resource in this region (see Figure 6). In the long run,

[7] Note, that in the Reference Scenario, production capacities are exogenously determined.

volumes from Yamal are exclusively exported to China, while volumes from Snøhvit are shipped mainly to Korea and Japan.

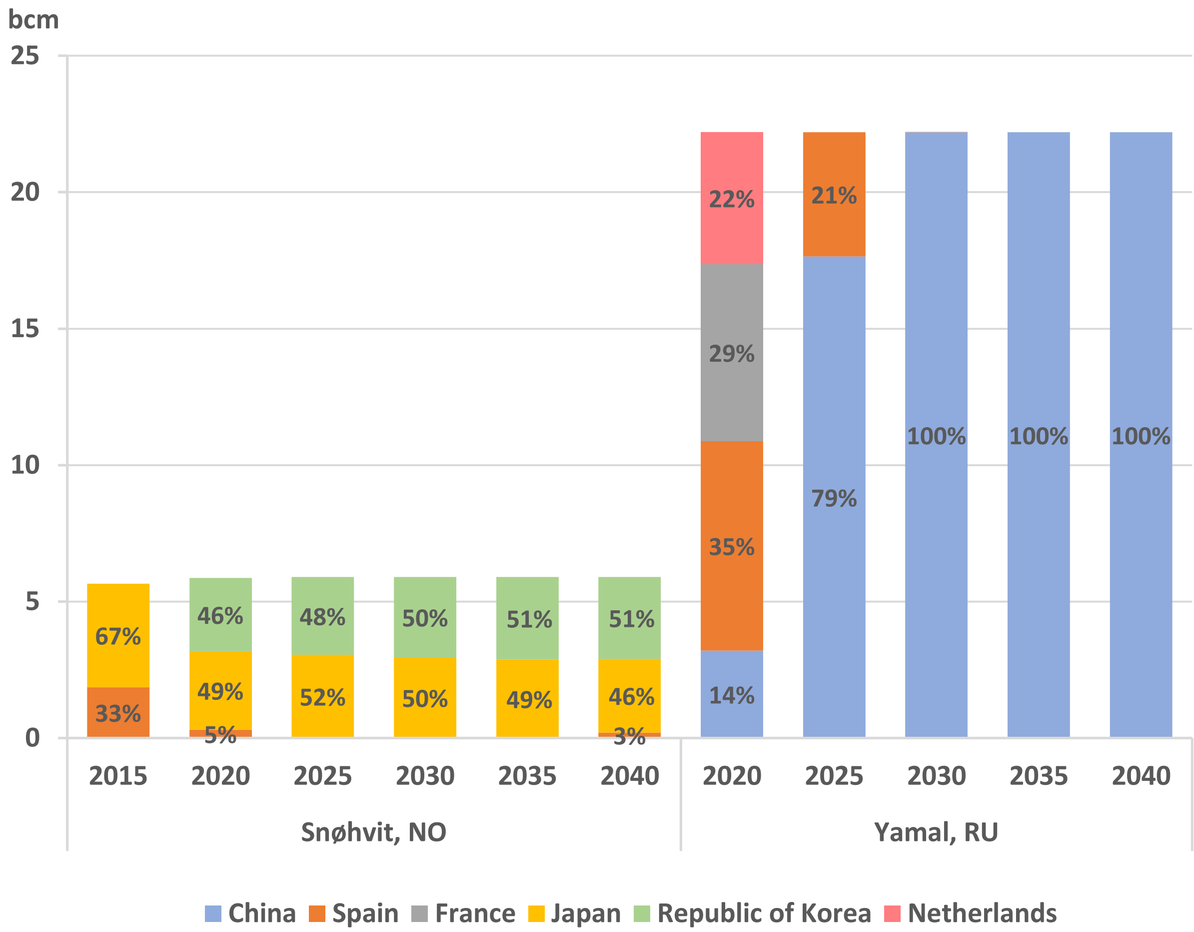


Figure 12: Destinations of Arctic LNG in the Reference Scenario
Source: Own presentation based on COLUMBUS model results.

When interpreting the results, it needs to be taken into account that in some cases, the receiving countries are predetermined by the existence of long-term contracts (LTCs). From 2025 onwards, volumes from Yamal to China exceed the 4 bcm/a fixed by the respective LTC. This demonstrates that this LTC is non-binding and volumes would have been transported to China in absence of the contract, too.[8] In contrast, contracts enforcing the delivery of volumes to Spain beyond 2030 are economically not rational in the sense that producers would like to deliver elsewhere in the absence of a contract, and represent thus a binding constraint. We elaborate on the role of long-term contracts in Section 7.4 below.

7.2.2. Scenario 1 ("Model-driven investment in existing locations")

Figure 13 reports the destinations of Arctic LNG for the case when model-driven investment in existing Arctic locations is possible. As increasing production volumes over time indicate, it

[8] A long-term contract is classified as "binding" if it was not economically rational to trade these volumes in the absence of this contract. If the same trade would take place in absence of the contract, the contract is classified as "non-binding".

is economically rational to expand existing Arctic LNG and production. According to the model results, both facilities double their production and liquefaction facilities by 2040. Qualitatively, the picture does not change, i.e. volumes are primarily sent to Asia in the long run. Higher production from Yamal only marginally increases the volumes shipped to Europe compared to the Reference Scenario.[9] Volumes to China, however, increase tenfold between 2020 and 2030 (from 3.2 bcm to 35.8 bcm).

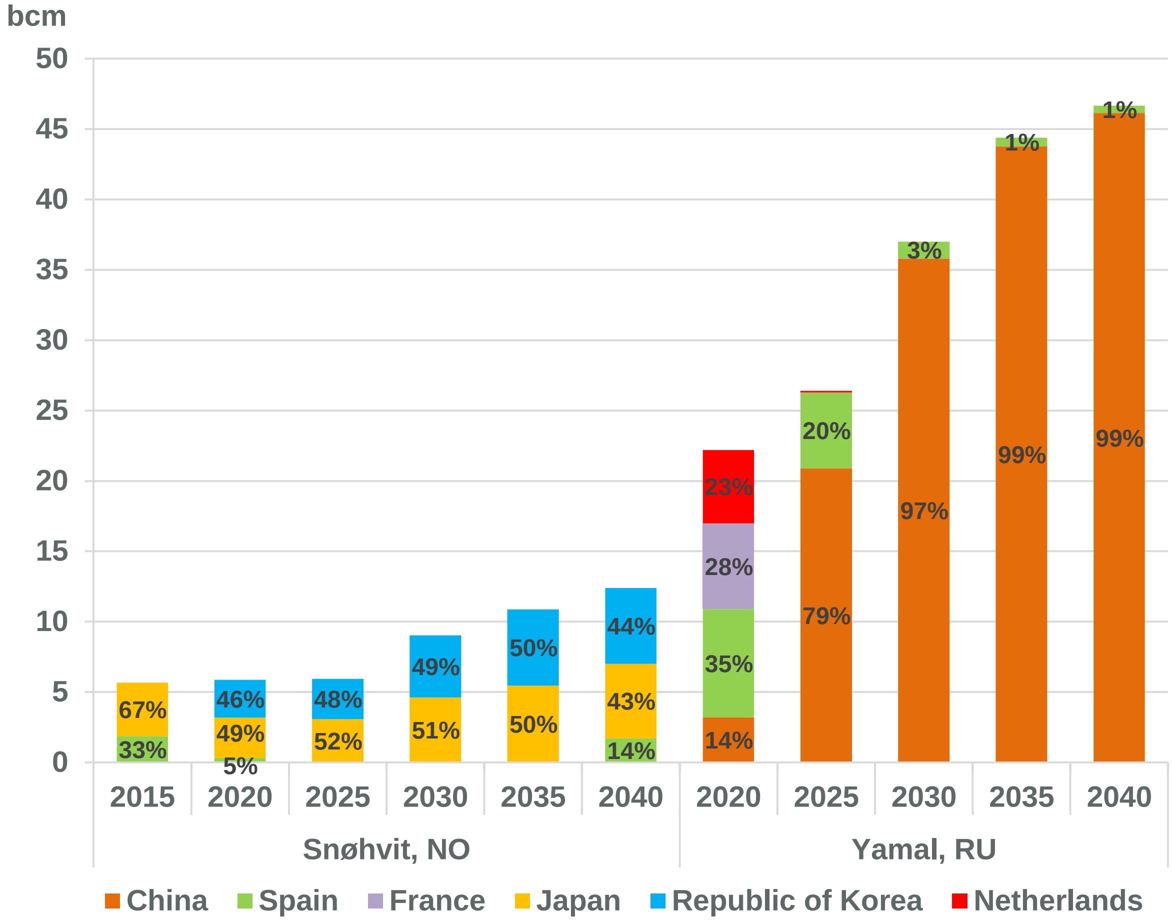


Figure 13: Destinations of Arctic LNG (Scenario 1; bcm).
Source: Own presentation based on COLUMBUS model results.

7.2.3. Scenario 2 (“Model-driven investment in Greenland”)

The results presented above (see Section 6.1.2) indicating that, despite differences in costs, it would be economically rational to develop Greenlandic gas production with any of the proposed technologies. The results presented in Figure 6 show for either technology that at any point in time, production capacity is fully utilized. Unlike Snøhvit and Yamal, Greenlandic volumes are exclusively shipped to Europe, largely to Poland and the Netherlands. In Poland, Greenlandic volumes replace supply from the United States whereas in the Netherland Greenlandic volumes replace supply from African countries and Qatar.

[9] In the Reference Scenario in 2025, 4.5 bcm are sent to Spain. In Scenario 1, this number increases to 5.4.

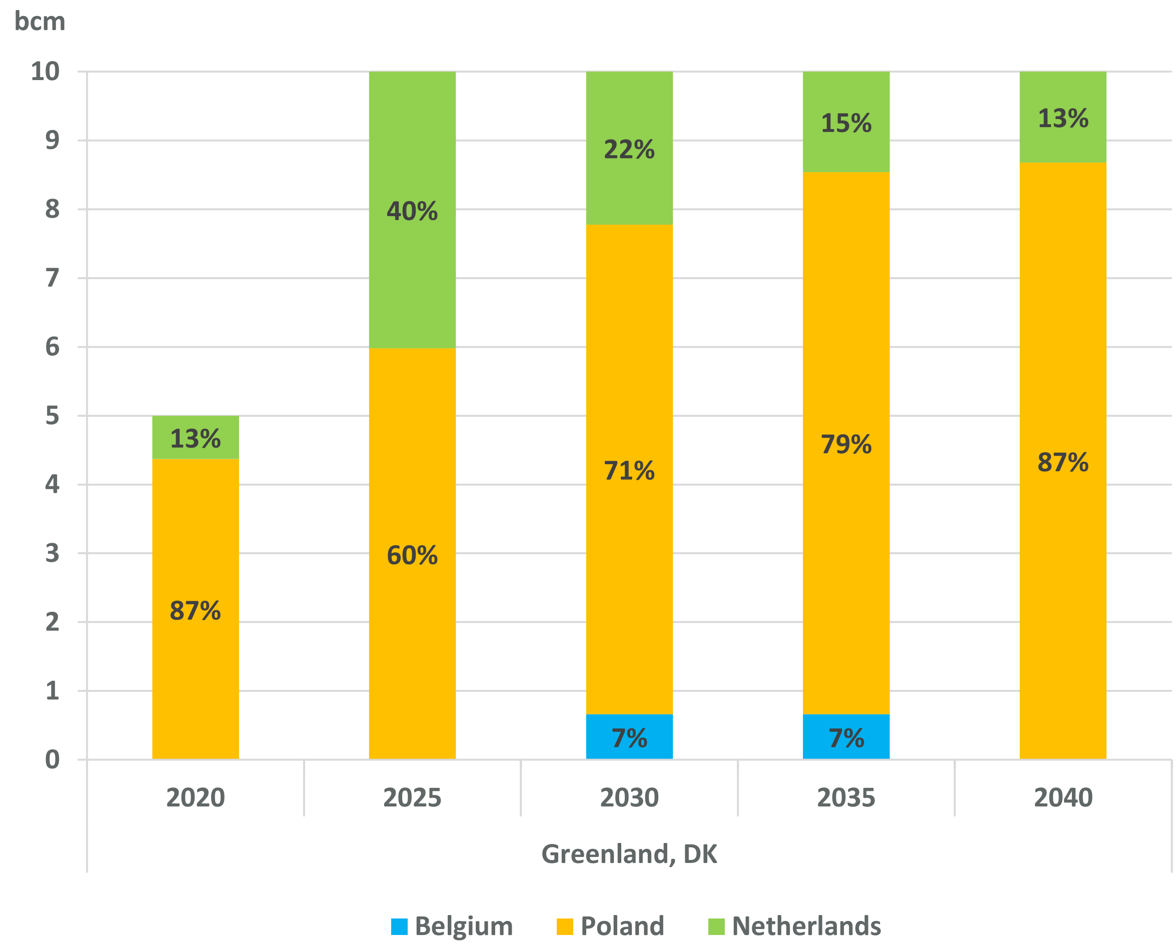


Figure 14: Endogenous Investment Scenario: Destinations of Arctic LNG (Scenario 2; bcm). Source: Own presentation based on COLUMBUS model results.

7.3. Arctic LNG in the EU's import portfolio

After having looked at the destination countries of Arctic LNG, the following sections assess the role of Arctic supply for the EU's import portfolio. For decades, European imports were mainly pipeline-based. In 2012, pipeline import capacity amounted to 350 bcm or 65 % of total import capacity. Regasification facilities, however, have become an alternative with an expected import capacity of 212 bcm in 2014. Given that there is an estimated excess import capacity of 190 bcm for 2014, infrastructure bottlenecks are not an impediment to Arctic supply.

7.3.1. Reference scenario ("most likely development")

Figure 15 reports the EU's import portfolio of pipeline gas, non-Arctic and Arctic LNG for the Reference Scenario. Again, the coloured bars indicate the share of imports from the different sources in the respective year. Between 2015 and 2040, total imports are expected to double due to increasing European demand and declining domestic production. Yet, the shares of LNG (non-Arctic) and pipeline gas are not subject to significant changes: Throughout the analysed time horizon, pipeline imports represent roughly two thirds of total imports.

Only in 2020 Arctic gas plays a visible role in the EU's import portfolio. In that year, Yamal-LNG is expected to account for about 6 % of total imports. To put it differently, 86 % (19 bcm) of total production at Yamal are shipped to Europe in that year. Beyond that year, except for the Yamal volumes contracted with Spain, all Arctic volumes are redirected to Asia (see Figure 12 above).

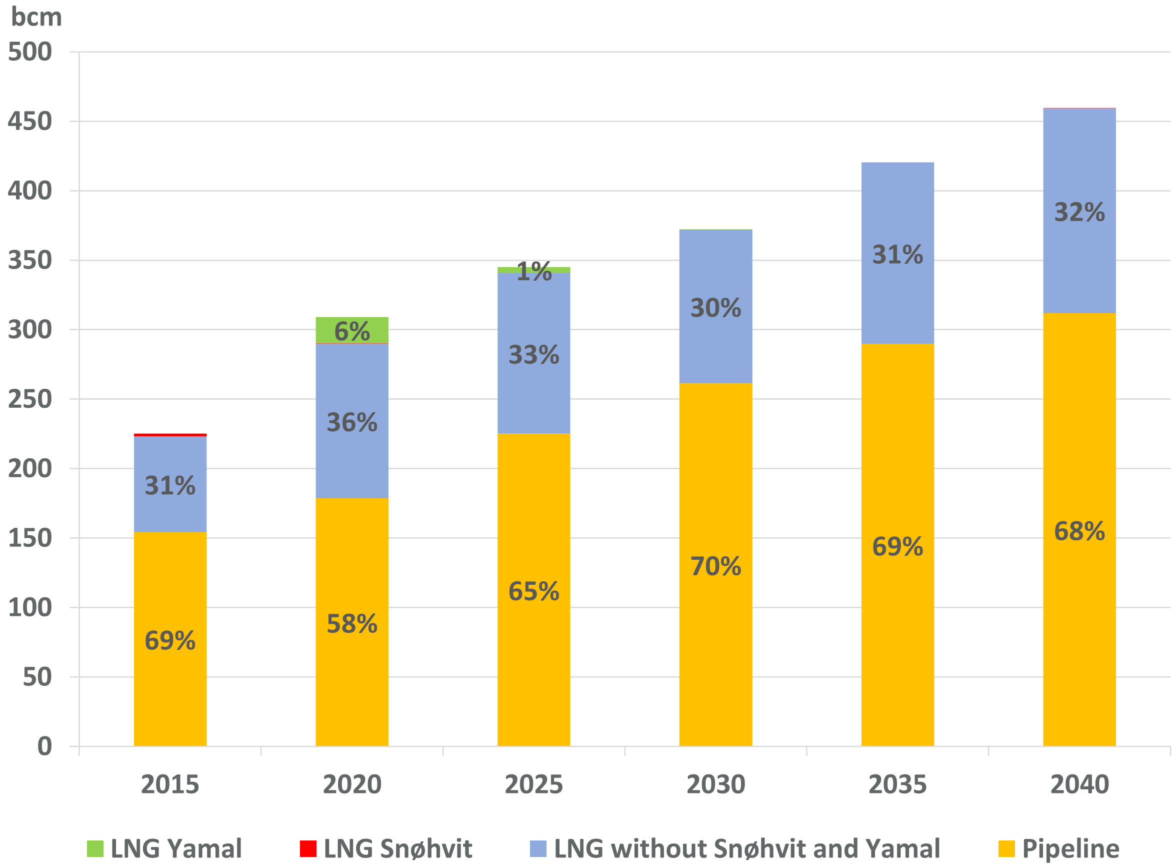


Figure 15: European Import Portfolio in the Reference Scenario (bcm).
Source: Own presentation based on COLUMBUS model results.

Our results have demonstrated that the availability of Arctic gas from Snøhvit and Yamal does not strikingly change the picture of the EU's gas imports. The explanation is twofold. First, natural gas volumes produced at Arctic facilities are of small size compared to aggregated European imports. Even if the entire Arctic production in 2025 was to be shipped to Europe (i.e. 28.2 bcm), this would represent only 8 % of the EU's imports. Hence volumes from the Arctic cannot drastically change the EU's supply pattern. Second, from an economic perspective, it is economically rational to ship the magnitude of Arctic gas to Asia. Except for some flows to Europe in the medium term, higher revenues can be generated in Asia.

7.3.2. Scenario 1 ("Model-driven investment in locations")

As mentioned in Section 7.2.2, additional production in this scenario compared to the "most likely" scenario is almost exclusively sent to Asia. Consequently, the European import portfolio does not change significantly and we refer to Figure 15 for graphical presentation.

7.3.3. Scenario 2 ("Model-driven investment in Greenland")

As the following figure shows (Figure 15), Greenlandic volumes represent a constant source of supply in the European import mix. Again, the coloured bars indicate the share of imports from the different sources in the respective year. Due to its small size, however, Greenlandic gas contributes less than 5 % to European imports.

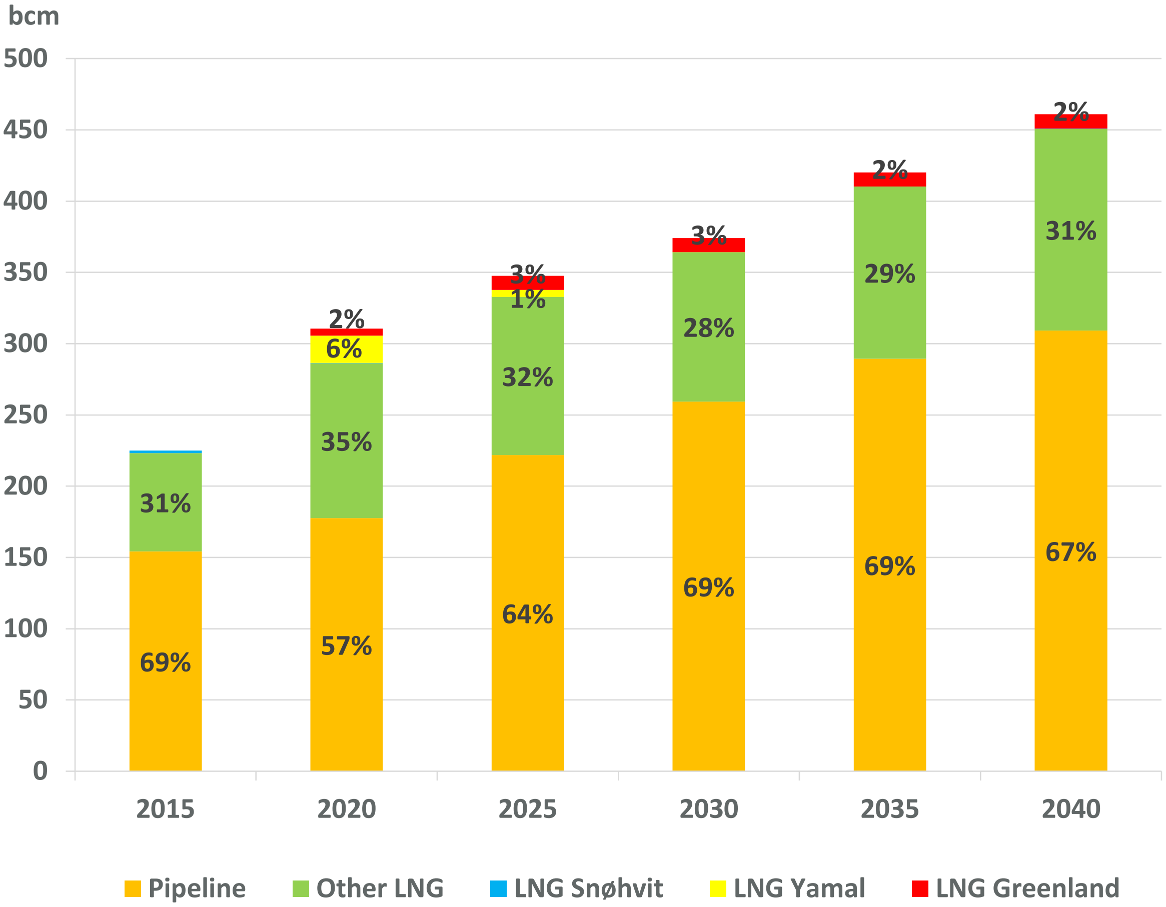


Figure 16: European Import Portfolio in the Greenland scenarios (bcm).
Source: Own presentation based on COLUMBUS model results.

7.4. Excursus: The role of long-term contracts

As stated before, some volumes from Yamal and Snøhvit are predetermined via long-term contracts. In order to judge to what extent these contracts are binding, a Counterfactual Scenario was modelled and results are compared to the Reference Scenario. In this Counterfactual Scenario, LNG from Snøhvit and Yamal is not bound by any contract and can freely be shipped to all available regasification terminals. Figure 17 represents the differences in supply between the Counterfactual and the Reference Scenario for both production plants. Thus, volumes with a negative sign are volumes that would not occur if the LTC did not exist ("bounded volumes"). The flows that occur in absence of the LTC have positive signs ("counterfactual volumes"). The blue dots indicate the total quantity of contracted volumes.

For Snøhvit 78% of the contracted volumes are binding in 2015. As the graph indicates, if there were no LTCs in 2015, it would be economically optimal to ship these volumes from

Snøhvit to Japan and Korea (positive counterfactual volumes). LTCs from Snøhvit decrease in size over time since per assumption the LTCs decrease in size (unless public information is available as to the exact duration of the contract). By 2025, contracted volumes are close to zero.

For Yamal, only about a third of the volumes being contracted in 2020 are binding. If volumes were not bound to China, they would mainly be supplied to France and Japan (positive counterfactual volumes). With Chinese demand experiencing a strong decrease, the volumes contracted with China are not binding in later years because trade with China becomes more economical and does not need to be "enforced" anymore.

For the alternative scenarios (Scenarios 1 to 4) we assume no long term contracts beyond those incorporated in the Reference Scenario.

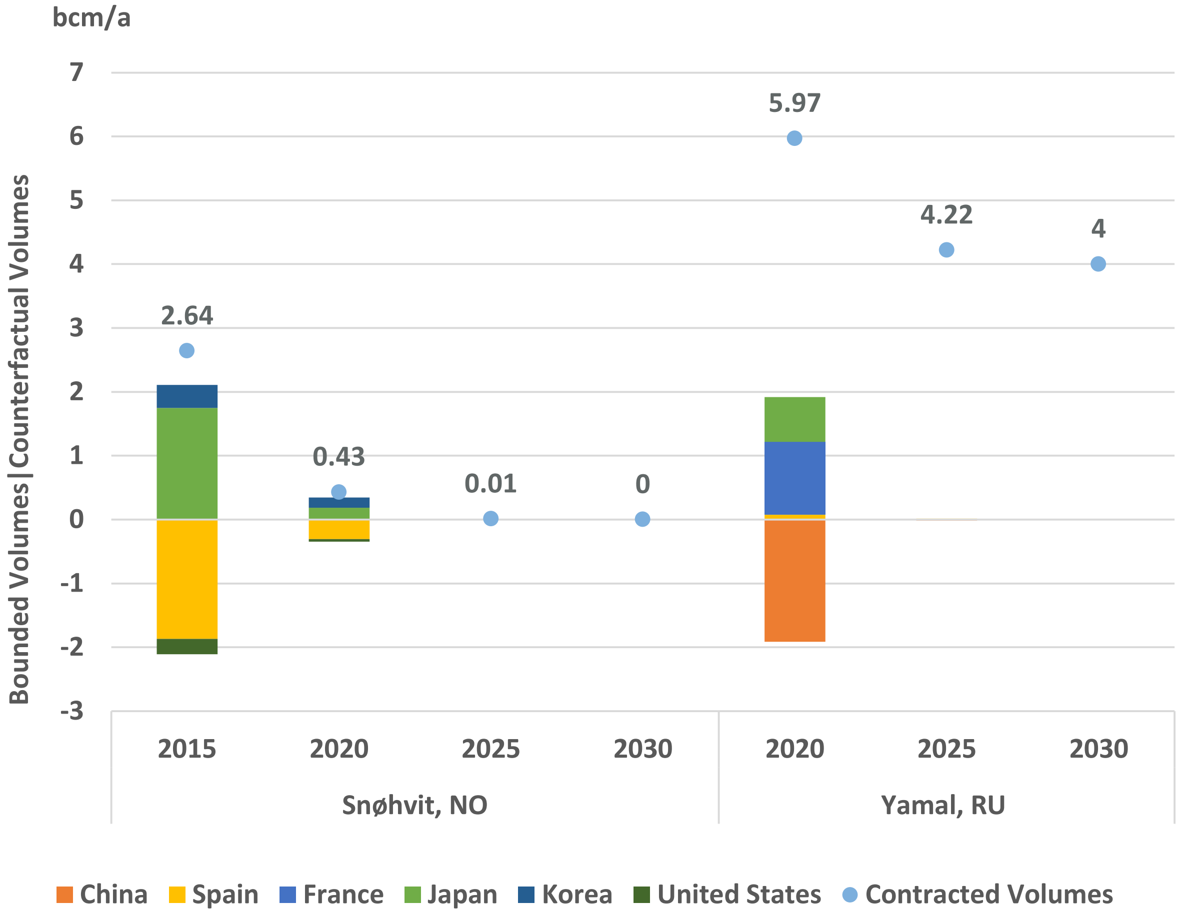


Figure 17: Difference between No-LTC case and Reference Scenario (bcm)
Source: Own presentation based on COLUMBUS model results.

7.5. Impact on GDP and welfare

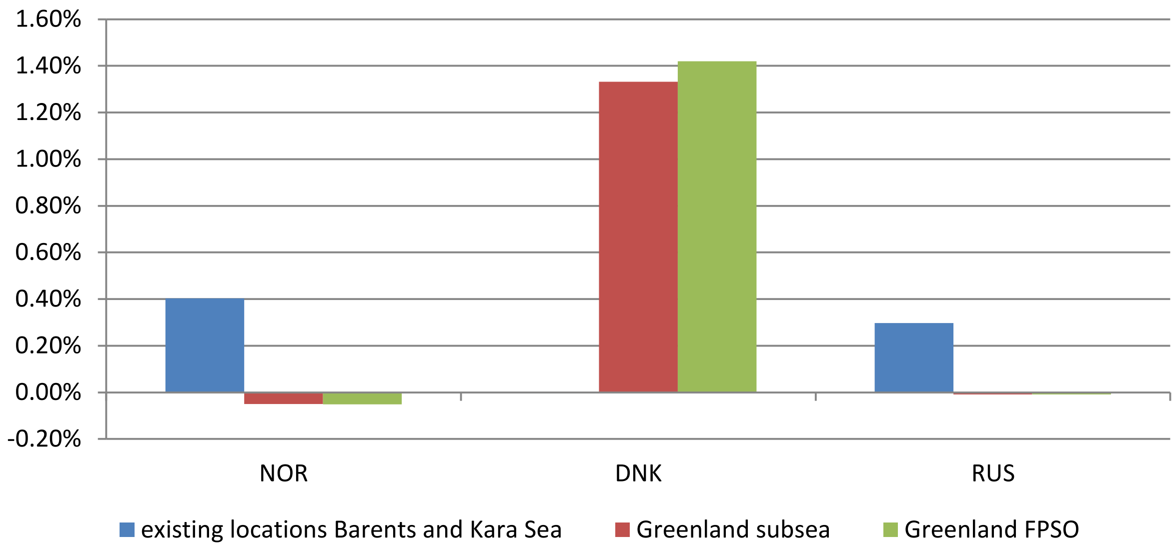
GDP is probably the most widely used indicator of economic performance. Representing the value of all traded goods and services, it is frequently used as a measure of the general economic success of an economy (even though this is a simplified and rather narrow view of economic success).

In many countries, including both Norway and Russia, resource production constitutes a significant part of economic activity. Due to its position upstream of other production chains, resource extraction has in addition to this direct effect significant second round effects. As both energy resources themselves and the products of downstream production chains are traded internationally, these second round effects spread to other countries that are not directly affected by additional resource production, e.g. by cheaper or more affluent imports or by changing competition on export markets. Using the CGE model DART, we can calculate the effects of additional natural gas production in the Arctic for the three Arctic countries we study (Panel a of Figure 18) and for other countries, that are only indirectly affected (Panel b).

Unsurprisingly, additional production of natural gas has an expansive effect on the economies of the producing country. Norway's and Russia's GDP grows in the order of 0.3 to 0.4 % in the "existing locations" scenario (Scenario 1) relative to the Reference Scenario. Despite the geographical proximity to the existing locations in Norway and Russia, the Danish GDP is not affected. Some other countries GDP are, however, mildly affected. Other natural gas producers, especially the North African countries (NAF), the Former Soviet Union countries excluding Russia (FSU) and the Middle East countries (MEA) suffer from increased competition on world gas markets and loose up to 0.08 % in GDP. Especially Eastern European countries inside (EEU) and outside (NEU) the EU that are in close proximity to Russia and Norway benefit from additional gas supply. They gain up to 0.04 % of GDP in the case of non-EU European countries, (NEU). In general, the impact on other countries remains small compared to the direct effects on Norway and Russia. Worldwide GDP does not change significantly, but increases between 0.004 % in the Greenland subsea scenario and 0.005 % in the "existing locations" scenario.

While the effect of additional production on GDP of the producing countries is considerable in the "existing locations" scenario, it is even higher for Greenland/Denmark in the two Greenland scenarios, but slightly negative for Norway (Scenario 2). Depending on the production technology, Danish GDP increases by around 1.4 % relative to the most likely scenario, with FPSO technology delivering slightly higher returns in GDP. In terms of third countries, the same countries are affected as in the "existing" scenario, although on an even smaller scale.

Panel a:



Panel b:

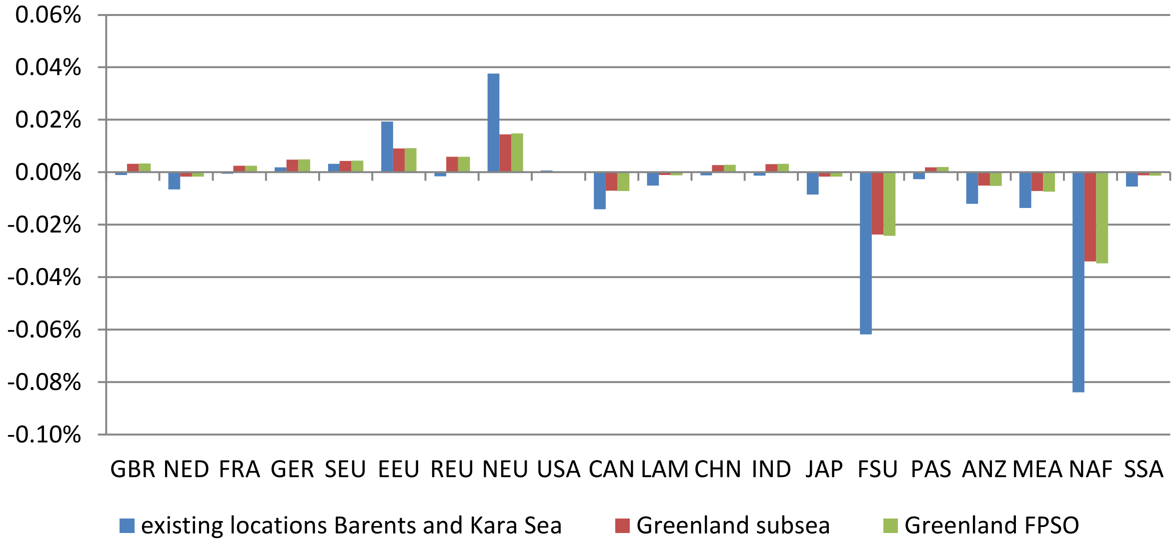
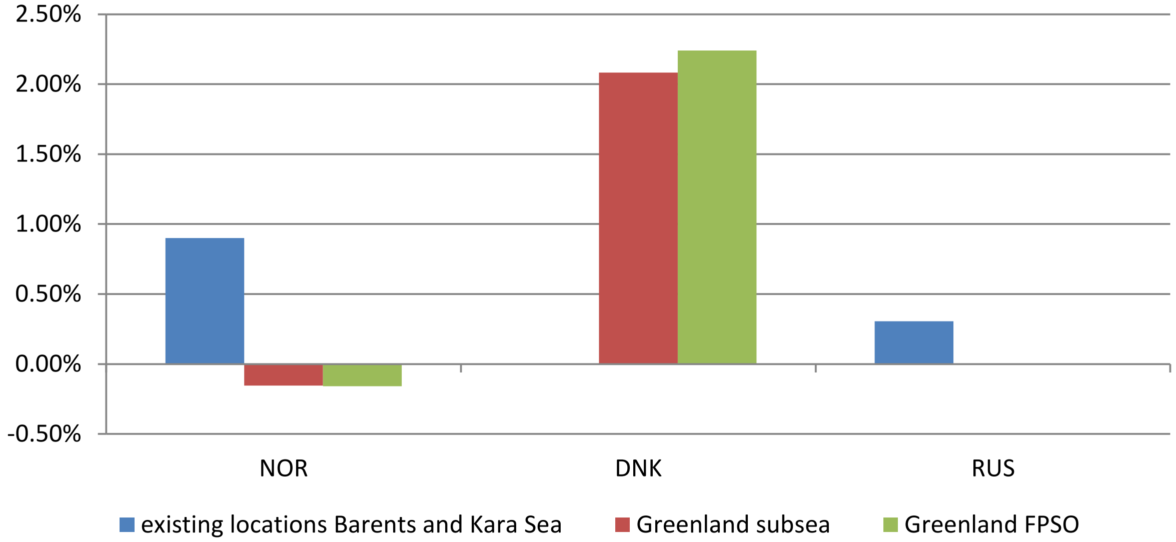


Figure 18: Change in GDP in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As mentioned above, GDP is necessarily an imperfect representation of economic activity. For this reason, we study an additional measure of economic performance, equivalent variation. Changes in equivalent variation or, more precise, Hicksian equivalent variation are defined as an income adjustment which maintains the consumer at a particular level of welfare. Thus, equivalent variation is the amount of income that must be given to a consumer to forego a gain to leave the consumer as well off as with the change.

Compared to GDP changes, gains from natural gas production are slightly larger if measured in terms of equivalent variation, both in the producing countries and in third countries benefitting from positive second round effects. Losses in other gas exporting countries are slightly smaller if measured in terms of equivalent variation and not GDP, except for Norway. Qualitatively, however, the results do not change.

Panel a:



Panel b:

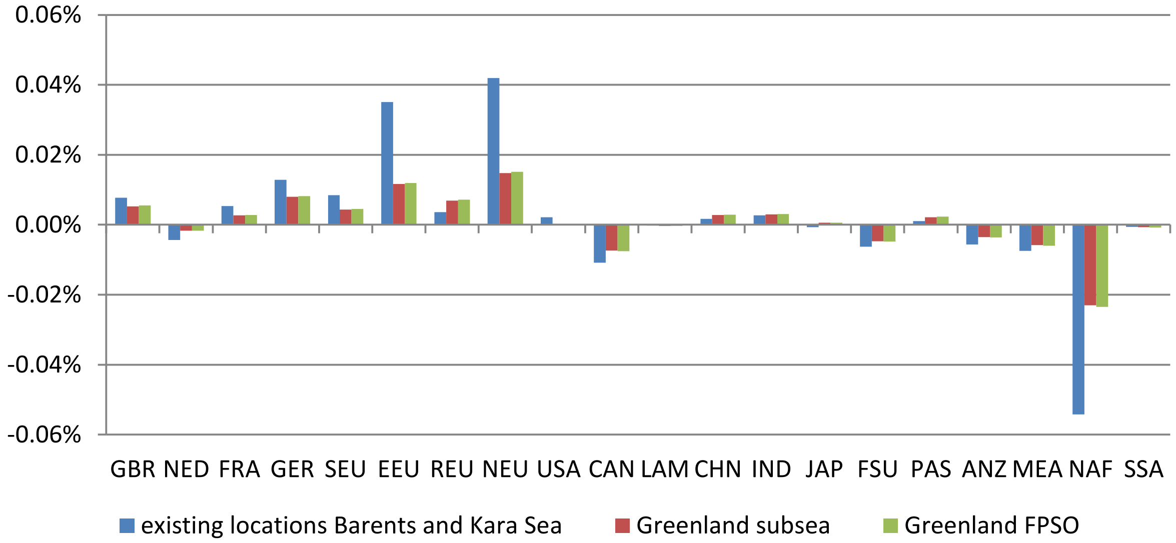


Figure 19: Change in equivalent variation in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

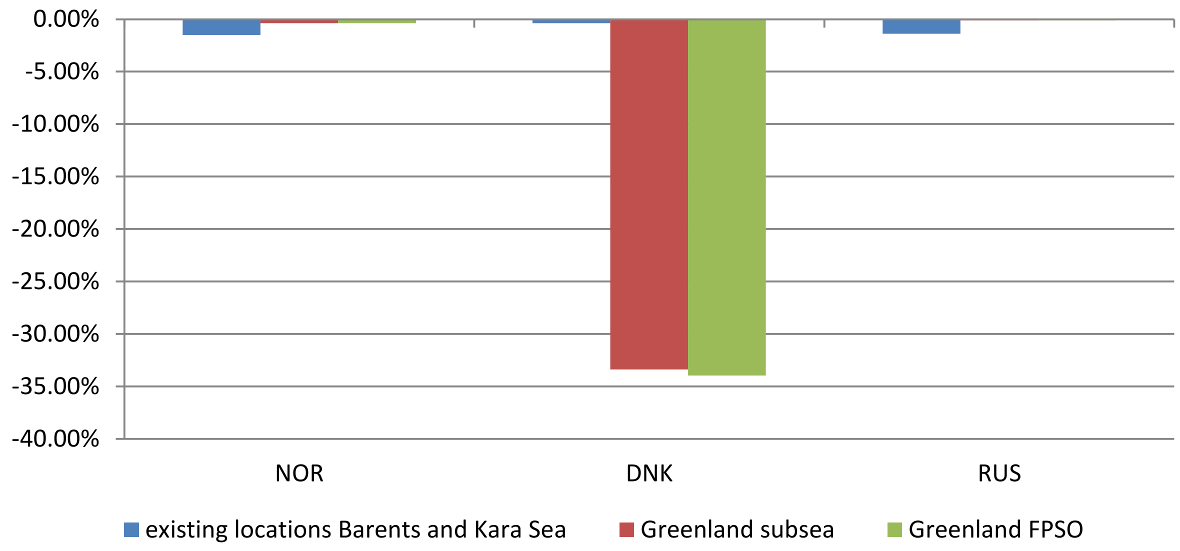
7.6. Impact on prices

Additional production of natural gas affects also price level both of producing countries and of countries that are affected only via the world market. Naturally, the price of natural gas is affected since more natural gas will usually lead to lower gas prices. Prices of other products may also be affected, (1) either because gas as an input becomes cheaper and these products compete with gas on the market for resources (in the case of substitute fuels) or (2) they compete with on input markets (such as the labour market). Also potential Dutch disease effects may affect prices via the exchange rate channel (see Section 7.7 for more detail). While the first channel will lead to lower prices of substitute goods, the other channels might lead to higher prices. Thus, the overall direction of price changes of other goods is unclear and depends on concrete circumstances. We study three price indices, the price for natural gas (Figure 20), a price index for all goods other than natural gas (Figure 21) and the overall price level (Figure 22).

Additional natural gas production from the Arctic leads to a decrease in natural gas prices both in the Arctic countries (panel a of Figure 20) and in non-Arctic countries (panel b). In the case of the "existing locations" scenario, the gas price decreases by 1.5 % in Norway and 1.4 % in Russia relative to the most Reference scenario. Third countries (including Denmark) are affected much less, but still considerably so. Especially in Europe and in other gas exporting countries such as the Former Soviet Union (FSU) and North Africa (NAF) prices decrease, with the price level in Germany decreasing most significantly by 0.87 % relative to the most Reference Scenario.

The considerable decrease in gas prices in Norway and Russia pales in comparison to the stark drop in the gas price in Denmark and Greenland that follows additional gas production in the "Greenland" scenarios (Scenario 2). Here, the gas price drops by about a third compared to the most Reference Scenario. Other countries are affected as much as in the "existing locations" scenario, with Norway, Germany and the REU countries being affected most.

Panel a:



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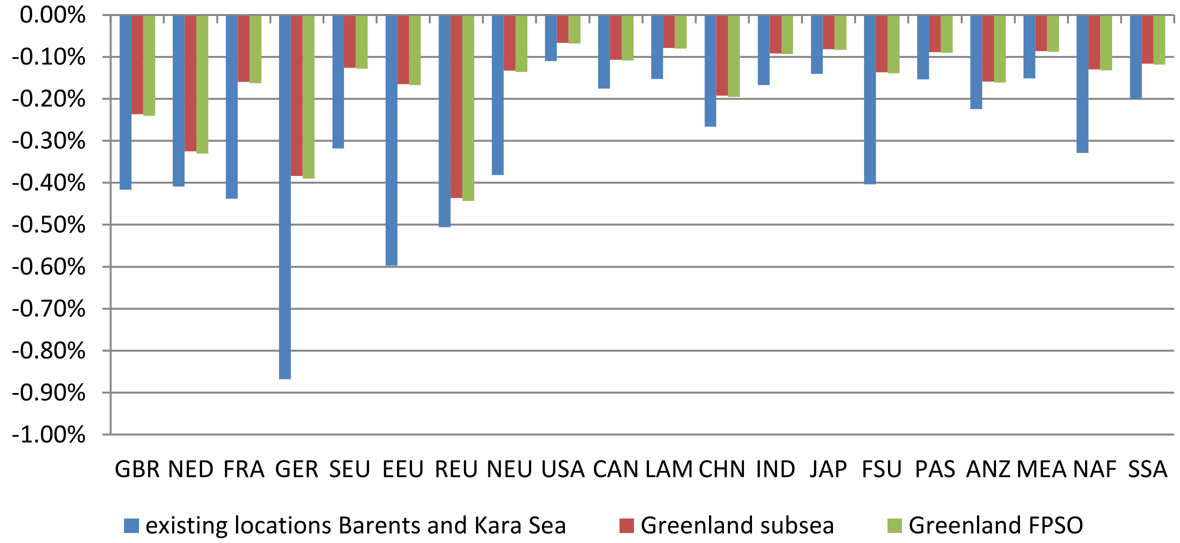
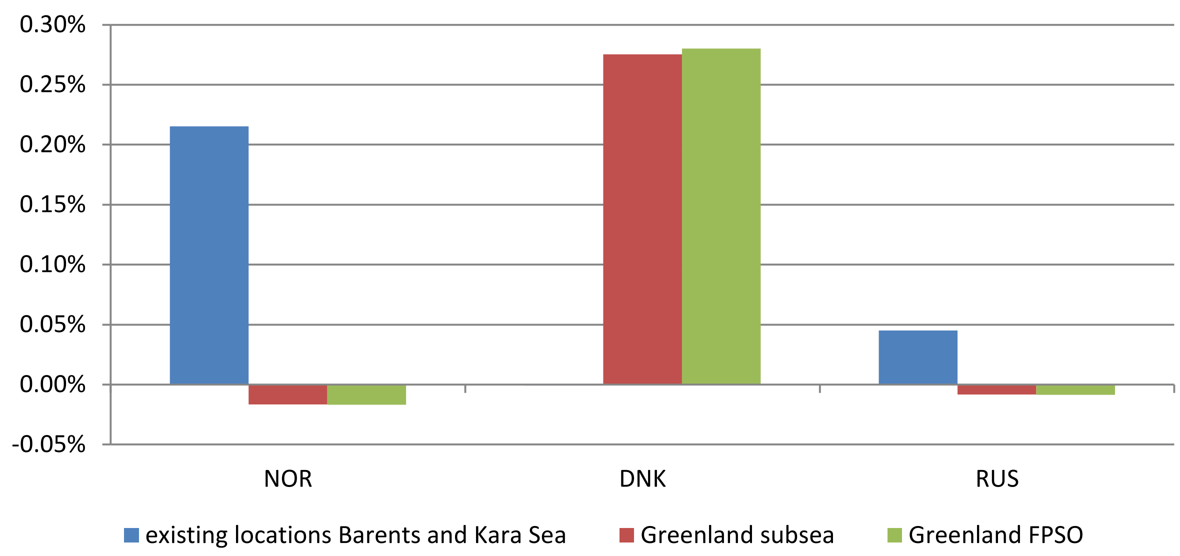


Figure 20: Change in gas price in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

While the increase in Arctic gas production decreases gas price globally, prices of goods other than gas change equivocally, yet not significantly (Figure 21). Price changes for goods other than gas are largest in the countries that are directly affected by additional Arctic gas production (panel a). Prices rise by 0.22 % in Norway in the “existing” scenario (Scenario 1) and 0.28 % in Denmark and Greenland in the “Greenland” scenarios (Scenario 2). Due to the small volume of additional natural gas from Yamal relative to total Russian gas production, prices for other goods only increase by 0.05 % in the “existing locations” scenario. Nevertheless, the price increasing effects of additional Arctic production, such as Dutch Disease effects, dominate in the directly affected countries (NOR, DNK and RUS). Effects on non-Arctic countries are small (panel b). Again, other natural gas exporters are affected most, such as countries from the former Soviet Union (FSU) and North Africa (NAF). Most of the larger price level changes are negative relative to the Reference Scenario, presumably due to lower input prices for gas.

Panel a:



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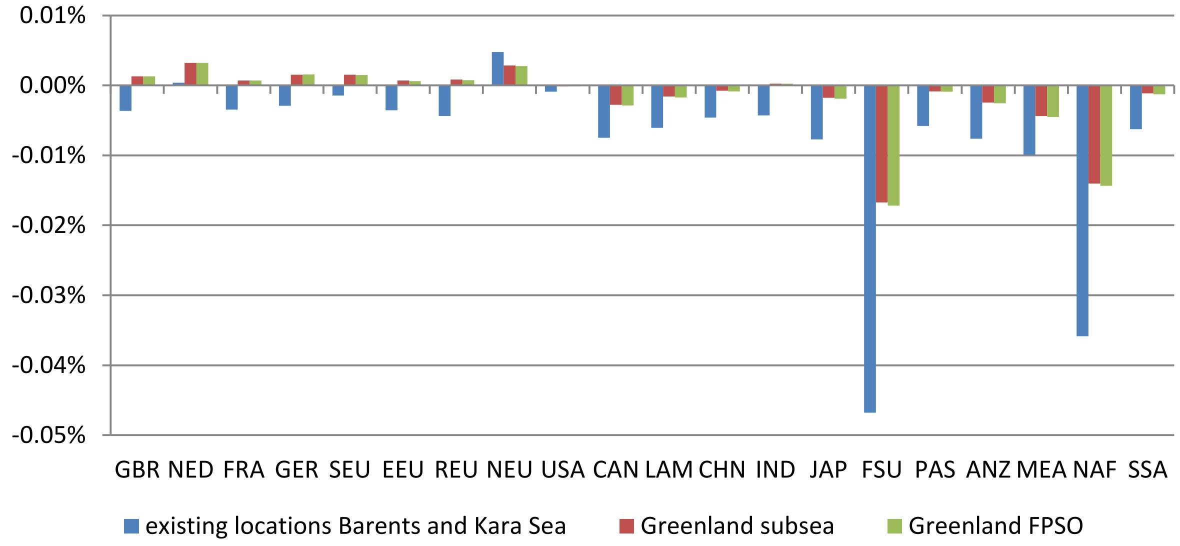
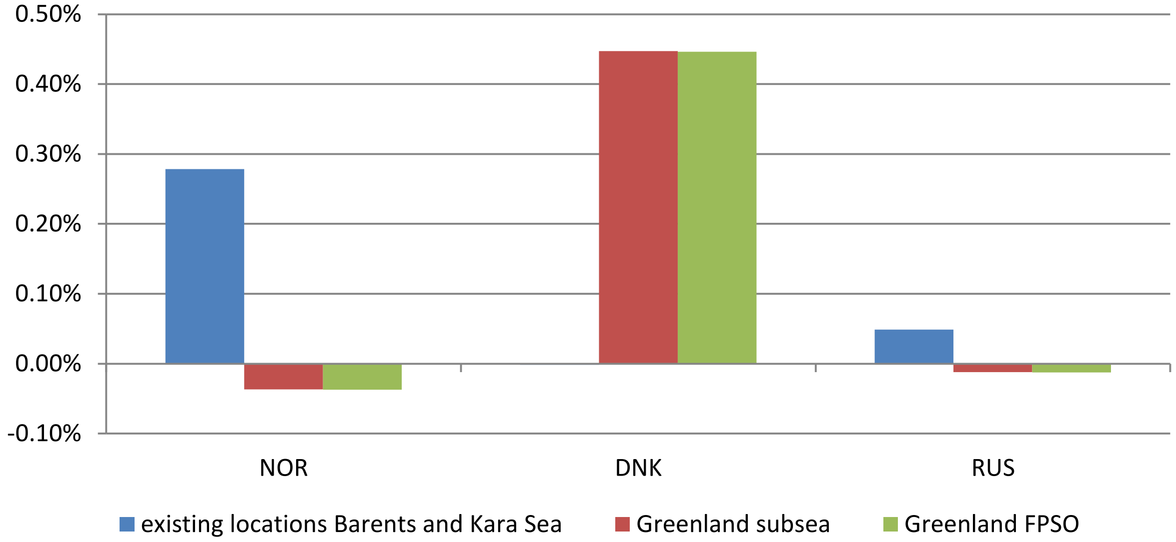


Figure 21: Change in overall price level excl. gas in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

While price changes in the natural gas sector are much larger than in the other sectors, the small size of the natural gas sector relative to the rest of the economies leads to indirect price changes dominating the overall price development in most economies (Figure 22). Even in Denmark in the “Greenland” scenarios, where we find a particularly large decrease in natural gas prices, the overall price level increases, if only by 0.45 % compared to the Reference Scenario. This equally applies for Norway and Russia in the “existing locations” scenario, though on a smaller scale (panel a). Since price changes in non-Arctic countries are negative both for natural gas and other goods, we find a small overall negative effect for non-Arctic economies, again natural gas exporters are affected most.

Panel a:



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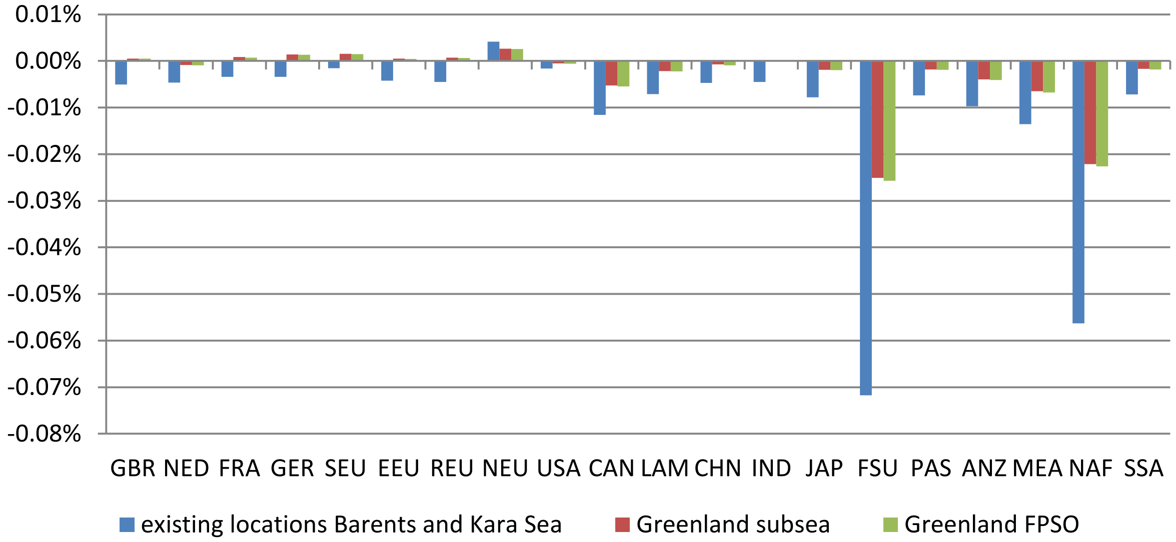


Figure 22: Change in overall price level in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.7. Impact on trade

Resource extraction activities usually affect the trading behaviour of both producing/ exporting countries as well as their trading partners. On the one hand, additional extraction of natural resources, such as natural gas, increase net exports of the resource, ceteris paribus increasing overall net exports of a producing country. At the same time, the additional (windfall) exports in the resource sector lead to an inflow of foreign capital and possibly an appreciation of the real exchange rate of a countries currency. This makes competition harder for sectors exporting other goods than the natural resource, such as manufacturing goods or goods from the primary sector. This phenomenon is known as “Dutch Disease”, a term coined after the Netherlands started to export North Sea natural gas in the middle of the 20th century, which led to a decline in the manufacturing sectors.

Countries that face a Dutch Disease situation have a number of options to counteract its detrimental effects, most notably the setup of sovereign wealth funds which save revenues from resource extraction and reinvest them outside the domestic economy, thus sterilizing foreign capital inflows and, as a positive side effect, stabilizing the revenue stream from natural resource extraction. A number of Arctic countries have implemented sovereign wealth funds, most notably Norway and Russia. It should be noted that DART does not include the setup of these funds explicitly, so any effect reported here does not take into account public action to expand or set up sovereign wealth funds as a reaction to the extraction of natural gas in the Arctic beyond the importance of these funds as of today.

In the following, we study the impact of natural gas production in the Arctic on the sector-level exports of Norway (Figure 24), Greenland/Denmark (Figure 25), and Russia (Figure 26). We then present the impact of gas- (Figure 27) and non-gas exports (Figure 28) of non-Arctic countries before we look at the overall development of exports in all countries (Figure 29). However, we start our analysis of the impact of natural gas production in the Arctic by looking at the terms of trade of countries (Figure 23). The terms of trade are the ratio of export prices over import prices of a country. If the terms of trade increase, a country is able to import more import goods for the same amount of export goods, domestic supply with goods improves.

Additional Arctic production of natural gas has considerable implications for the terms of trade of the producing countries (panel a of Figure 23). As natural gas is an export good and the price of natural gas is decreasing with increasing production, the terms of trade decrease. This is especially true for Norway in the “existing locations” scenario (Scenario 1) and for Denmark in the “Greenland” scenarios (Scenario 2), terms of trade decrease by around 1 % in both countries relative to the most likely scenario. In the “existing locations” scenario Russia is not affected as much as the other Arctic producers, as export of other goods and gas from other locations reduce the negative effect of additional Arctic production in Russia. Non-Arctic countries (panel b) are hit much less, with rates of change below 0.02 %.

Panel a:

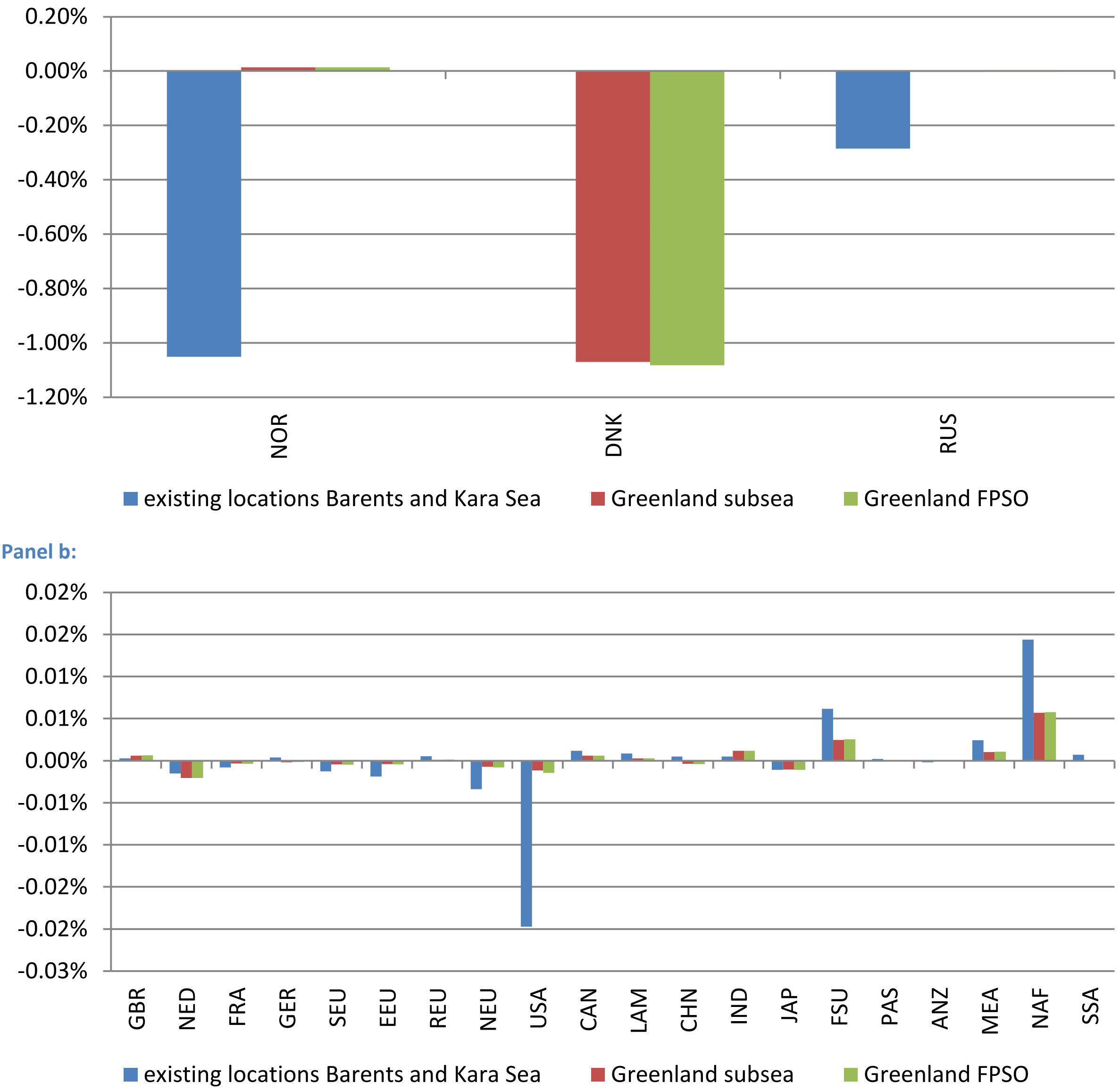


Figure 23: Change in terms of trade in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Exports and export composition in the three Arctic countries is affected in different ways. The value of Norwegian exports decrease in all other sectors apart from the natural gas sector in the “existing locations” scenario (Figure 24). Especially manufacturing export values are reduced by up to 1.2 % compared to the Reference Scenario, presumably either because of competition about inputs or because of a Dutch Disease situation. Other energy sectors are affected relatively little, with decreases in export values highest in the electricity sector, where export value s decrease by 0.5 %; other energy related sectors are hardly affected at all. Due to the large increases in export values of natural gas that overcompensate losses in the other sectors, overall, the value of Norwegian exports increase slightly by 0.73 % (Figure 29, panel a).

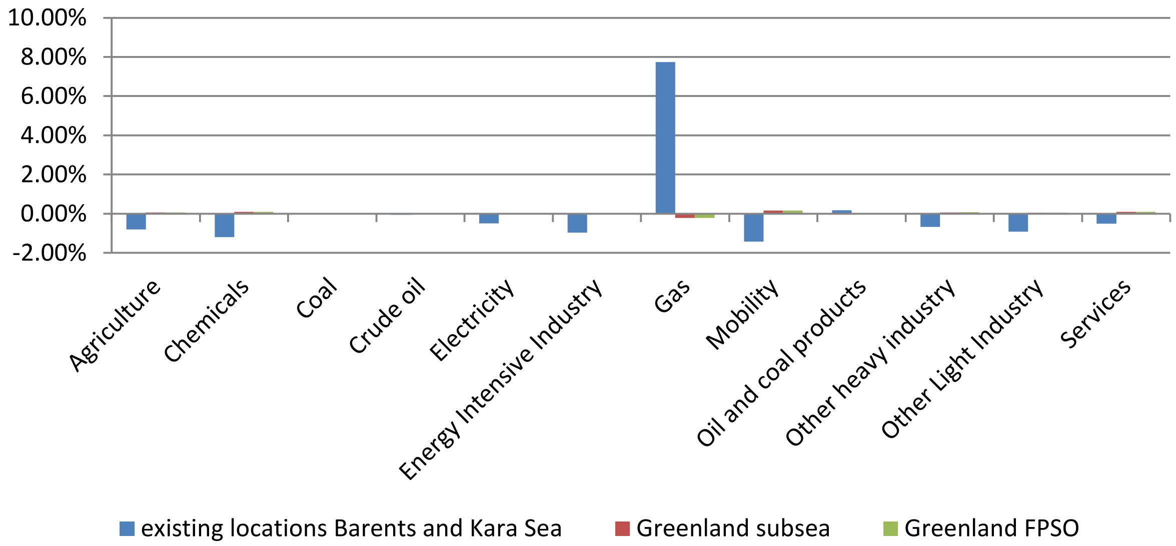


Figure 24: Change in Norwegian export values in 2040 relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Sectors in Denmark are, contrary to the case of Norway, affected differently in the "Greenland" scenarios (Figure 25). As expected, the value of natural gas exports skyrocket, mainly because of a small base value for gas exports in the Reference Scenario. But also other sectors export values increase: Both energy intensive and light industry sectors increase their export values by 2 and 1.5 %, respectively, relative to the Reference Scenario. They profit from the cheaper supply of natural gas that constitutes an important input for their production. Heavy industry, transport, electricity and services sectors show a decrease in export values. Overall export values increase, though only by 0.6 % (Figure 29, panel a).

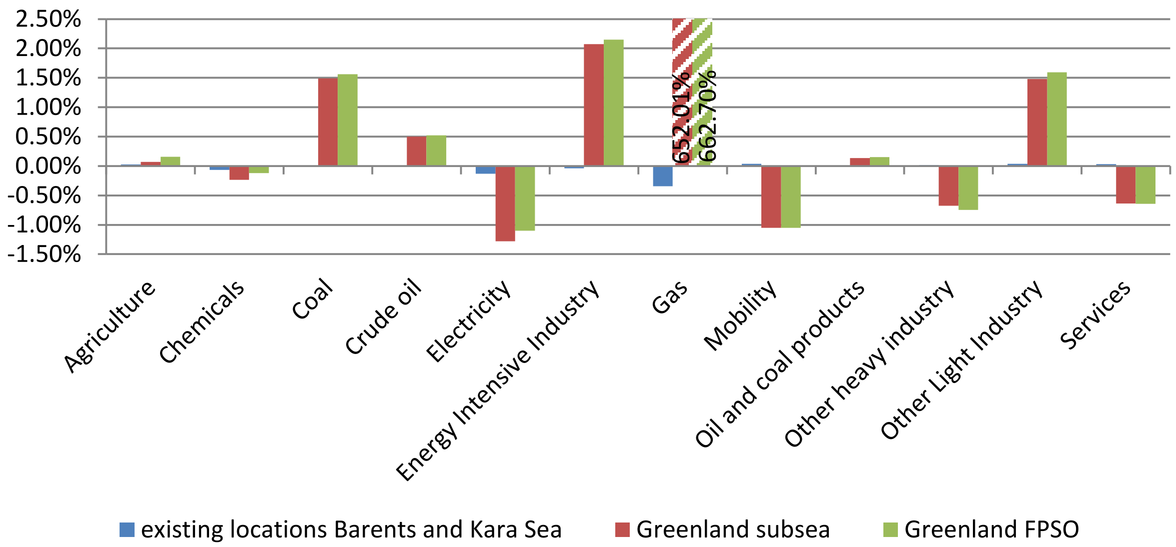


Figure 25: Change in Danish export values in 2040 relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Comparable to Denmark in the "Greenland scenario" (Scenario 2), Russian export values develop equivocally across sectors in the "existing locations" scenario (Figure 26). Here, it is also those sectors that profit from cheaper natural gas supply as input factor, that export values increase, the chemicals (+1.8 % compared to the Reference Scenario), electricity (+2.5 %) and energy intensive industry (+0.5 %) sectors. Some other sectors, including light and heavy industry, export values decrease, though only slightly so. Obviously, natural gas export values increase (+4 %). The overall value of exports increase, too, but again only slightly (+0.25 %).

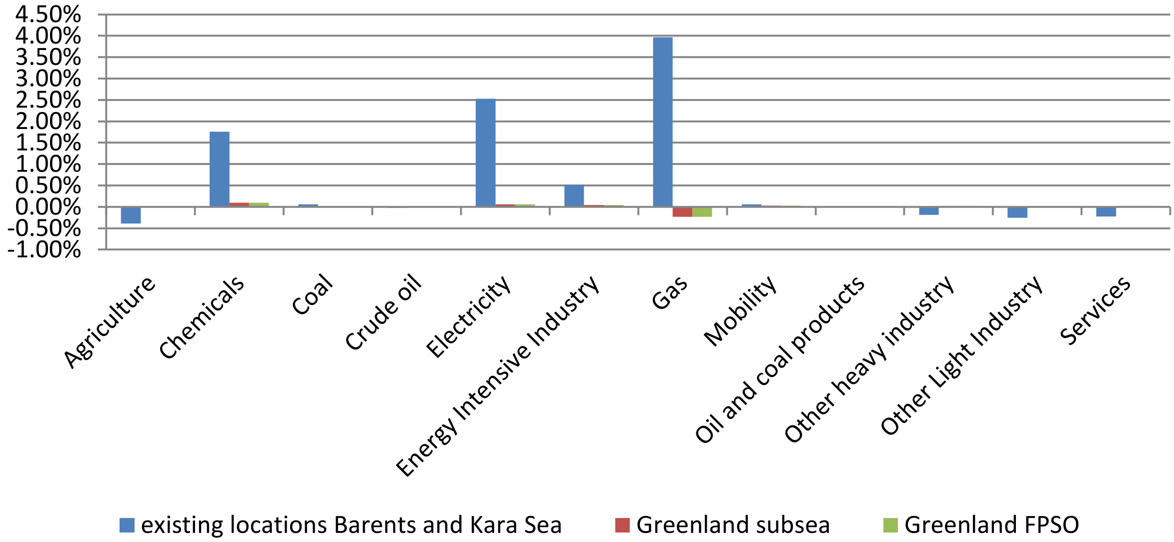


Figure 26: Change in Russian export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Countries that are indirectly affected by additional Arctic production via world markets usually show a decrease in the value of their own gas exports due to increased competition (Figure 27), but an increase in the value of their non-gas exports (Figure 28), as input supply gets better. Rare exceptions are Germany (GER), where both the value of gas exports (on a low level and relative to an export value of close to zero in the Reference Scenario) and non-gas exports slightly increase, and the REU countries, which expand the value of their gas exports in the “Greenland” scenarios, while the value of non-gas exports is lower in the “existing locations” scenario.

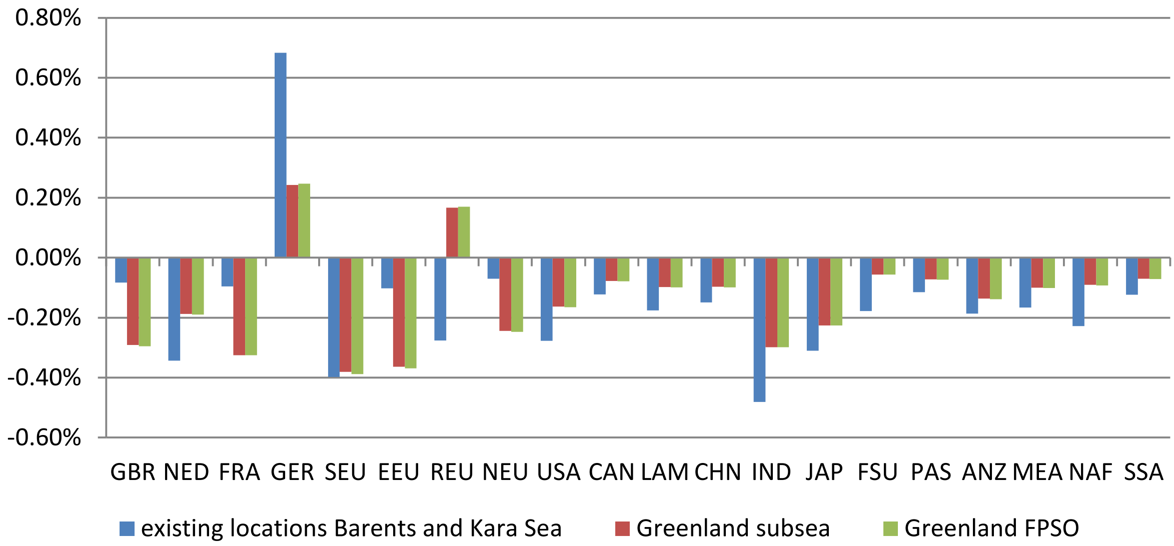


Figure 27: Change in gas export values of non-Arctic countries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

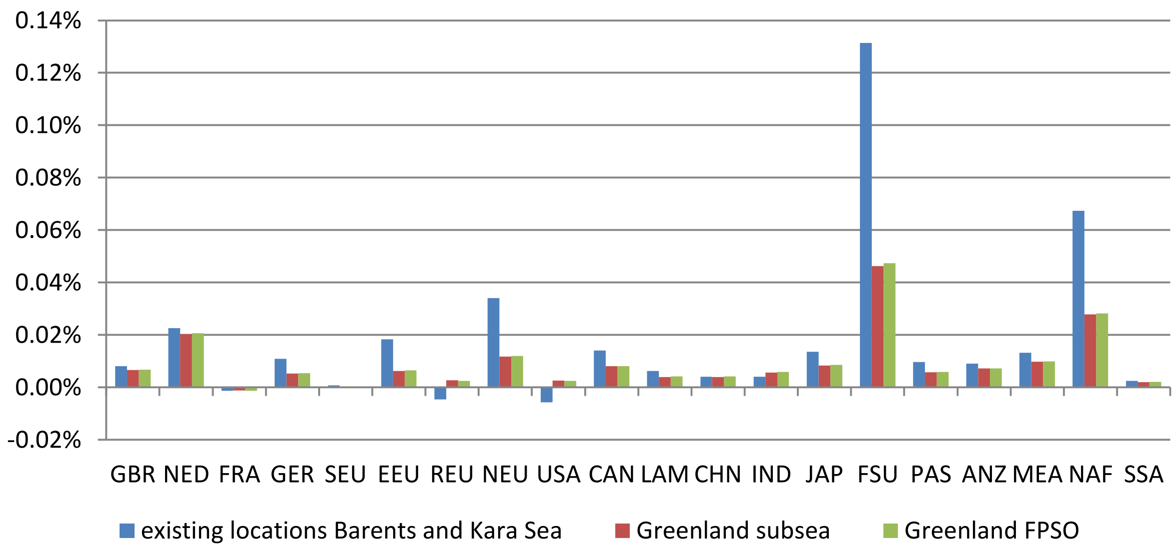
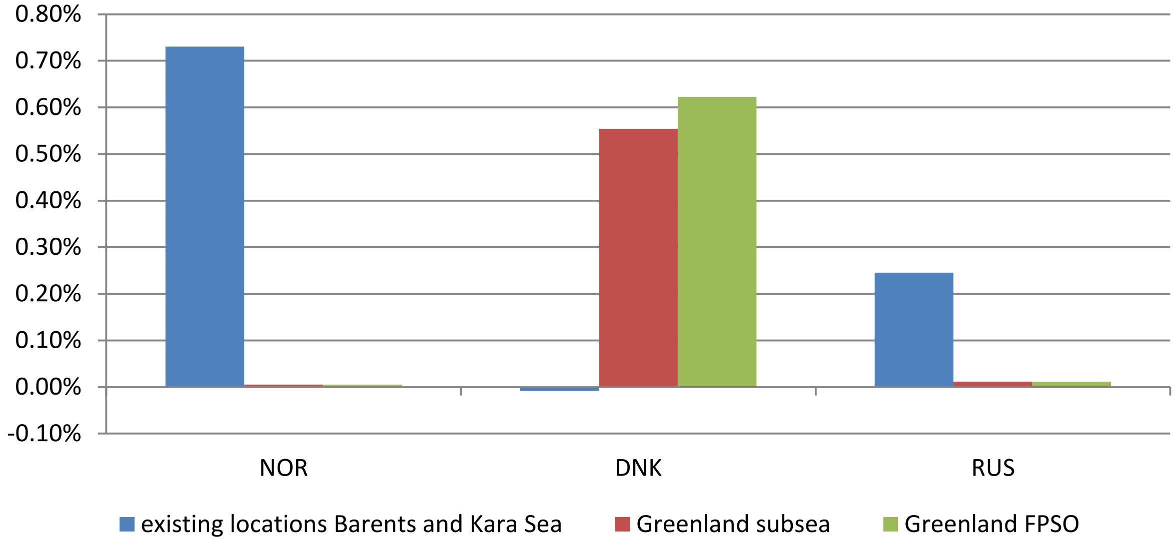


Figure 28: Change in non-gas export values of non-Arctic countries in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

Overall, the value of exports mostly increase (Figure 29), with the Former Soviet Union (FSU) countries benefitting most as increases in the value of non-gas exports overcompensate losses in the value of gas exports. Here and in general the effects of the "existing locations" scenario are larger than the effects of the "Greenland" scenarios, both because of the larger size of the intervention, and for some countries such as the FSU because of close interlinkages with the Russian economy.

Panel a:



Panel b:

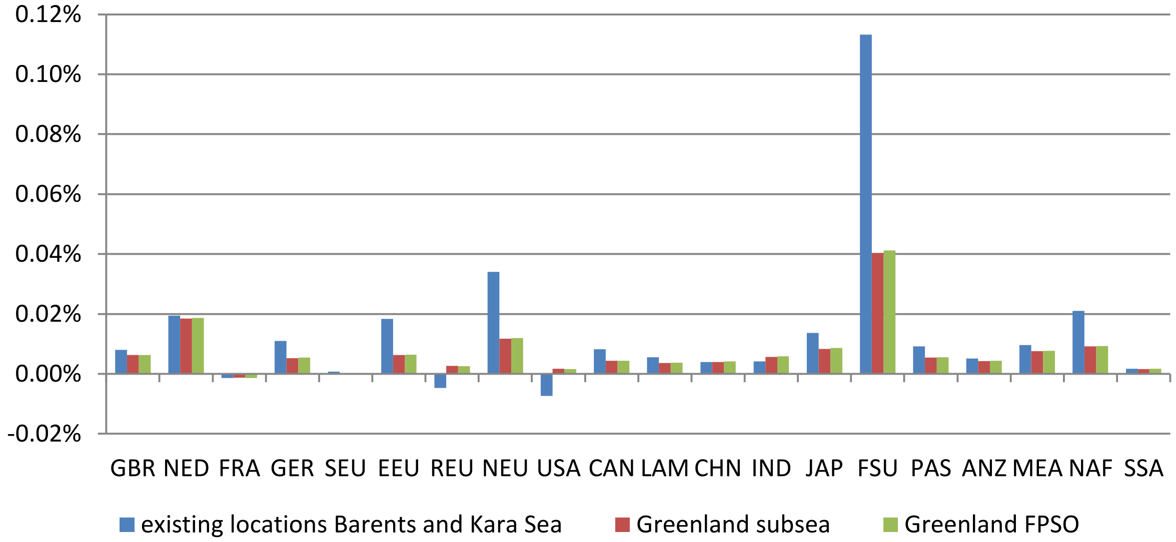


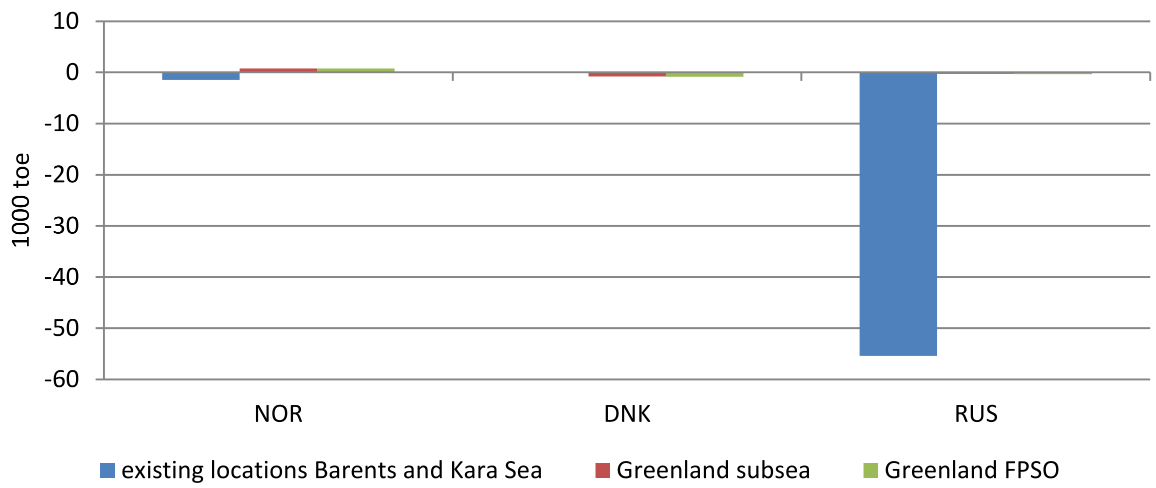
Figure 29: Change in total export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.8. Impact on the production of other fuels

The production of other fuels than natural gas is naturally affected by additional production of natural gas form the Arctic Ocean. If the cross-relation between another fuel and natural gas is substitutional, we expect a negative reaction to additional gas production in the first round, while first-round effects should be positive in the case of complementary goods. Additionally, some fuels, namely electricity, will use natural gas as an input factor for production. With regard to economy-wide general equilibria, the interrelation between Arctic natural gas and other fuels is complicated by different reactions in different sectors. Also different transportation costs will affect the reaction of different countries, especially since natural gas markets are regional. We study the change in production of coal (Figure 30), crude oil (Figure 31), natural gas from non-Arctic sources (Figure 32), electricity (Figure 33), and processed energy fuels other than electricity, i.e. mainly petroleum products and coke (Figure 34) for Scenarios 1 and 2 relative to the Reference Scenario.

Coal production, as a classical substitute for natural gas, is mainly affected negatively by additional production of natural gas from the Arctic Ocean. This is true both for the directly affected countries (Figure 30, panel a) and for countries only indirectly affected (panel b). Among the Arctic countries from panel a, Russia stands out with 55 000 toe less coal production in the "existing locations" scenario compared to the Reference Scenario, although this a reduction of total production by 0.02 %. In relative terms, the reduction in Norwegian coal production is highest, with a decrease of 0.05 %. The only somewhat sizeable reaction to additional gas from the Arctic is the German expansion of coal production by 135 000 toe, or 0.16 % in the "existing locations" scenario relative to Reference scenario. It should be noted, however, that the German coal sector suffers both from heavy market distortions in the (outphasing) production of hard coal and is characterised by a high share of lignite, which make projections of German coal production in a highly stylized world market context like this one difficult. Other coal producers are not affected to a significant extent.

Panel a:



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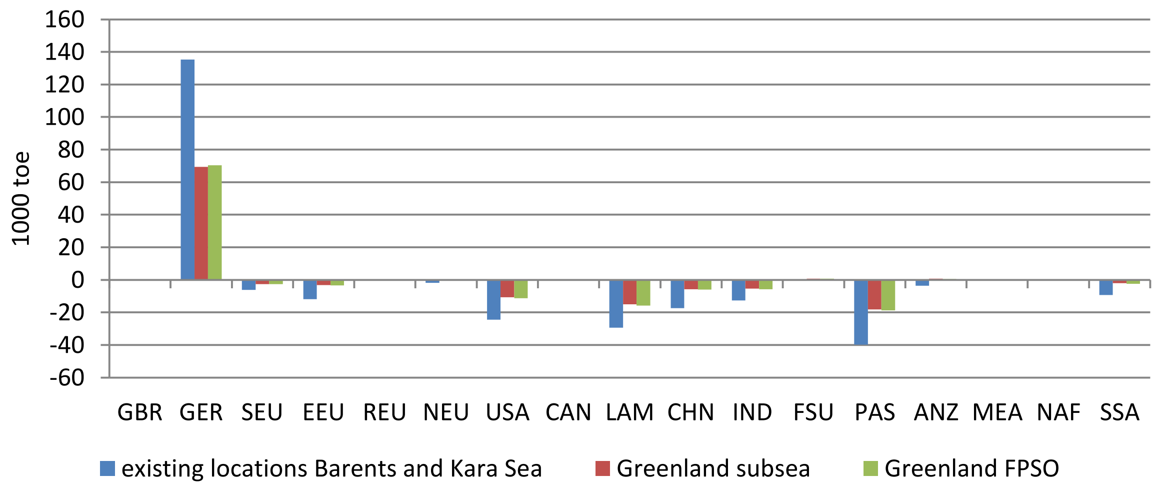
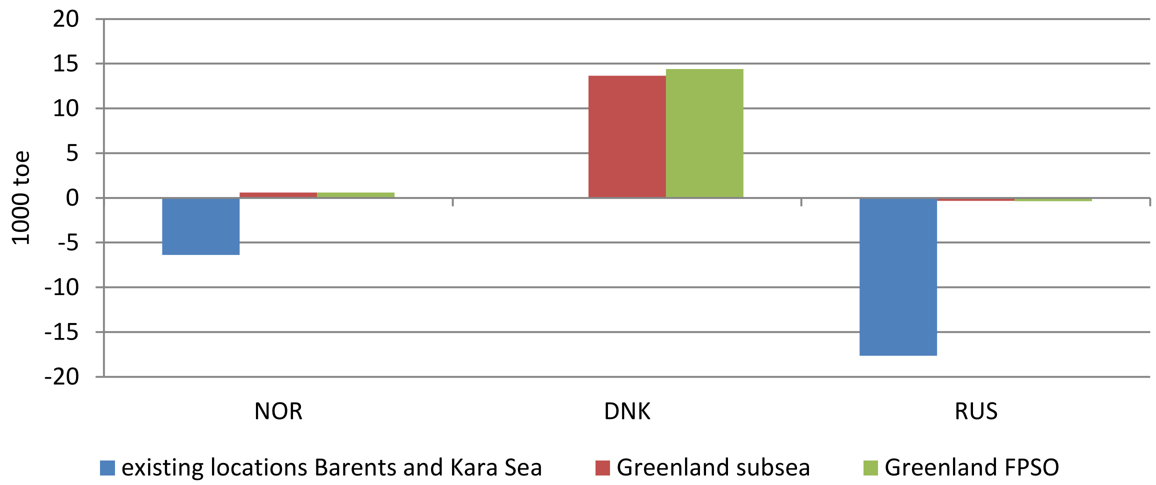


Figure 30: Change in production of coal in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

Crude oil production is less affected than coal production. Even the reductions shown for Russia in the “existing locations” scenario (Figure 31, panel a) and in the Middle East for all scenarios (panel b), do not represent any significant change in production relative to the overall size of the crude oil sector in these countries.

Panel a:



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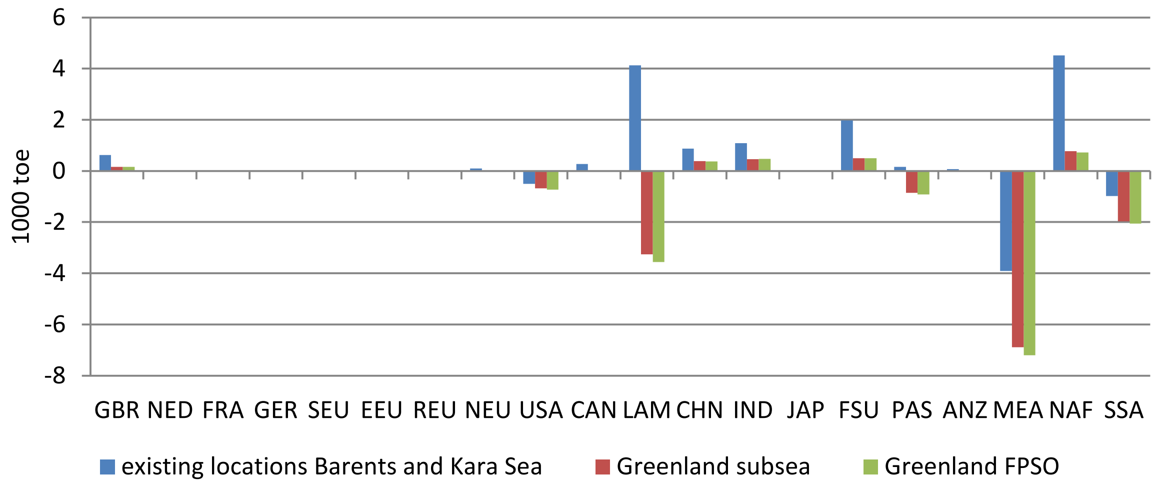
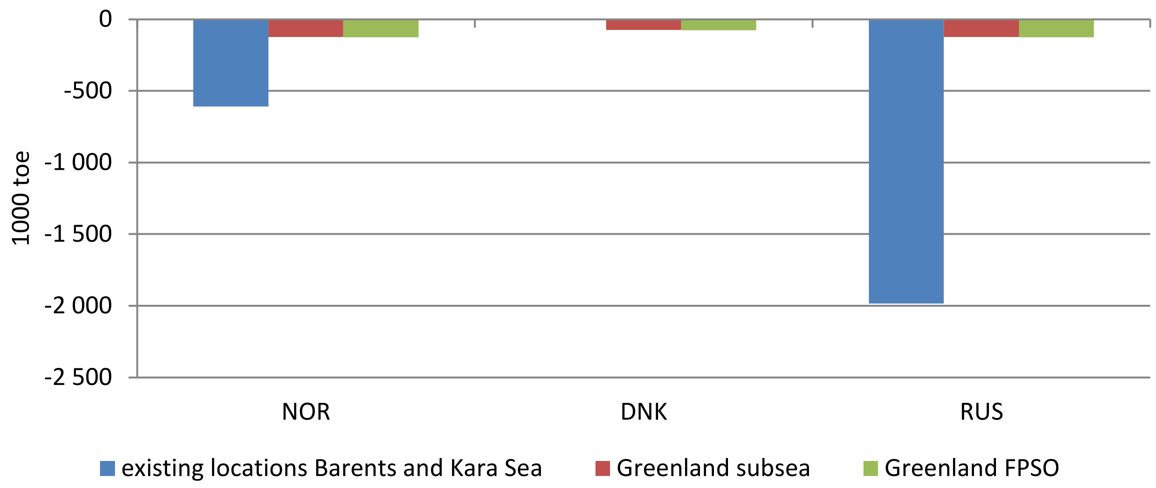


Figure 31: Change in production of crude oil in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

Unsurprisingly, the fuel that is most affected throughout a number of countries is natural gas production from non-Arctic sources. Non-Arctic production is reduced by 1.5 mtoe (-0.2 %) in Russia and 0.5 mtoe (-1 %) in Norway in the “existing locations” scenario relative to the Reference Scenario (Figure 32, panel a) and also traditional gas producers in Latin America (LAM), North Africa (NAF), and the Middle East (MDE) are affected by reductions in the order of several thousand toe (panel b). Again, however, relative to overall gas production in these countries the decline is negligible.

Panel a:



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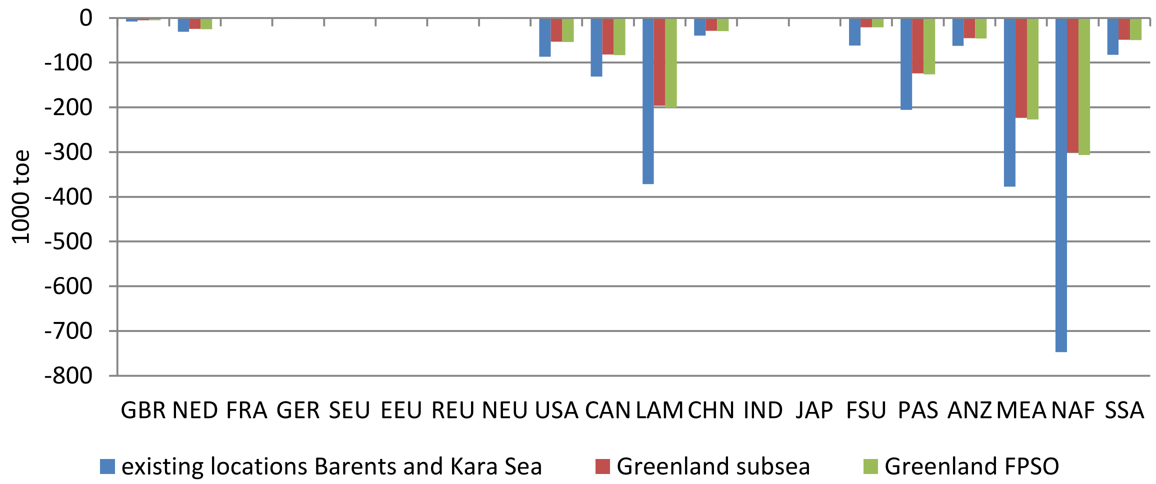


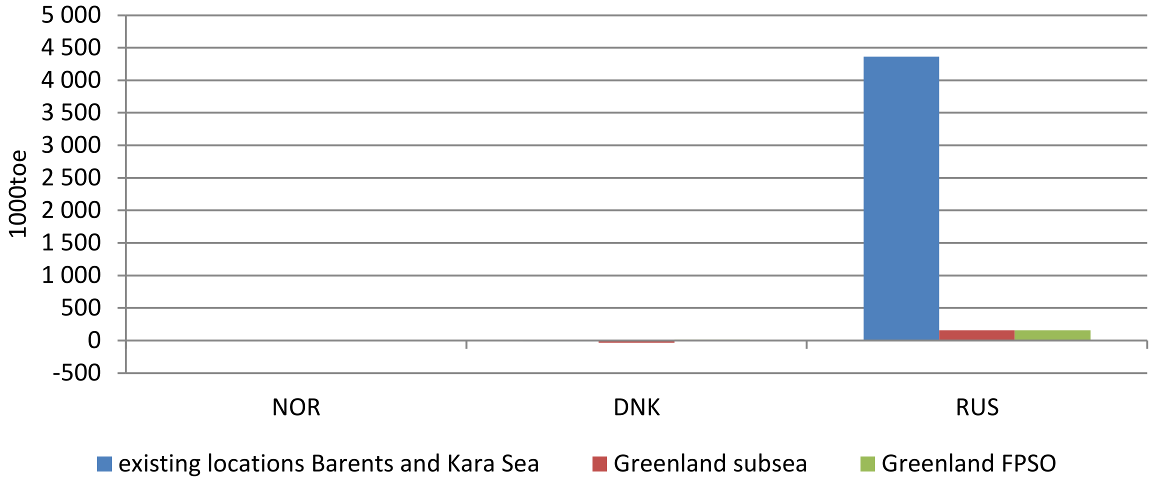
Figure 32: Change in production of non-Arctic natural gas in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

As the previous figures demonstrated, the effect of additional Arctic gas production on energy production of other primary fuels such as coal, crude oil, or competing natural gas is limited. The situation is slightly different for electricity, where natural gas is not only a competing substitute, but also potentially an input factor for production. As can be seen from Figure 33 (panel a), especially Russian electricity production reacts to cheaper access to natural gas, with production rising by 4.4 mtoe in the "existing locations" scenario relative to the Reference Scenario, corresponding to an increase of 1.2 %.[10] Similar reactions of much smaller magnitude are displayed for non-EU Europe (NEU), EEU countries and the Former Soviet Union (FSU) countries, and also in the USA and China (CHN). Countries further away

[10] Electricity, as any other form of energy, can be measured in tonnes of oil equivalent, since a tonne of oil equivalent is a general energy unit, standardized using the energy content of crude oil. A tonne of oil equivalent is equivalent to approximately 42 GJ.

from sources are not significantly affected, which is, apart from the limited size of the shock, presumably also a reason for the smaller impact of Greenlandic natural gas.

Panel a:



Panel b:

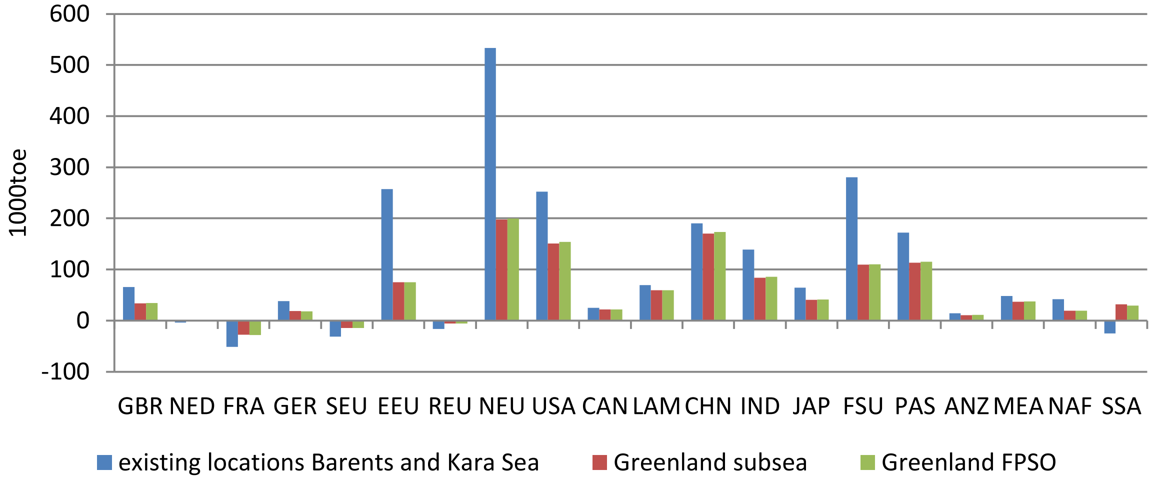
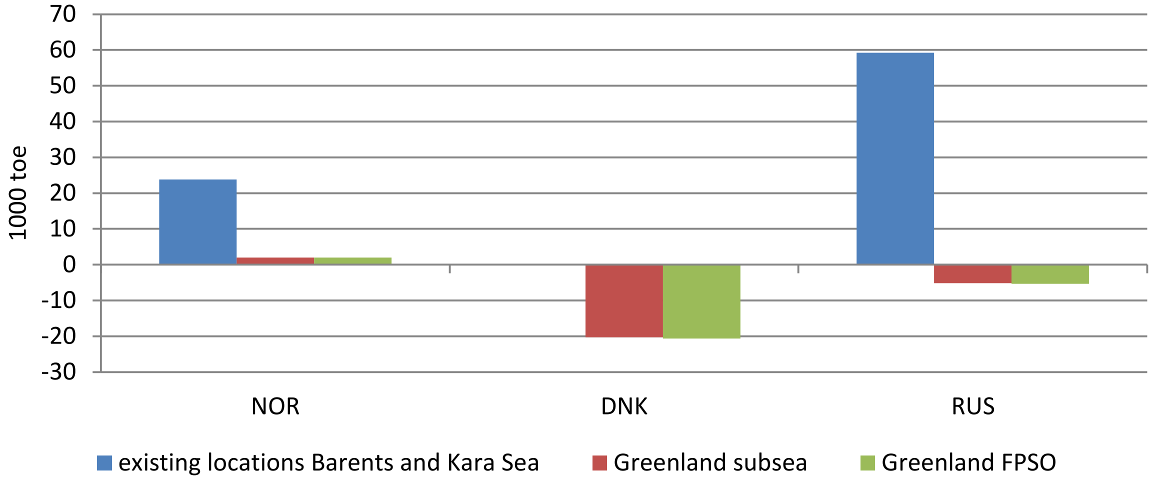


Figure 33: Change in production of electricity in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

The final fuels under examination are processed oil and coal products. Unsurprisingly, and due to the longer distance in terms of value chains compared to other fuels, reactions are very small. Production increases slightly in Norway and Russia in the “existing locations” scenario, relative to the Reference Scenario (Figure 34, panel a). Production increases by 24 000 toe (0.14 %) and 59 000 toe (0.03 %), respectively. Among the non-Arctic countries, Japan is the most affected, as the natural gas share in the overall energy mix is especially large here.

Over all fuels, and probably contrary to intuition, the impact of additional Arctic natural gas production on these fuels is relatively small, apart from some excemptions, such as production of electricity and non-Arctic natural gas in Russia.

Panel a:



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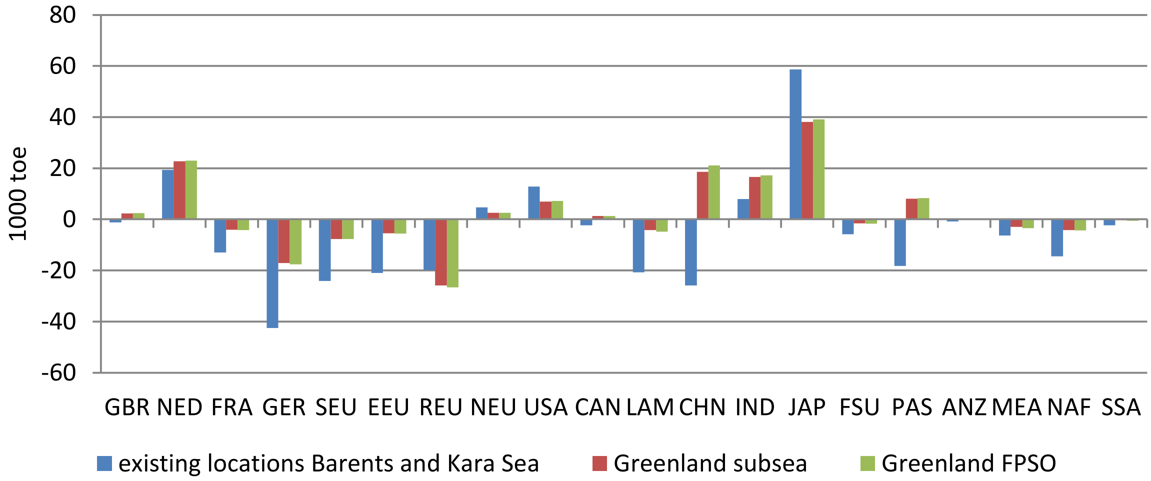


Figure 34: Change in production of petroleum and coal products in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

7.9. Impact on other sectors

One of the benefits of studying additional Arctic natural gas production in a general equilibrium context is the ability to analyse the effects on other sectors of the economy. Other sectors will be affected if they compete with the natural gas sector about inputs, such as labour, capital or other factors of production, or on output markets.

Along the input market channel, we expect negative effects of additional gas production, especially in but not limited to the country in which additional production takes place. As qualified labour is an important and, especially compared to capital and intermediate goods, a less mobile factor of production, we devote a separate section to the impact of natural gas on the labour market (see Section 7.10 below).

Apart from competition about inputs, additional Arctic natural gas production may also have impacts on (1) downstream sectors that use natural gas as an input and (2) on other energy sectors that compete with Arctic natural gas on downstream markets. In the case of downstream sectors, an expansive effect from cheaper energy inputs may counteract any negative effects from competition about other factor inputs. In the case of other energy sectors, the enhanced competition on output markets for energy add to the negative effect of enhanced competition on factor input markets. We analyse the effects on other sectors in Norway (Figure 35), Denmark (Figure 36), and Russia (Figure 37) first and then provide a sector-by-sector analysis for the non-Arctic countries (Figure 38 to Figure 44).

For Norway, we find a small negative effect of additional Arctic production on output values of most other sectors for the “existing locations” scenario relative to the Reference Scenario (Figure 35). Especially the chemicals and manufacturing sectors are hurt by competition on factor markets, with reductions in output by up to 1 % relative to the Reference Scenario. Apart from the non-Arctic natural gas sector, other energy producing sectors, such as the coal or oil producers are not significantly affected. In case of the “Greenland” scenarios, we find significant effects only for the natural gas sector, where output values decrease by -0.2 % relative to the Reference Scenario. Other sectors profit slightly, but only on a marginal scale.

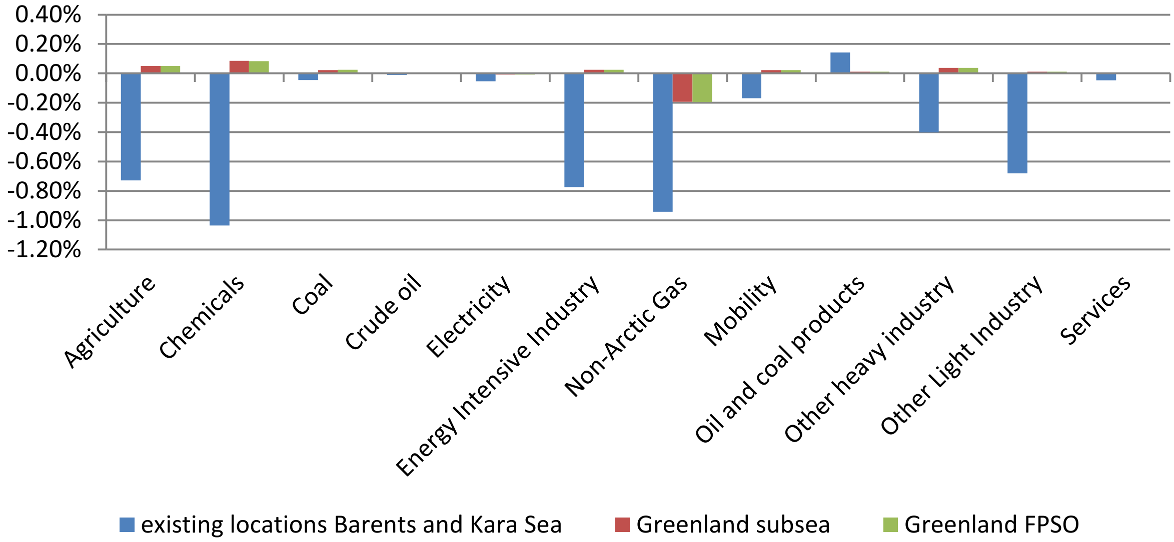


Figure 35: Change in output values per sector (Norway) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As results presented in Section 7.5 have demonstrated, the Danish economy profits most from additional Arctic production, with GDP increasing by up to 1.4 % in the “Greenland” scenarios relative to the Reference Scenario. Figure 36 shows that these gains are realized not only in the country’s natural gas sector, but also in downstream sectors. Especially energy intensive manufacturing sectors and light manufacturing profits from cheaper access to natural gas, output values increase by up to 1.7 % compared to the Reference Scenario. Especially other energy sectors (non-Arctic gas, coal) loose, though only slightly (see also Section 7.8). Individual sectors’ output values are only marginally affected from additional production in Norway or Russia in the “existing locations” scenario compared to the Reference Scenario, also because of the small size of the Danish natural gas sector, where the impact should be largest.

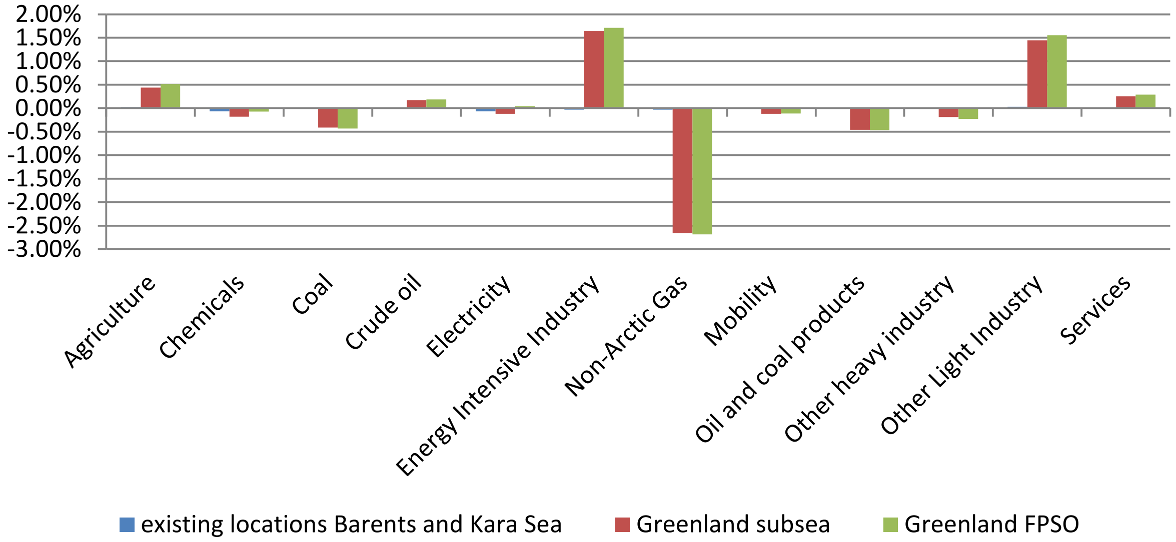


Figure 36: Output per sector (Denmark) in 2040, difference relative to most likely (natural gas)
Source: Own presentation based on DART model results.

Similar to Denmark, sectors in Russia mainly profit from additional Russian Arctic natural gas production (Figure 37). Due to the different production structure in Russia relative to Denmark or Norway, however, other sectors profit. In Russia, it is mainly the chemical and the electricity sectors that gain, in the case of chemicals output value increases by 1.5 % for the “existing locations” scenario relative to the Reference Scenario. Given the importance of natural gas as input for the Russian economy in general and manufacturing in particular, the energy intensive manufacturing sector profits as well. Only agriculture and, as expected, non-Arctic natural gas production is negatively affected but only slightly so. Production of natural gas in Greenland has only small effects on the Russian economy, with small gains in output values in the chemicals industry sector.

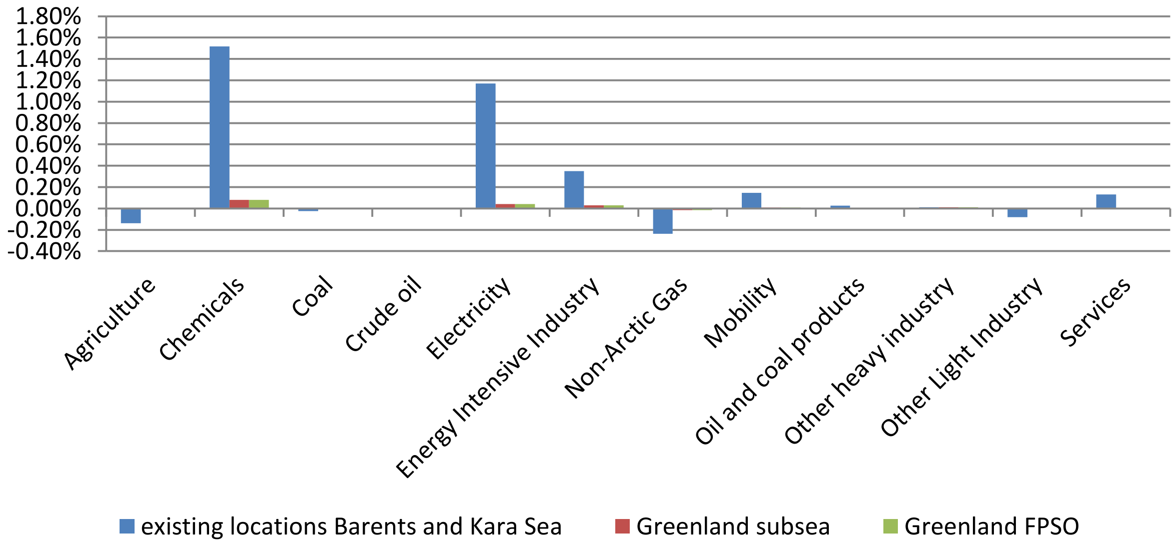


Figure 37: Change in output values per sector (Russia) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Apart from the countries that produce the additional Arctic natural gas the same mechanisms we described above apply also to non-producing countries that are linked to Arctic producers via international goods and factor markets, including migration of employees. We analyse output changes in non-Arctic countries sector-by-sector, studying agriculture (Figure 38), chemicals (Figure 39), energy intensive industries (Figure 40), mobility, which includes air, sea, and land-based transportation (Figure 41), heavy industries (Figure 42), light industries (Figure 43), and services (Figure 44).

Overall, the effects are generally small. Only chemicals and energy intensive industries show significant responses, mainly positive. As before, countries are more affected that are in close proximity and very integrated with producing countries, namely Russia. This holds true especially for countries of the Former Soviet Union (FSU) and non-EU (NEU) countries. Also, other gas producing countries, such as the Netherlands (NED) or North African Countries (NAF) are affected. In the "existing locations" scenario two sectors in FSU benefit in particular; the chemicals industry (+0.75 % relative to Reference Scenario) and energy intensive industries (+0.17 %). Reactions to the "Greenland" scenarios are generally much smaller compared to the "existing locations" scenario, irrespective of country and sector.

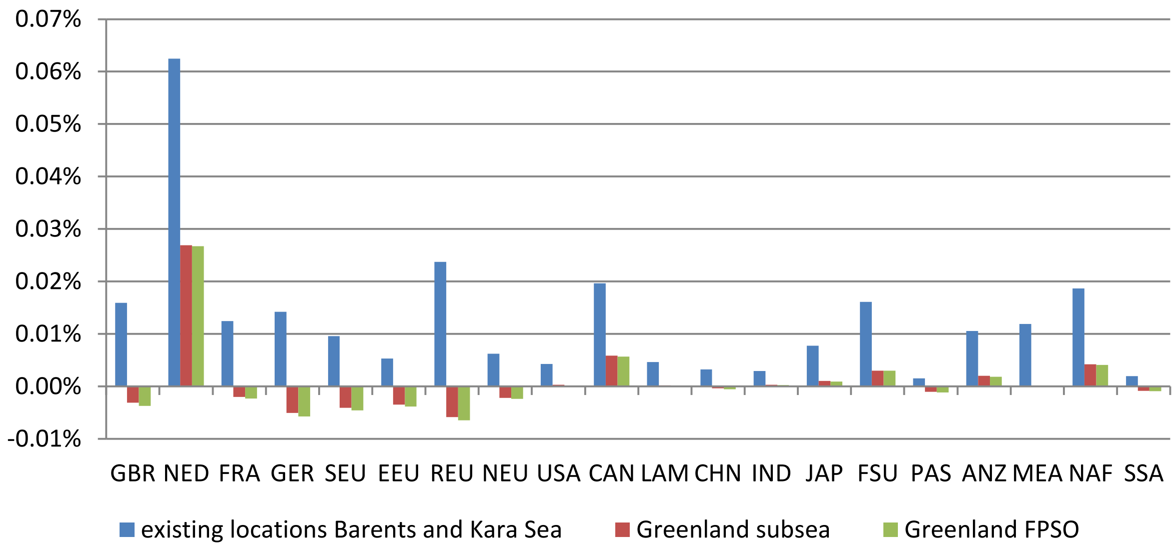


Figure 38: Change in agricultural output values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

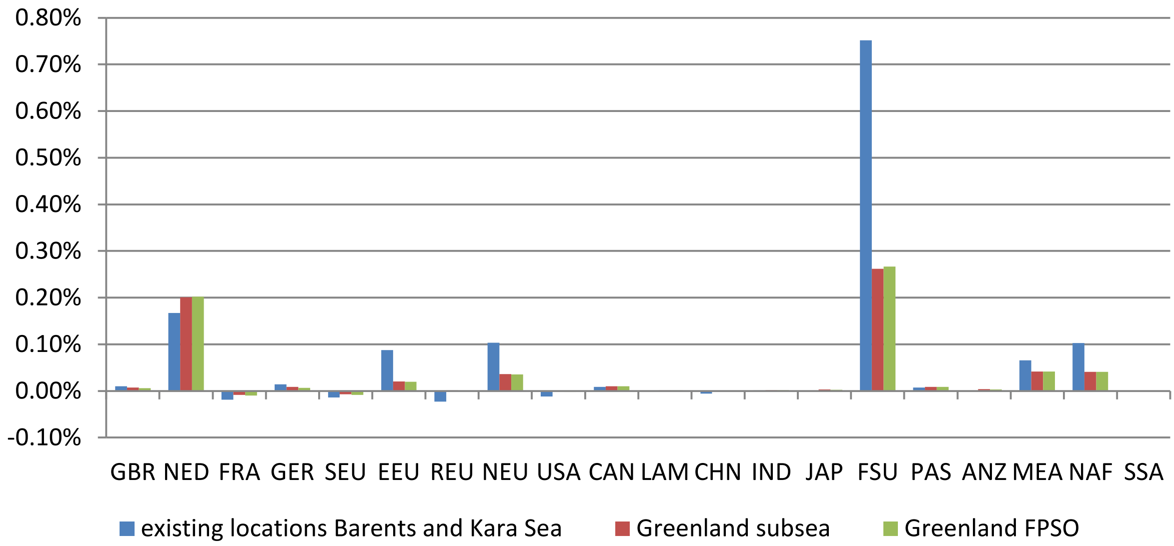


Figure 39: Change in the output value of chemical products in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

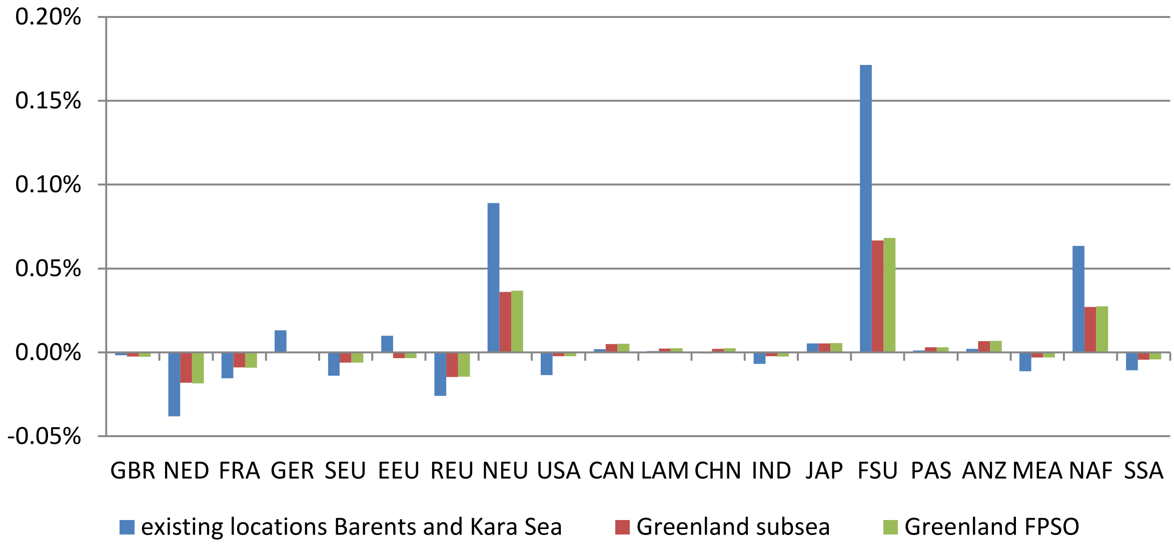


Figure 40: Change in the output value of energy intensive industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

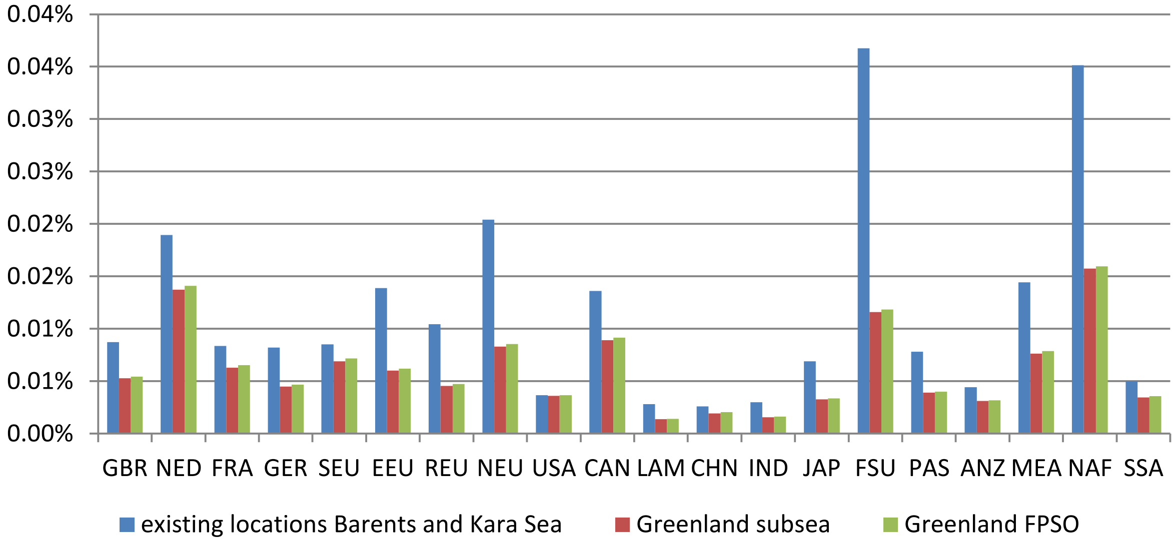


Figure 41: Change in the output value of mobility services in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

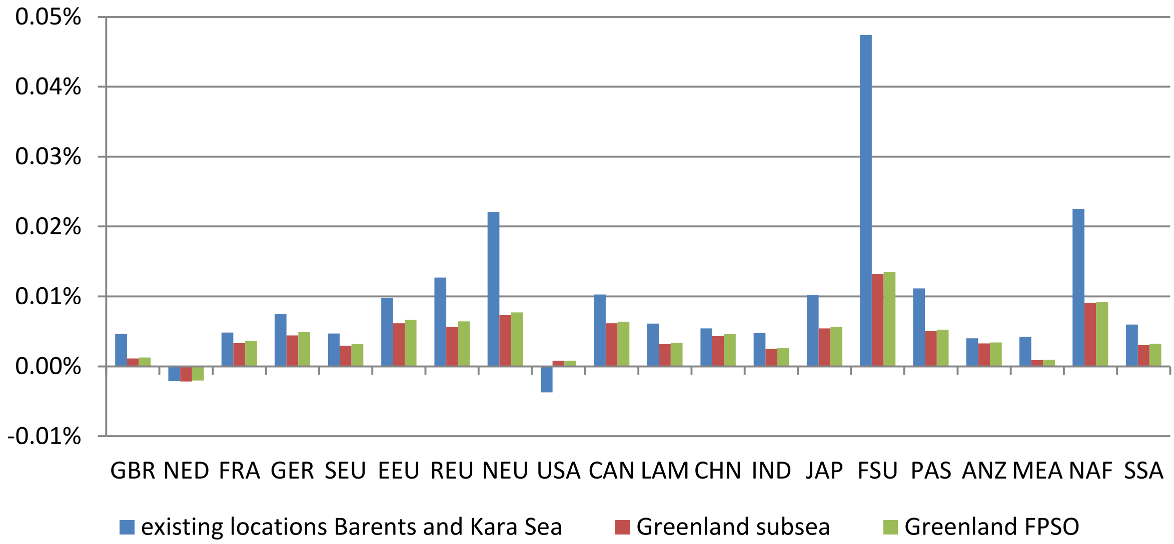


Figure 42: Change in output value of other heavy industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

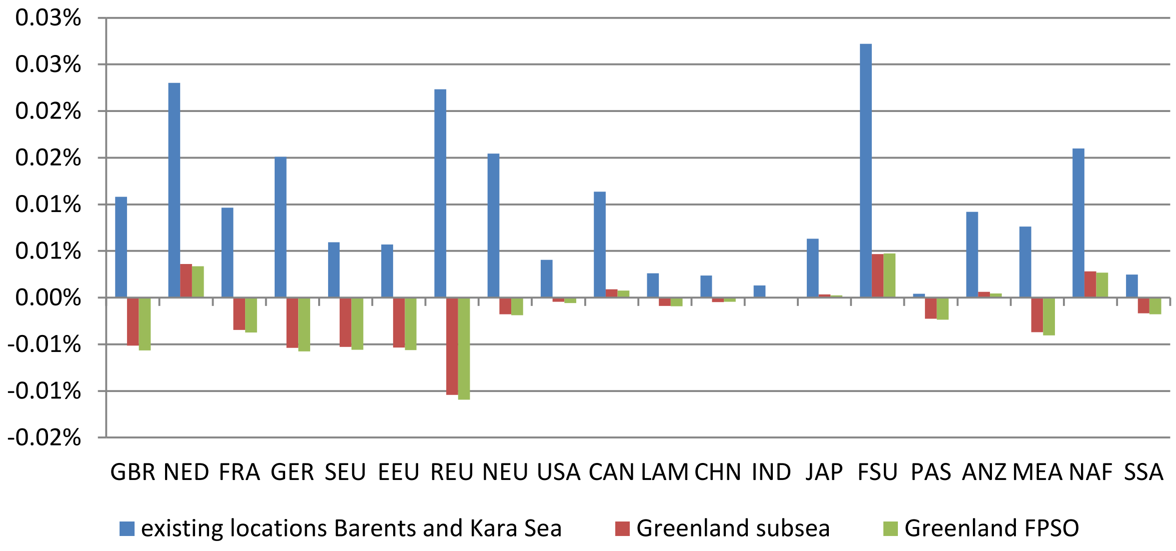


Figure 43: Change in output value of other light industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

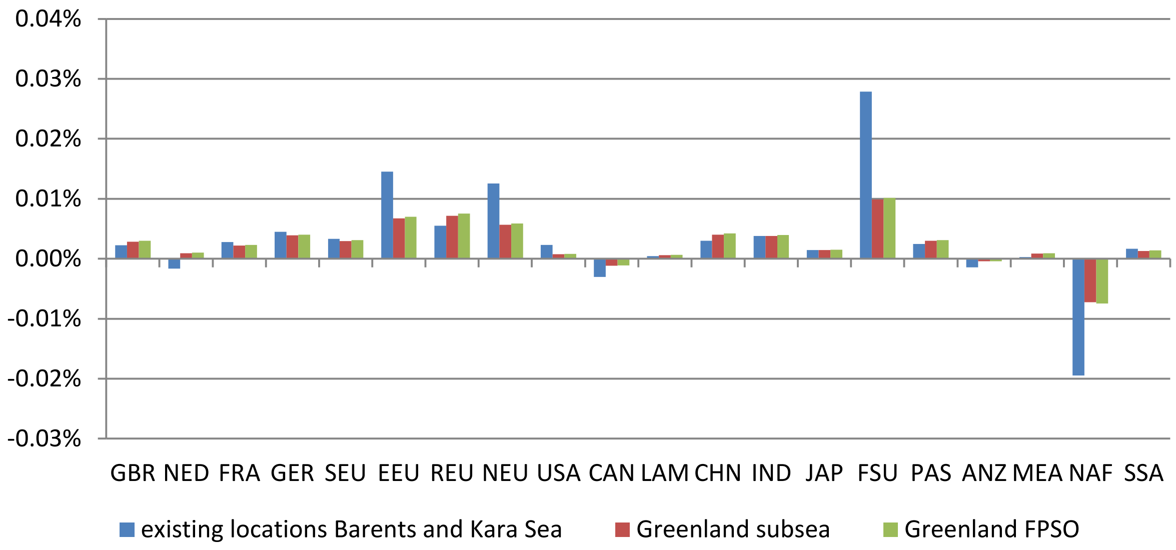


Figure 44: Change in output value of the service sectors in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.10. Impact on the labour market

As explained in Section 7.9, competition of the natural gas producing sector with other sectors about input factors for production is an important channel that drives sectoral and economy-wide activity. Labour is of particular importance in that respect, because it is relatively immobile across countries and supply is only price-elastic in the long run. Especially companies engaging in offshore hydrocarbons production have been facing shortage of highly specialized and qualified labour in the past. This may not only pose a restriction for the expansion of production in the energy sectors, but the resulting high wages may also lead to inflows of labour from other sectors, especially from manufacturing, with negative effects on these industries. At the same time, potential positive effects on sectoral output in the other sectors, as described in Section 7.9, may lead to positive effects on employment.

In the CGE framework employed here an increase of labour in one sector is always compensated by a corresponding decrease in labour in another sector. While this might underestimate the supply of unqualified, low-wage labour in some economies, it is suitable for qualified, high-wage labour, which makes up a crucial part of employment in the production of offshore hydrocarbons. For this reason, we concentrate less on the overall development of employment, but more on inter-sectoral shifts of labour input. We concentrate first on those shifts for the three Arctic countries Norway (Figure 45), Denmark (Figure 46), and Russia (Figure 47), which are supposedly affected most. After that we present a sector-by-sector presentation of the non-Arctic economies (Figure 48 to Figure 58).

For Norway, the increase of labour input in the natural gas sector (Arctic and non-Arctic) of 2.7 % in the "existing locations" scenario relative to the Reference Scenario comes at the expense of reduced labour input especially in the manufacturing sectors (Figure 45). Employment in the chemicals industry sector is hit most (- 1 %), but also the energy intensive industry sector, heavy industry, light industry, production of oil and coal products, as well as agriculture employ less, with decreases of 0.3 % to 0.7 % in the "existing locations" scenario relative to the Reference Scenario. Labour input in Norway is not significantly altered by gas production in Greenland, with the exception of the natural gas sector, where input decreases by 0.4 % in the "Greenland" scenarios relative to the Reference Scenario.

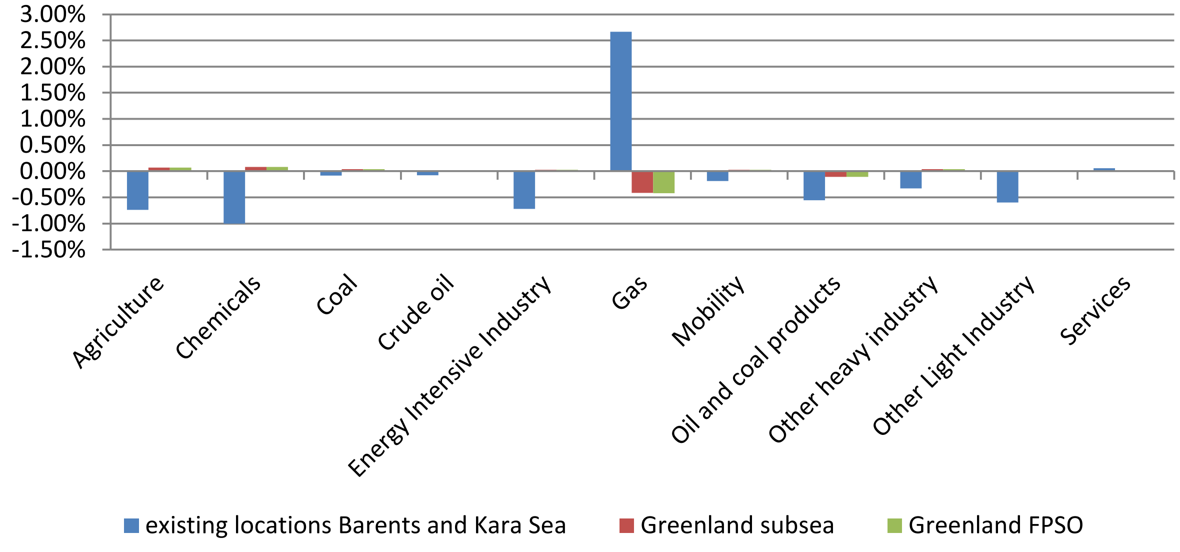


Figure 45: Change in labour input value per sector (Norway) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Additional natural gas production in Greenland has a much larger effects on the Greenlandic/Danish labour market compared to Norway, due to the much smaller size of the natural gas labour market in Greenland/Denmark in the first place. In line with the increase in output in the natural gas industry (see Figure 36 in Section 7.9), labour input in the natural gas industry skyrockets in the "Greenland" scenarios compared to the Reference Scenario (Figure 46). The sector suffering most in terms of employment is the production of oil and coal products, with decreases of 1.2 % if subsea technology is used and 1.5 % for FPSO technology, the difference being due to the higher capital intensity (and consequently lower labour intensity) of subsea production. Also, the chemicals industry, coal production, the mobility services sector, and heavy industry sectors reduce employment by 0.4 % to 0.9 % relative to the Reference Scenario. Unlike Norway, there is one sector that expands employment if gas production increases. The crude oil production sector increases labour input by 1.4 % in the "Greenland" scenarios relative to the Reference Scenario. Potential reasons include synergies in the necessary infrastructure or increased energy demand in downstream industries, such as energy intensive or light industry sectors, where output increases (see Figure 36 in Section 7.9). We find no significant reaction of sector-level employment levels in Denmark to additional gas production in Norway, even employment in the (small) natural gas sector decreases by less than 1 % in the "existing locations" scenario relative to the Reference Scenario.

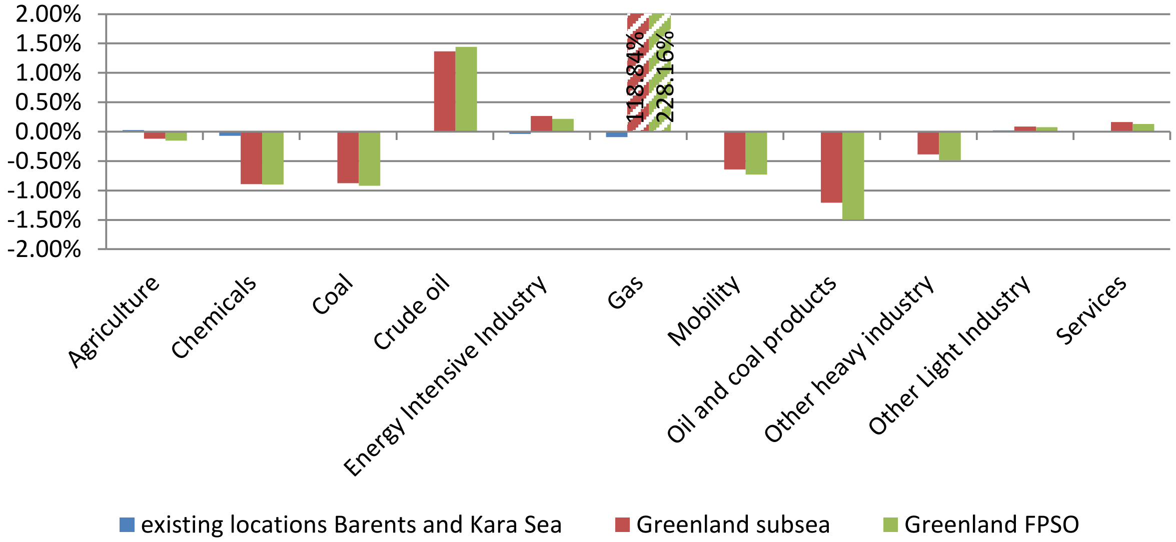


Figure 46: Change in labour input value per sector (Denmark) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As production in Yamal increases, labour input shifts between the different sectors in Russia (Figure 47). The increased labour input in the natural gas sector is fed mostly by decreased employment in the oil and coal products sector (-0.7 % in the "existing locations" scenario relative to the Reference Scenario) and also, though to a smaller extent, from various industrial sectors. In general, however, decreases in employment in the other sectors are smaller and more dispersed compared to Norway and Denmark. Also, unlike Norway and Denmark, the chemicals industry sector increases employment, analogue to the increase in sectoral output (see Figure 37 in Section 7.9).

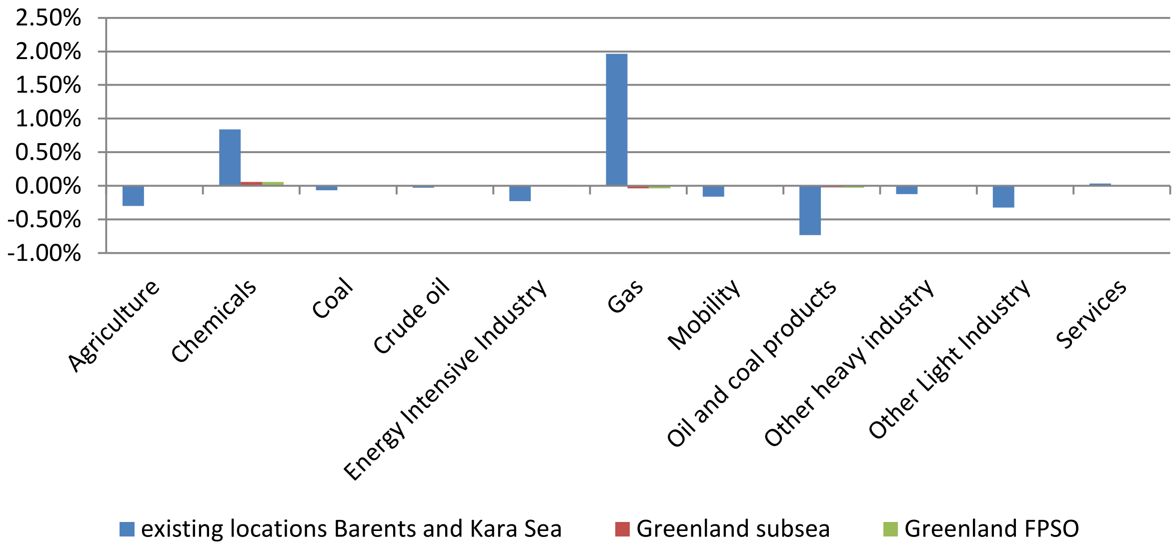


Figure 47: Change in labour input value per sector (Russia) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As international integration of labour markets is low, effects on labour markets in non-Arctic economies are small. In the following we analyse changes in labour input in non-Arctic countries sector-by-sector, studying agriculture (Figure 48), coal production (Figure 49), chemicals (Figure 50), energy intensive industries (Figure 52), the natural gas sector (Figure 53), mobility services (Figure 54), heavy industries (Figure 55), petroleum and coal products (Figure 56), light industries (Figure 57), and services (Figure 58).

As expected, the largest change in labour input, regardless of the scenario, is observable in the natural gas sector, where major non-Arctic natural gas producers, including the North African Countries (NAF), the Netherlands (NED), and also Australia and New Zealand (ANZ). Still, reductions in employment in the natural gas sector are well below 0.3 % relative to the Reference Scenario for all countries and scenarios (Figure 53). Overall, Norway is the country hit most by additional Arctic production in another country, with a drop in employment of 0.4 % in the “Greenland” scenarios (Figure 45).

Other sectors in non-Arctic countries are generally not significantly affected, with changes in employment of less than 0.01 %. Notable exceptions are the chemicals industry sector and, to a much smaller degree, the sectors producing petroleum and coal products. In the chemicals industry sector, cheaper natural gas fosters employment, especially in the Netherlands (NED) and the countries of the Former Soviet Union (FSU). Still, the maximum increase is 0.6 % in the FSU countries for the “existing locations” scenario relative to the Reference Scenario. In the petroleum and coal products, employment decreases universally in all non-Arctic countries, but by less than 0.14 %.

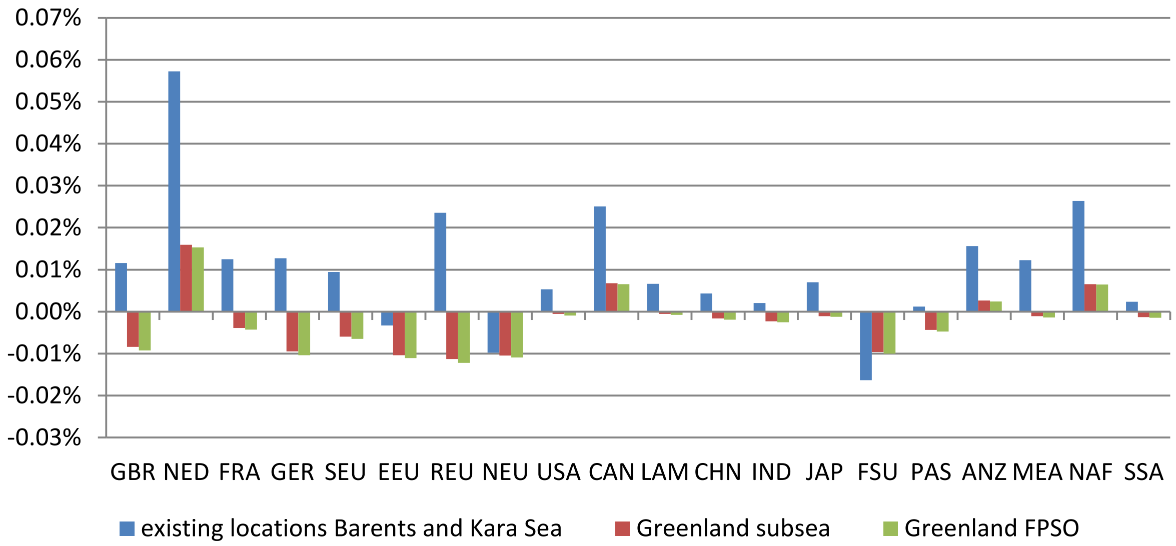


Figure 48: Change in labour input value in agriculture in 2040, difference relative to Reference Scenario
Source: Own presentation based on DART model results.

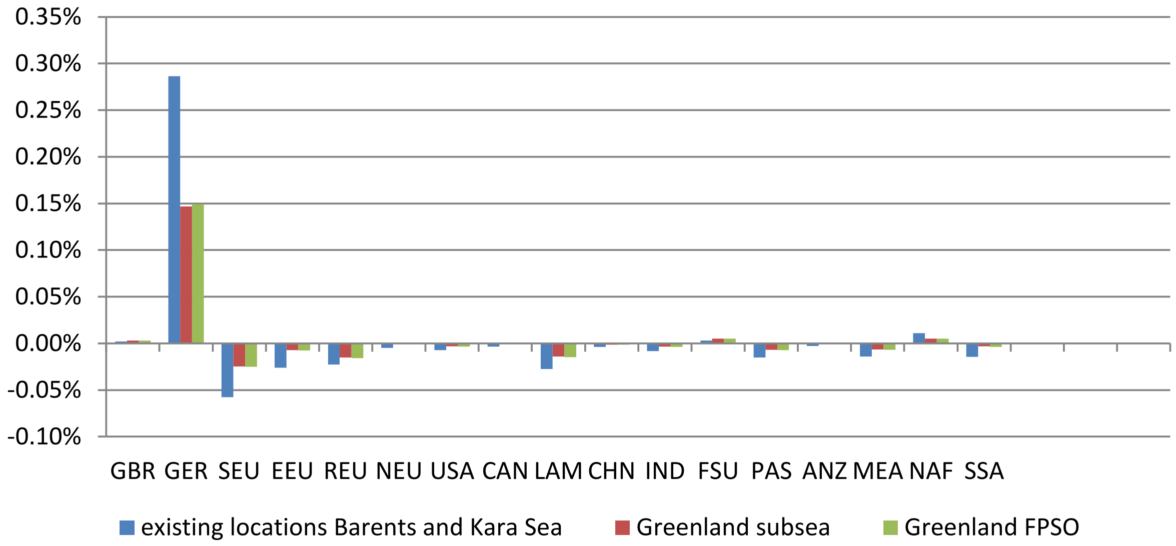


Figure 49: Change in labour input value in the coal sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

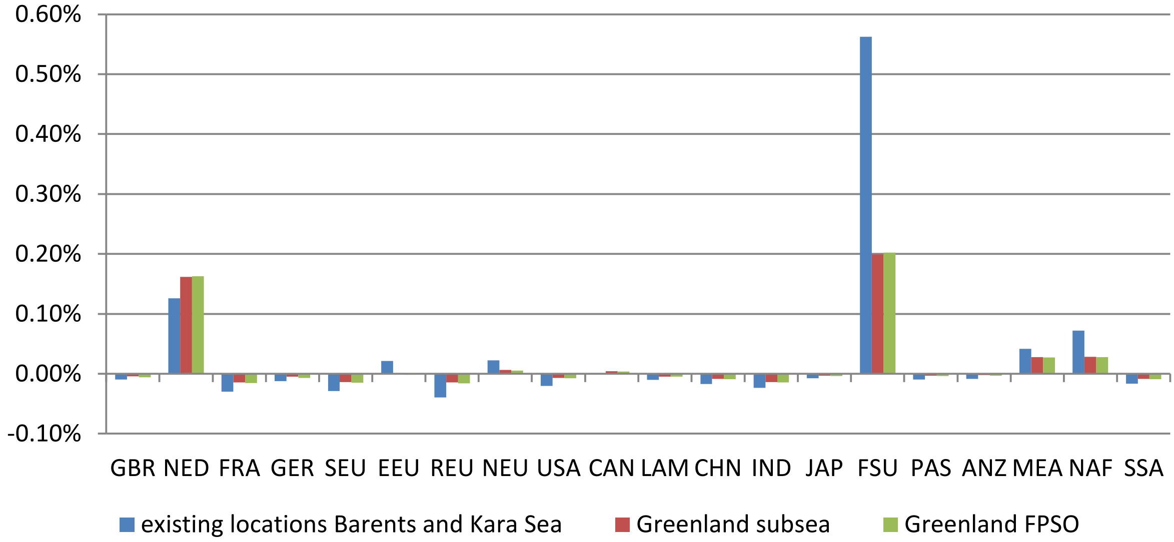


Figure 50: Change in labour input value in the chemical products sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

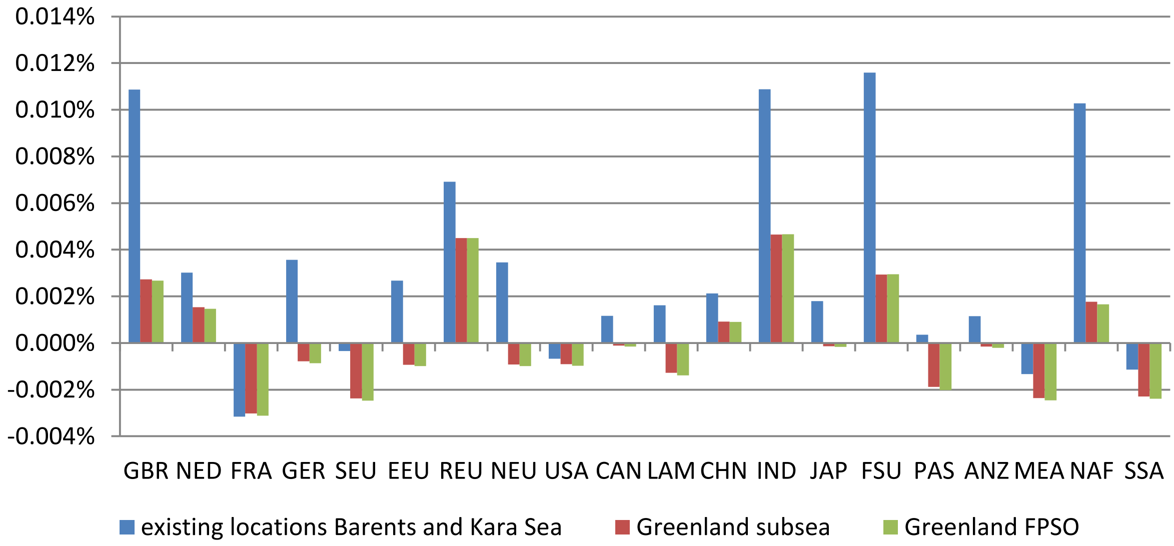


Figure 51: Change in labour input value in the crude oil sector in 2040, difference relative to Reference Scenario
Source: Own presentation based on DART model results.

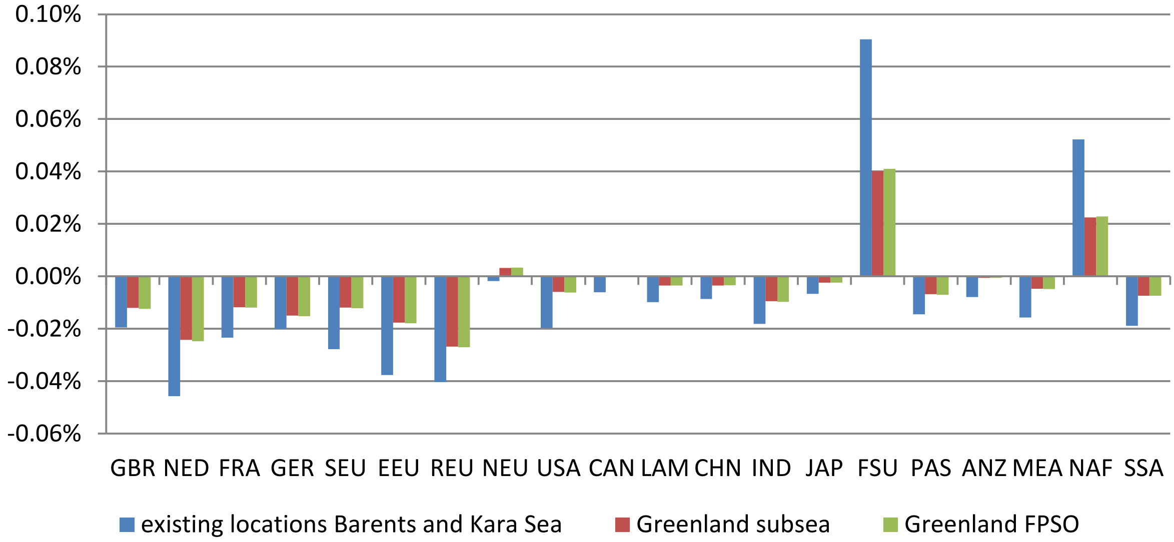


Figure 52: Change in labour input value in the energy intensive industries sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

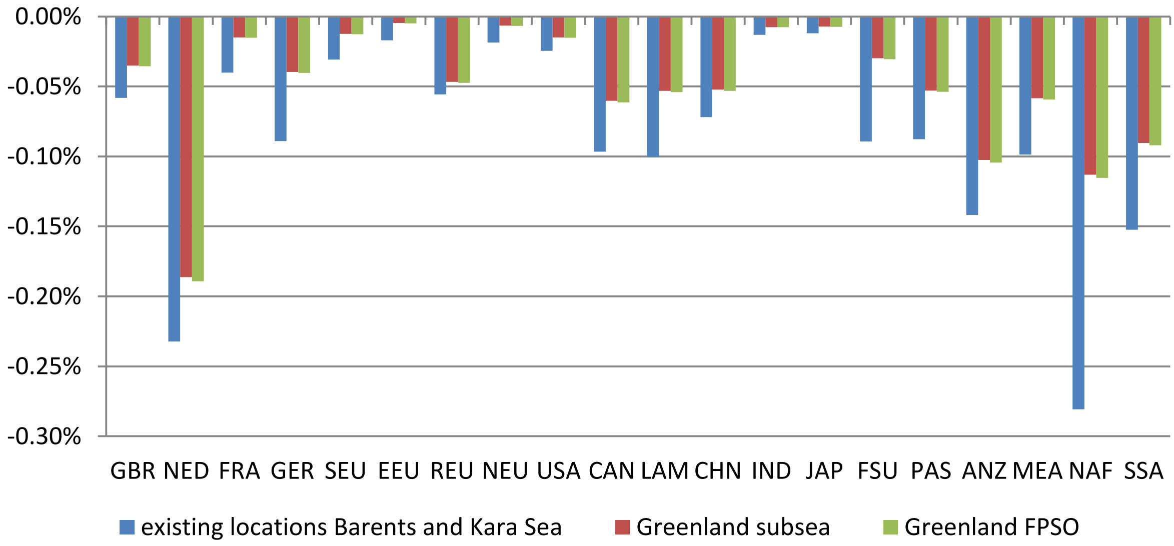


Figure 53: Change in labour input value in the natural gas sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

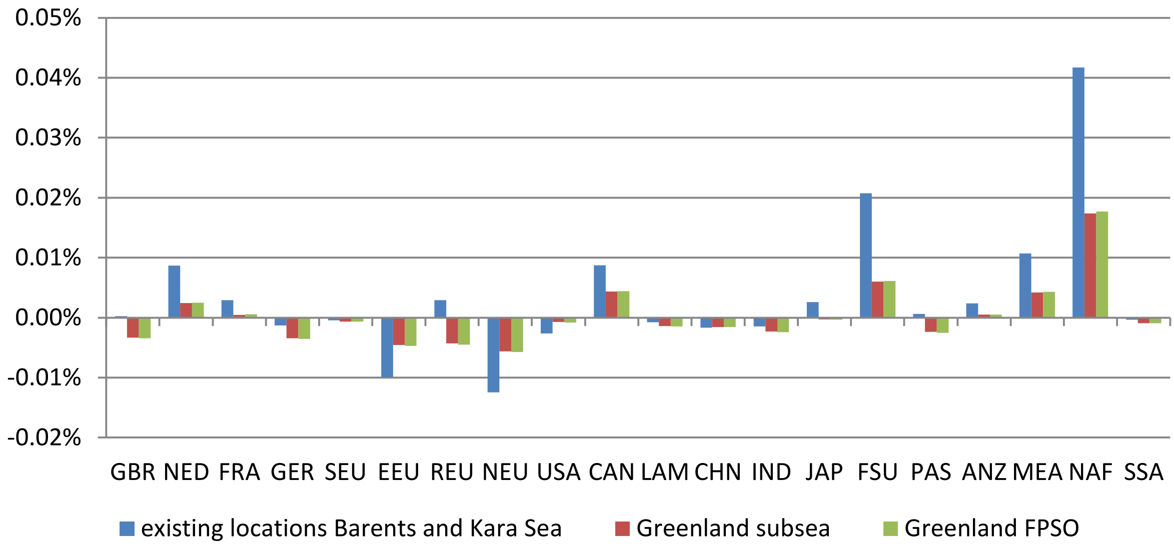


Figure 54: Change in labour input value in the mobility sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

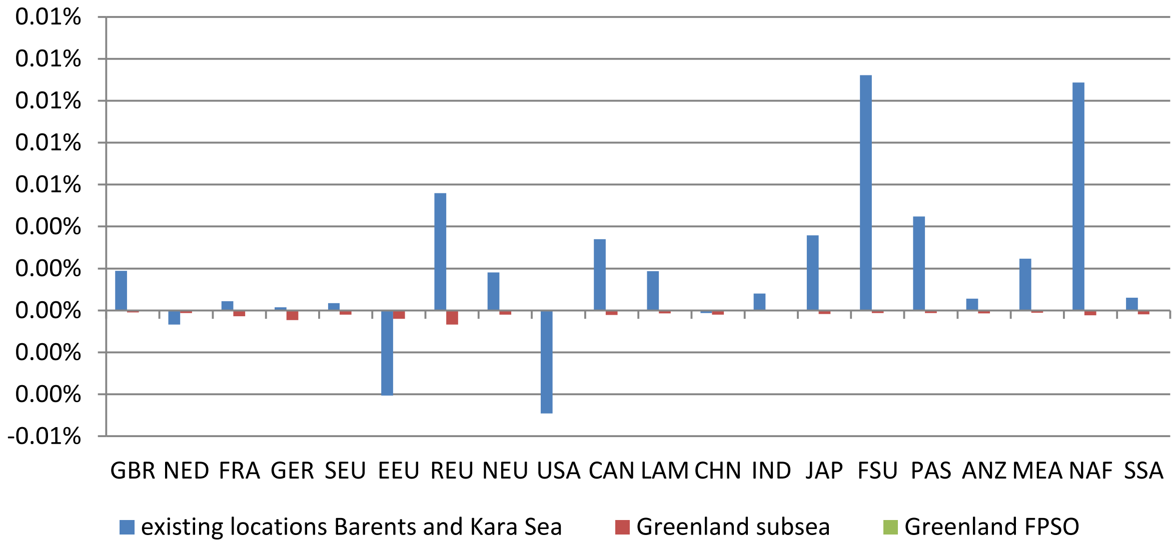


Figure 55: Change in labour input value in other heavy industries in 2040, difference relative to Reference Scenario
Source: Own presentation based on DART model results.

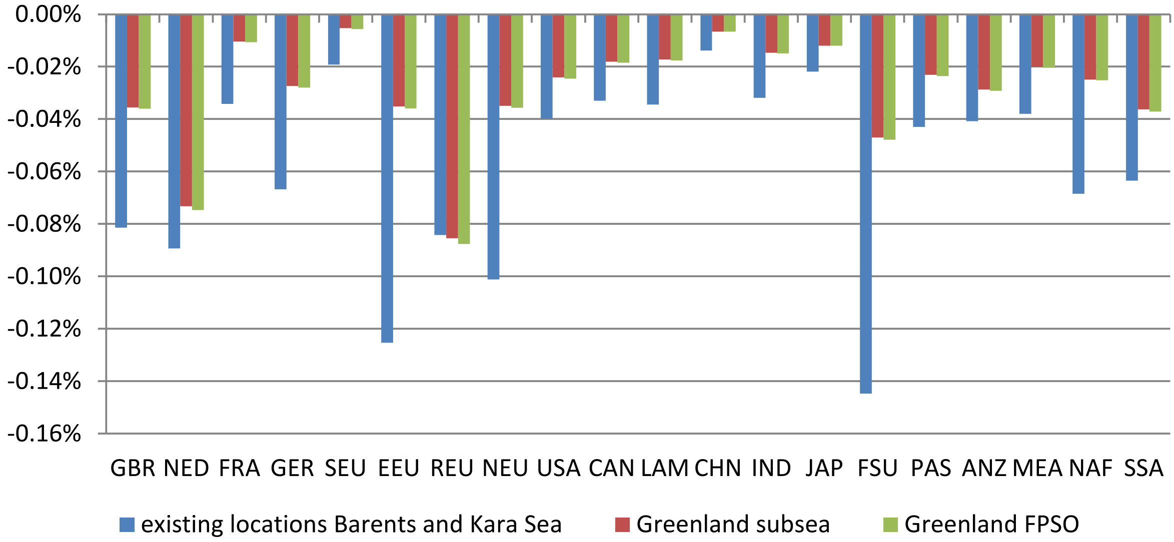


Figure 56: Change in labour input value in the petroleum and coal producing sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

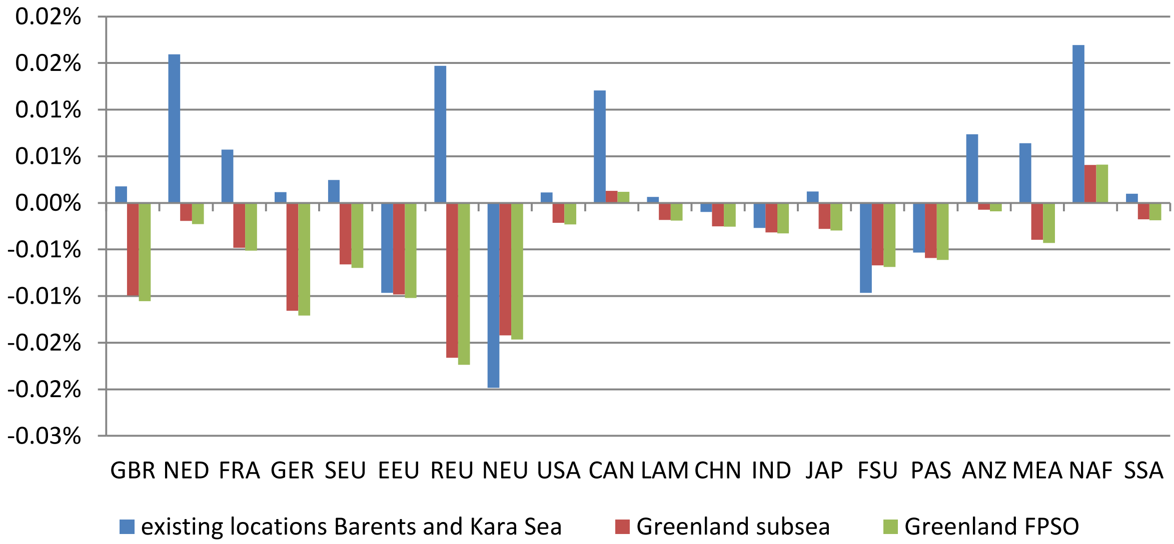


Figure 57: Change in labour input value in other light industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

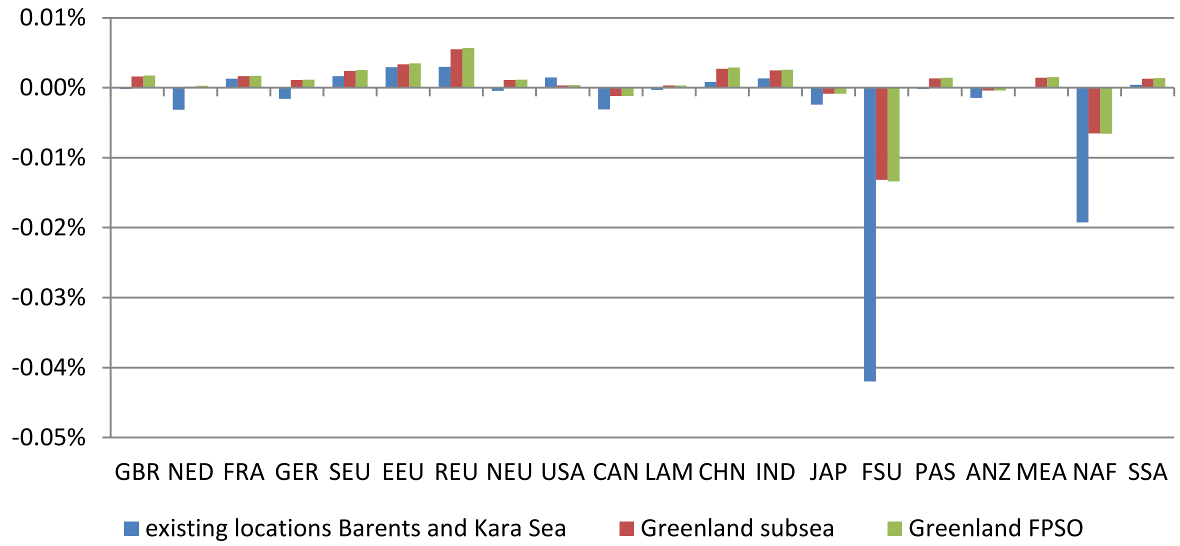


Figure 58: Change in labour input value in the service sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.11. Impact on international decarbonisation efforts

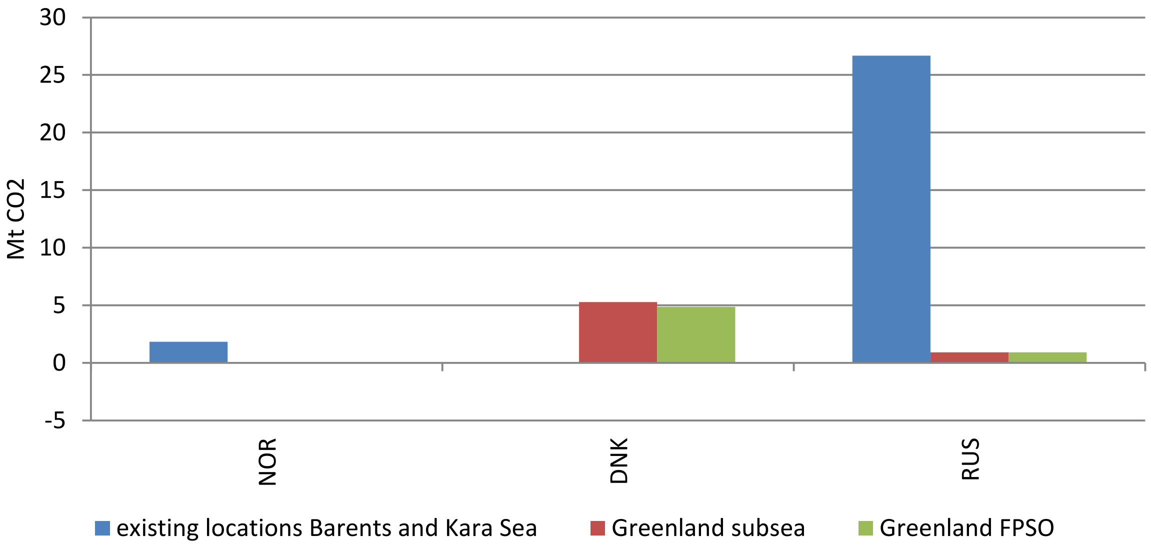
The decarbonisation of economic activity is one of the major policy goals globally. The EU, for example, aims at a 40 % reduction of CO_2 emissions relative to 1990 in 2030. Obviously, the composition of the EU's energy mix is a key determinant of CO_2 emissions in Europe and globally, and so is the production of natural gas. Additional natural gas production increases the share of natural gas in the energy mix (see Section 7.8). Natural gas has an ambiguous role for decarbonisation. On the one hand, natural gas competes with comparably less carbon intensive renewable sources, such as wind and solar power, and nuclear power. On the other hand, natural gas production more directly competes with coal and petroleum products, which are more carbon intensive. The general equilibrium framework or our analysis enables us to depict the resulting net effect of additional Arctic gas supply on CO_2 emissions. CO_2 emissions turn out to increase following increased production of natural gas, both regionally and worldwide.

Global CO_2-emissions from burning coal, gas and oil increase by 58.2 mt (0.1 %) in the "existing locations" scenario and by around 22 mt in the "Greenland" scenarios (0.04 %) relative to the Reference Scenario. Given the small volume of additional natural gas from the Arctic in both scenarios relative to global energy production, and given that natural gas is less energy intensive than oil and coal, the increase is surprisingly sizable. In fact, we find that emission intensity increases in all countries and country groups analysed (Figure 59). Obviously, the impact on producing countries is largest. Russia alone accounts for almost half of the global increase in CO_2-emissions in the "existing locations" scenario, with an increase of 26.7 mt. Norwegian CO_2-emissions, on the other hand, increase by only 1.8 mt in the same scenario, the figure is surpassed by increases in Non-EU Europe (NEU), China (CPA), the Former Soviet Union (FSU) the USA, and a number of other countries that do not increase their own natural gas production.

Given the smaller projected volume of additional production in Greenland, the impact of is smaller. In this scenario Greenland/Denmark itself accounts for the largest share in the global CO_2-emission increase, with an increase of 5 mt, followed by China (CPA), Non-EU Europe (NEU), Germany (GER), and the Middle East (MEA).

Overall, additional natural gas production in the Arctic is detrimental to reaching the EU's and global climate protection goals. Our results indicate that the additional natural gas does not replace more carbon intensive fuels such as coal or oil, or potential gains from fuel switching are overcompensated by the global increase in GDP (see Section 7.5).

Panel a:



Panel b:

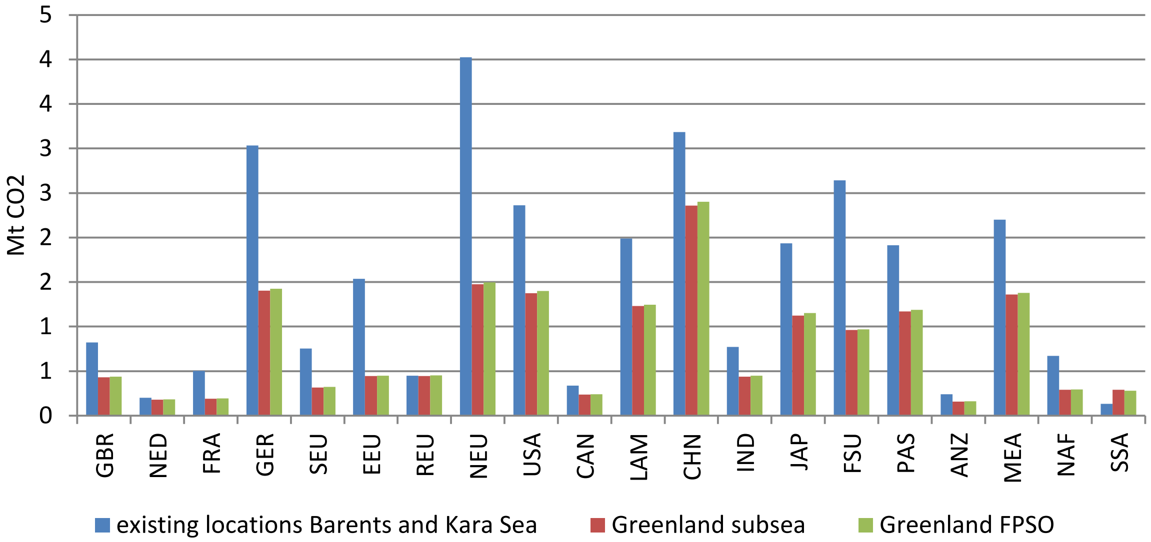


Figure 59: Change in emissions from coal, gas, oil (Mt CO2) in 2040, absolute difference to Reference Scenario
Source: Own presentation based on DART model results.

7.12. Excursus: Russian embargo (Scenario 5)

As Russia is a major supplier of natural gas on the EU's gas market, a Russian gas embargo is one of the prototypical threat scenarios regarding security of supply in Europe. Compensation through Arctic gas fields in non-Russia Europe are one potential counterstrategy against such a threat.

In this scenario, we model a Russian embargo to find out whether this supply shortage would initiate further development of European Arctic gas fields relative to the Reference Scenario in order to ensure the EU's security of supply. It should be noted that we do not take into account other so far untapped sources of natural gas in Western Europe, such as non-conventional sources, which might alter the picture significantly. From a modelling perspective, it is irrelevant which country or countries impose a hypothetical embargo or boycott. We model the embargo or boycott as a lasting cut-off of all trade in natural gas between Russia and countries of the EU.

In the following we present again both direct effects on the gas market using the partial equilibrium model COLUMBUS as well as indirect effects on the rest of the economies using the CGE-model DART.[11] For the benefit of comparison, we also show the results for the "existing locations" scenario, too.

7.12.1. Arctic production, destinations of Arctic LNG, and impact on the European import portfolio

Indeed, model-driven investment in facilities in the European Arctic is intensified once supply from Russia is stopped. As a consequence, Arctic gas from European facilities becomes a substantial supply source for the EU (Figure 60). Especially in Greenland and in the Norwegian Barents Sea model-driven investment takes place. By 2040, capacities increase up to 42 mtoe/50 bcm in Greenland and 50 mtoe/54 bcm in the Norwegian Barents Sea. The Snøhvit facility, however, is not enlarged and stays at its initial capacity of 5.9 bcm. This is due to the fact that the discounted capital costs in a subsea facility exceed the costs for an FLNG-facility. Instead of enlarging the existing subsea facility it is economically more reasonable to invest in FLNG facilities in Greenland.

[11] Under this scenario, starting in 2015, the gas exports from Russia to the European Union are eliminated. To reach this objective, the corresponding import taxes in the European Union are increased to very high levels that eliminate trade between Russia and the European Union. To avoid (re)exports from transit countries, we also increased the tariff to eliminate trade between the former Soviet Union (FSU) and Eastern Europe (EEU). To give more room to countries to adapt to the dramatic change in the gas market and trade, the Armington elasticity of substitution between imports from different regions has been increased from 8 to 14 in all regions, except in EEU where it has been increased to 10.

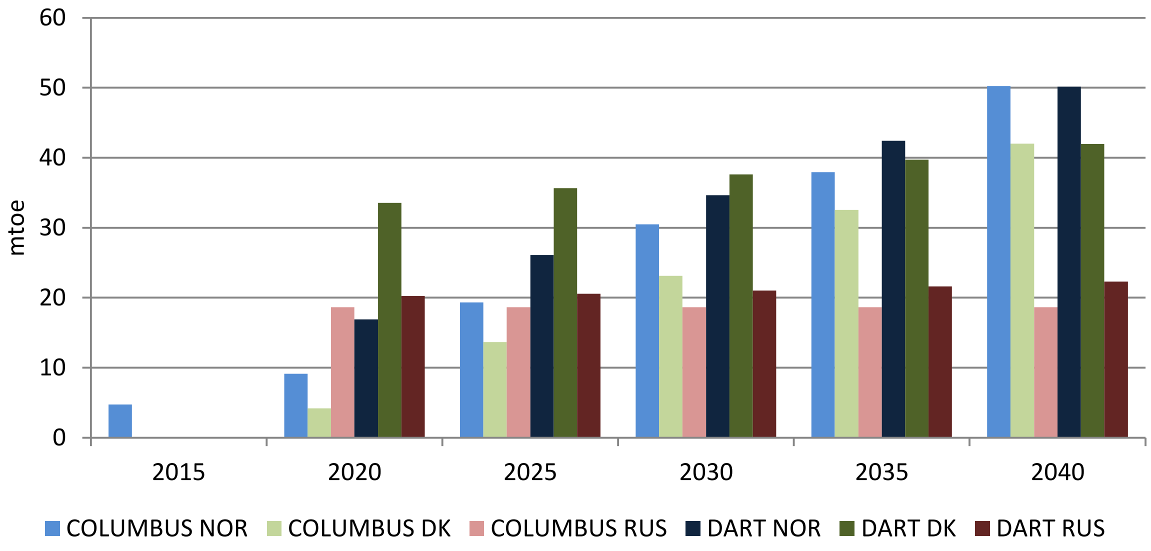


Figure 60: Arctic production under Russian embargo, difference to Reference Scenario (mteo). Source: Own presentation based on model results.

While volumes from Greenland are exclusively delivered to European LNG-terminals, destinations of Norwegian LNG are more diverse (Figure 61). As such, until 2030 Japan and Korea receive more than 50 % of Norwegian LNG. Compared to the Reference Scenario, however, Europe receives large quantities of Arctic LNG as well. In 2040, about 35 bcm are delivered from Norwegian fields in the Arctic to Europe if exports from Russia to the EU are stopped. For comparison, in the Reference Scenario, only 0.2 bcm were delivered from Snøhvit to Europe in 2040.

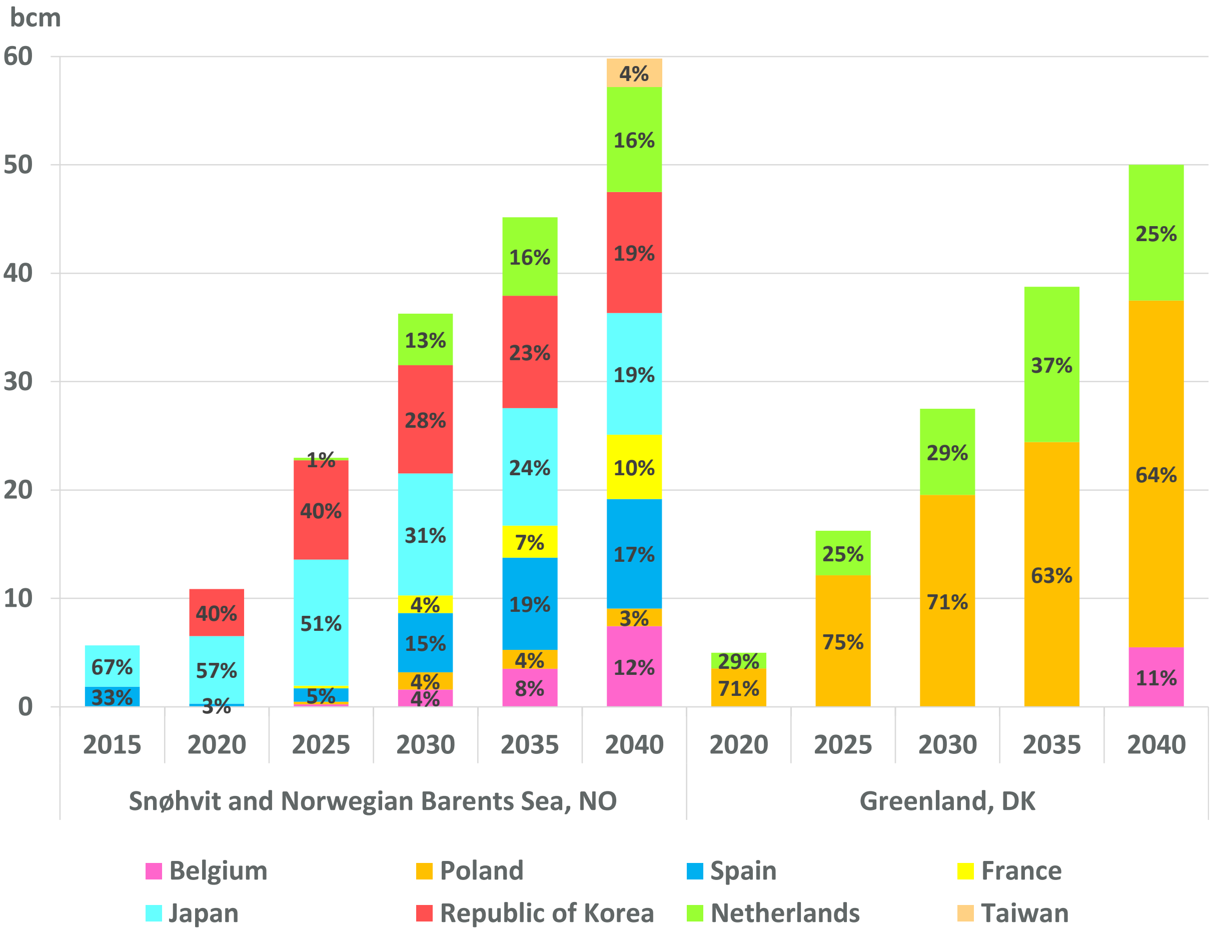


Figure 61: Destinations of European Artic LNG under Russian Embargo (bcm)
Source: Own presentation based on COLUMBUS model results.

The Russian embargo has a large impact on the EU's gas supply portfolio. Since Russia, the most important European pipeline supplier, stops exports to Europe, LNG volumes from the Middle East, the U.S. and the European Arctic gain in importance. As Figure 62 shows, the share of LNG in the EU's import portfolio increases up to about 60 % in 2040 compared to 30% in the Reference Scenario. LNG from the European Arctic represents about 6 % of the European import portfolio in 2025 but increases to about 18 % in 2040. Hence, if Russia stops exporting to Europe, new supply from the Arctic becomes more important. Yet, as shown before, volumes from these facilities are only partly transported to Europe since, as for the Reference Scenario, volumes are also shipped to Asia.

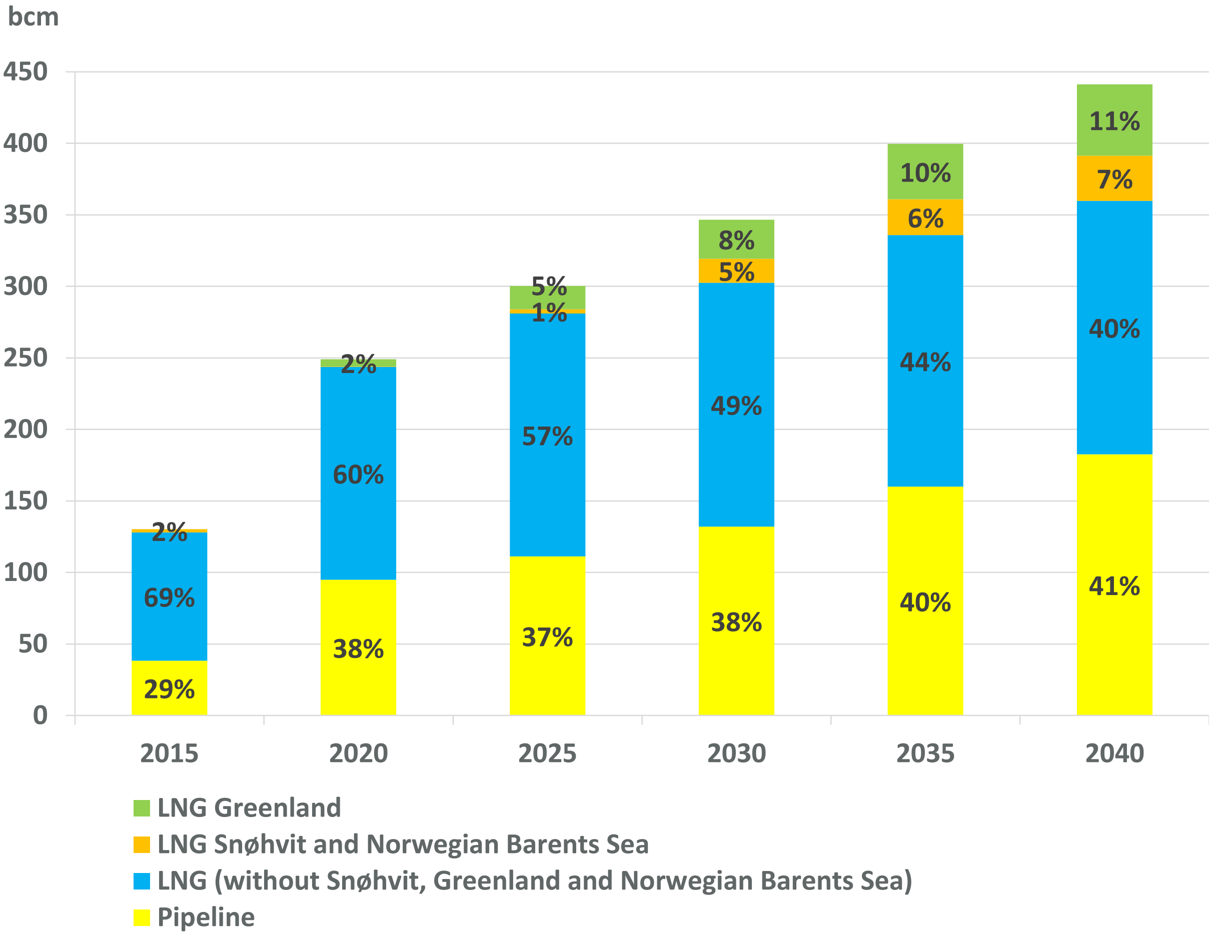
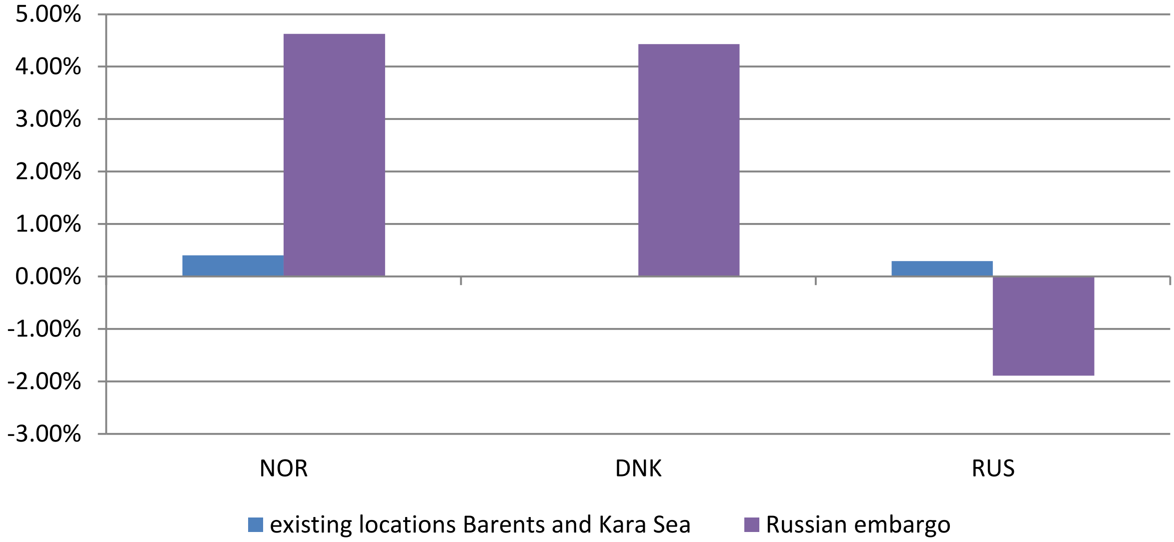


Figure 62: European import of natural gas under Russian Embargo (bcm)
Source: Own presentation based on COLUMBUS model results.

7.12.2. Impact on GDP and welfare

A drastic step such as cutting all natural gas trade between Russia and the EU has significant long-term economic implications, both for Russia and other European countries. Without gas exports to the EU, Russian GDP in 2040 is 1.9 % lower relative to the Reference Scenario (Panel a of Figure 63). On the other hand, Norwegian and Danish GDP increase by more than 4.4 %, as additional gas is produced and exported. Economic development is affected unevenly in the European Union. Countries in the East of the EU (EEU), where some countries are completely relying on natural gas from Russia, GDP is 1.7 % below the Reference Scenario, while other EU countries are practically not affected in the long run (Panel b of Figure 63). Global GDP decreases by 0.05 %. Both losses in Eastern EU countries and gains in Norway and Denmark are even larger in terms of equivalent variation (Figure 64).

Panel a:



Panel b:

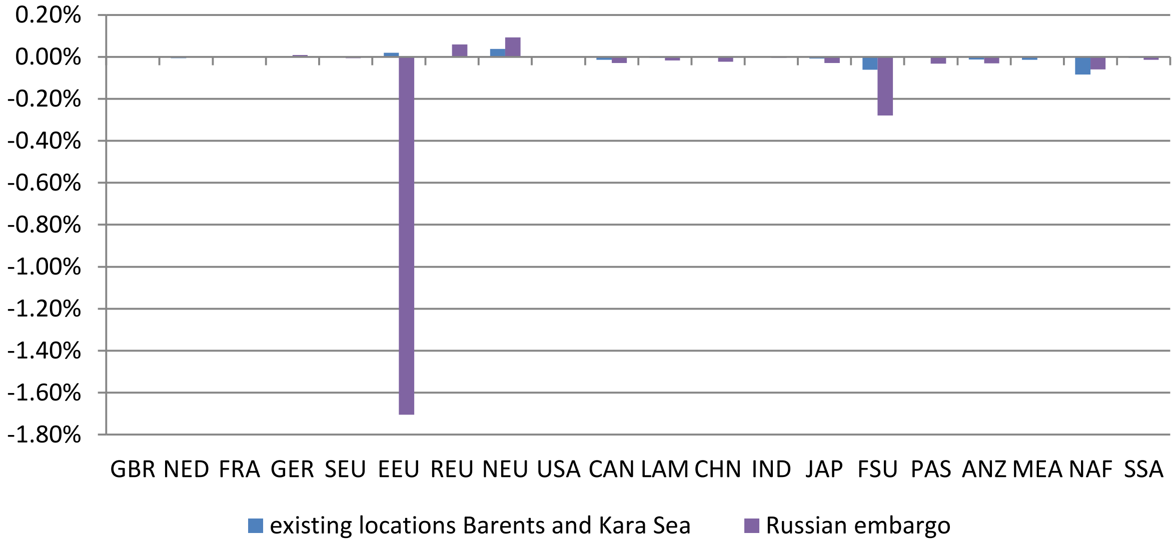
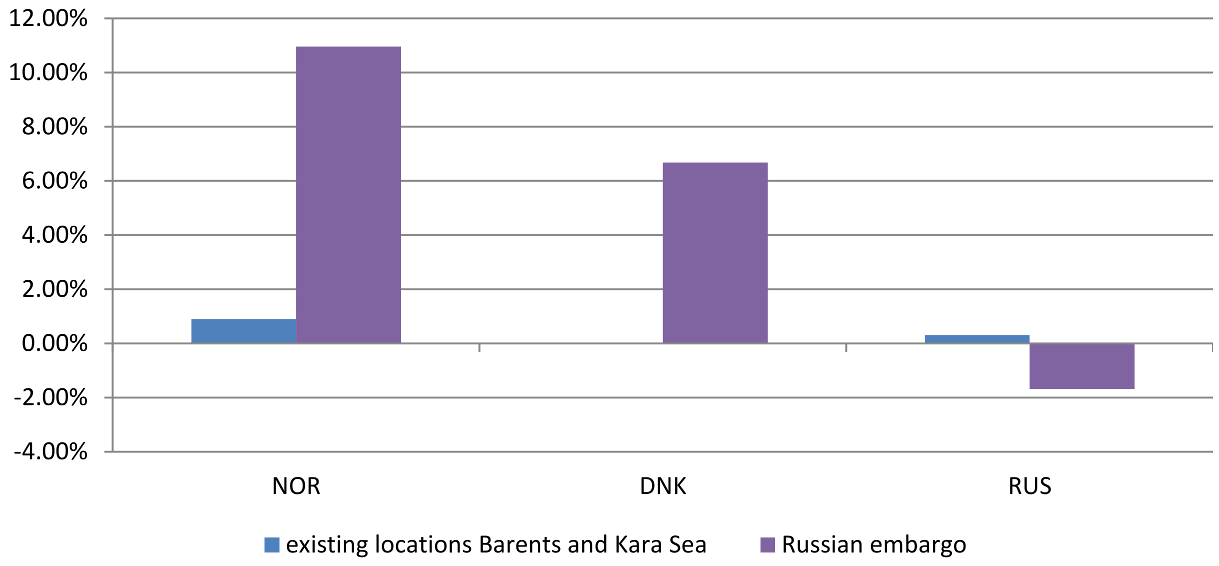


Figure 63: Change in GDP in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

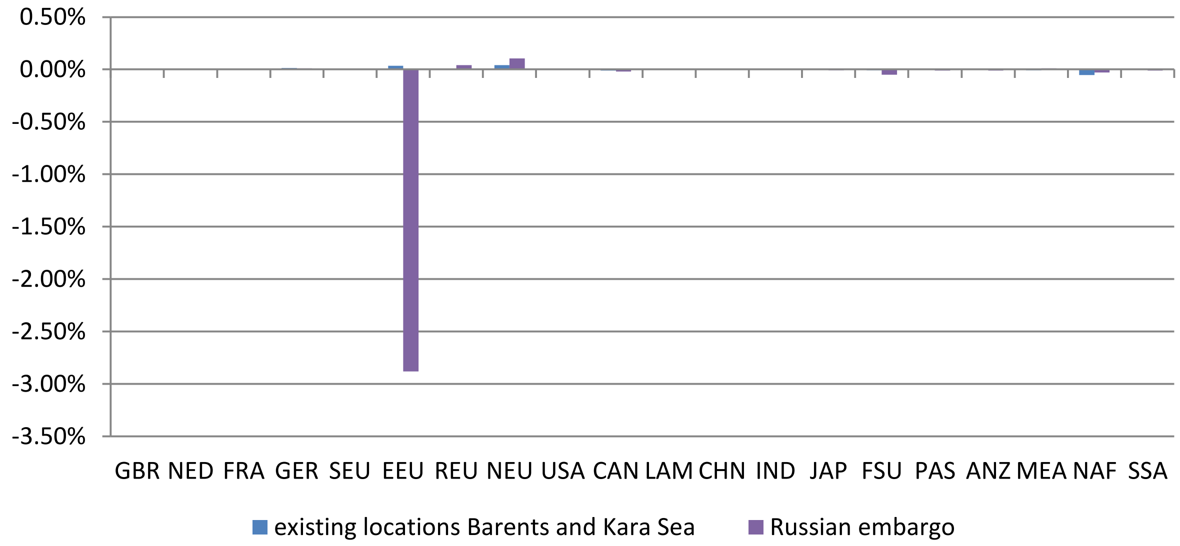


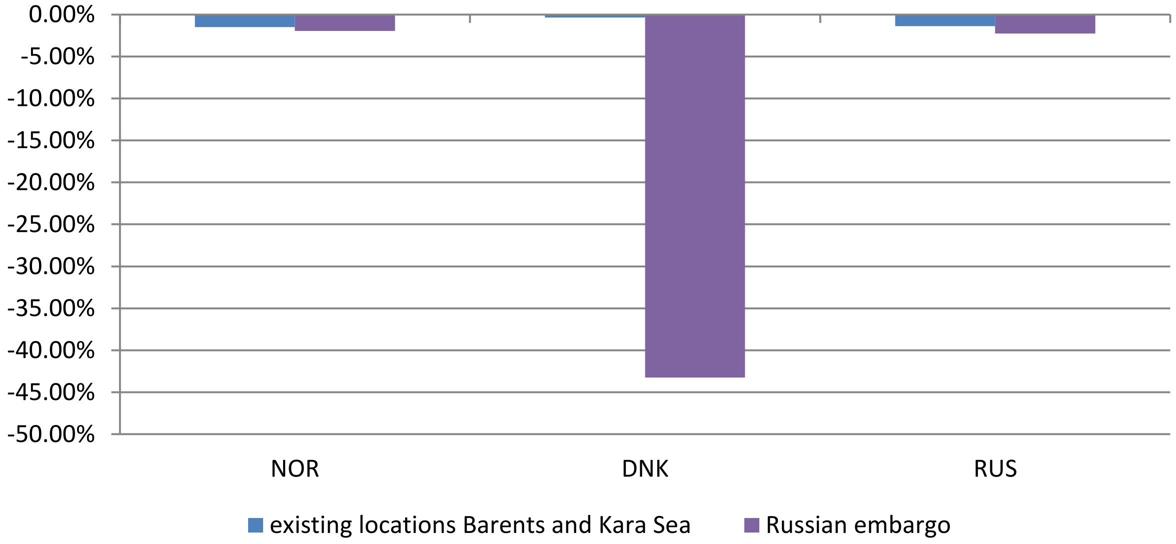
Figure 64: Change in equivalent variation in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.12.3. Impact on prices

Due to the excess supply of gas in Russia and additional production in Norway and Denmark, prices for natural gas drop in these countries relative to the Reference Scenario (Panel a of Figure 65). While Norway and Russia witness price decreases of 2 % and 2.3 %, respectively, gas prices in Greenland/Denmark drop by over 43 %. In Western European gas prices increase only modestly by about 1.2% relative to the Reference Scenario, countries include The Netherlands (NED), Germany (GER), or the UK (GBR). The Eastern EU countries (EEU) are, again, hit hardest with a projected price increase of over 70 % relative to the Reference Scenario.

As described in Section 7.6 for the other scenarios, the lower gas price for Arctic gas producers translate into a price increase for other goods (Figure 66). These price increases direct the development of the overall price level (Figure 67). Prices in Norway increase overall by 3.4 % and in Denmark by 1.6 %. Small price reductions in non-gas sectors moderate the price increase in the gas sector for the Eastern EU countries (EEU), so that the overall price level increases only slightly.

Panel a:



Panel b:

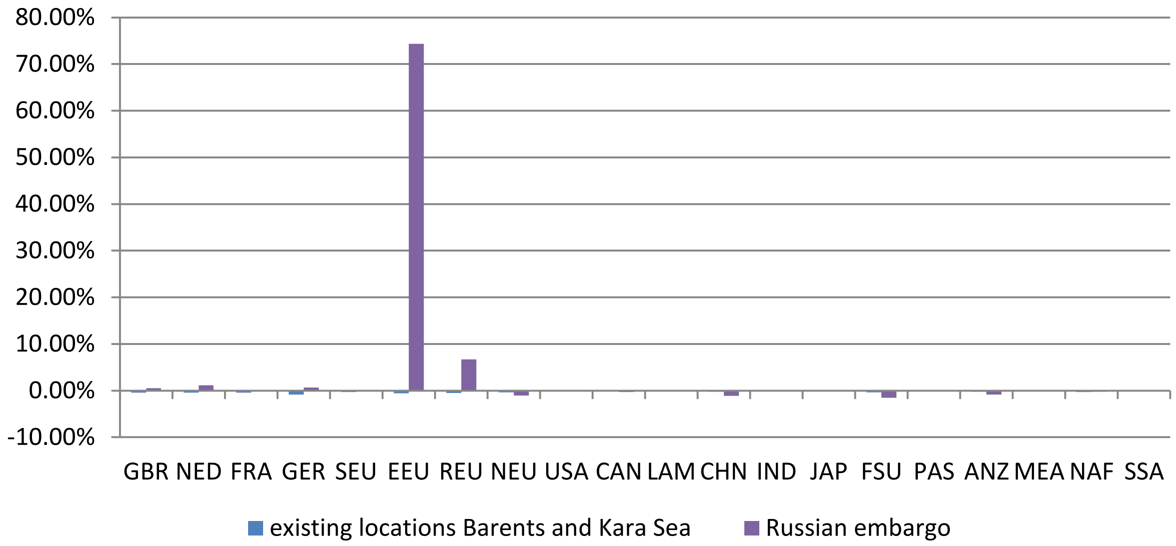
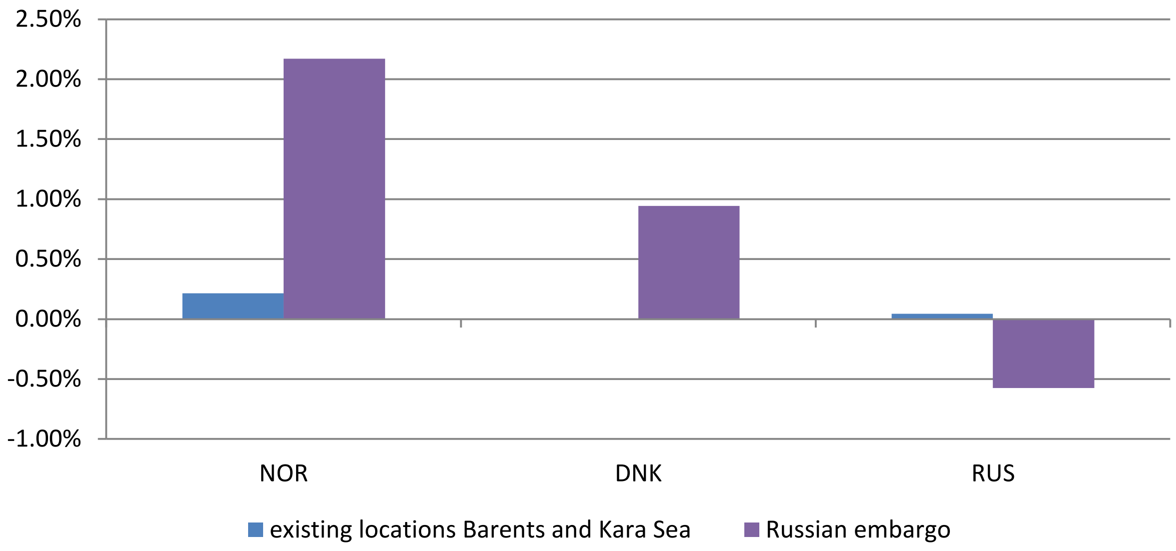


Figure 65: Change in gas price in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

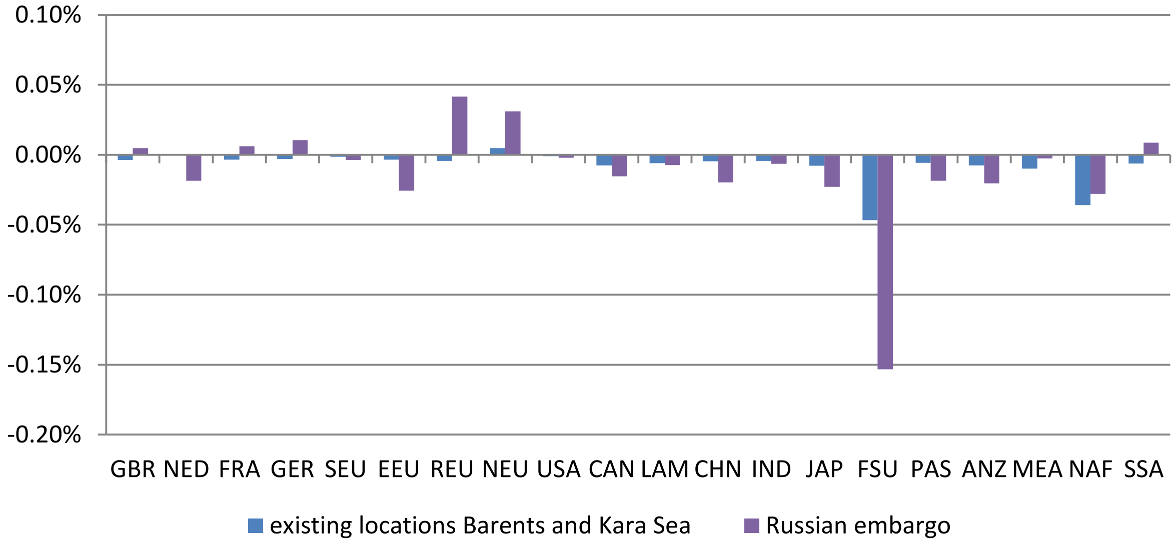
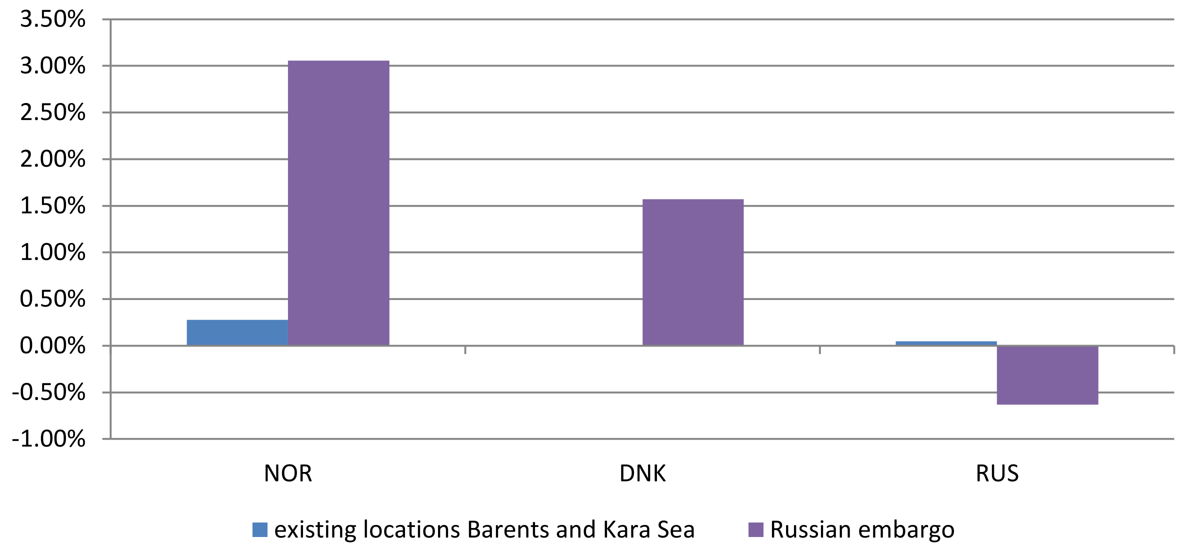


Figure 66: Change in overall price level (excl. gas) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

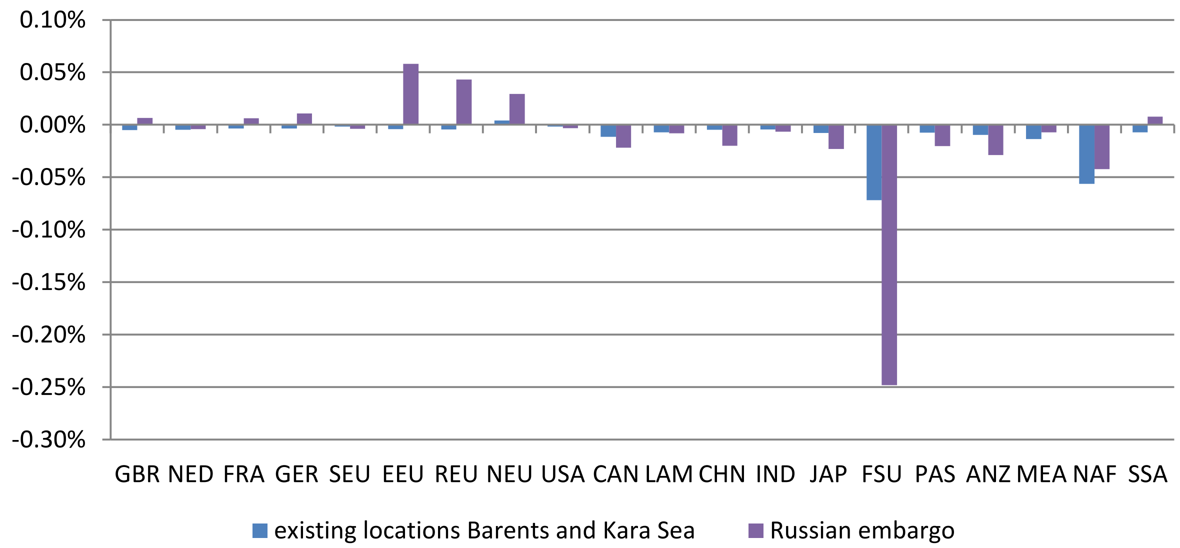


Figure 67: Change in overall price level in 2040, difference relative to Reference Scenario(%)
Source: Own presentation based on DART model results.

7.12.4. Impact on trade

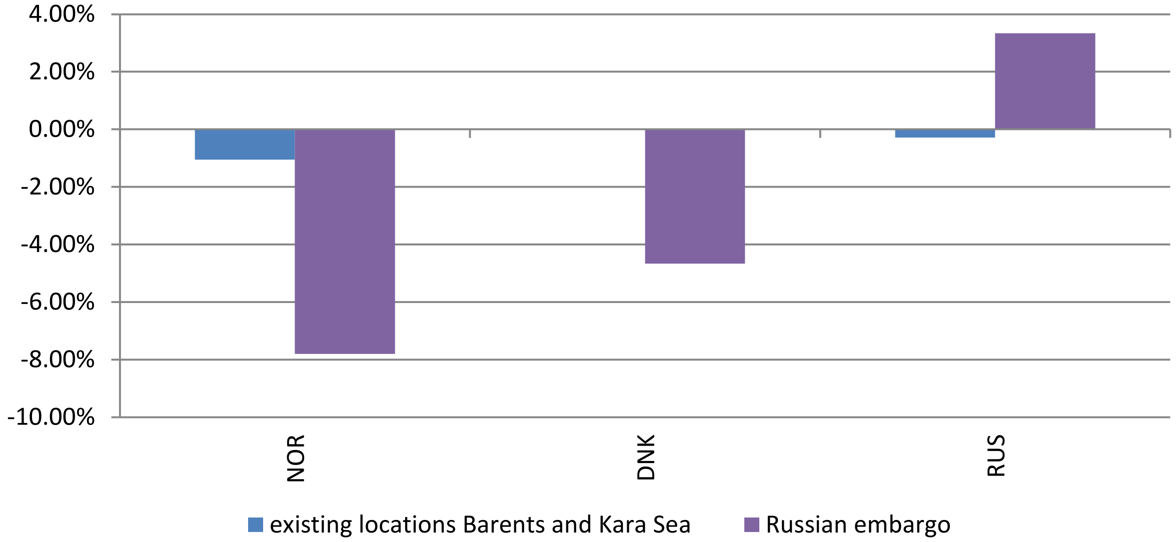
The cut-off of major trade ties in natural gas trade has severe implications on trade, not only in trade of natural gas, but also beyond. As a consequence of the drop in gas prices in Norway and Denmark, the new exporters of Arctic natural gas, the terms of trade in these two countries decrease significantly (Panel a of Figure 68). Norwegian terms of trade drop by 7.8 % and Danish terms of trade by 4.7 % relative to the Reference Scenario. Russian terms of trade do not decrease, but increase as non-gas prices drop.

At the same time, the change in export values for both Norwegian and Danish gas exports is skyrocketing, with increases of 64 % in Norway and far beyond, though from a very low level, in Demark (Figure 69 and Figure 70). For all other sectors in Norway and Denmark export values are lower compared to the Reference Scenario. The value of Russian gas exports is almost unaffected by the embargo as Russia finds other trading partners (Figure 71). We still find major shifts in exporting activity in Russia. The value of exports in the oil and coal products sector increases significantly. The heavy industry sector is the largest loser in terms of exporting values, while most other sectors export values slightly increase.

Non-Arctic countries are hardly affected regarding changes in terms of trade (Panel b of Figure 68). Larger effects can be observed in gas exporting Eastern Europe (EEU), where terms of trade increase compared to the Reference Scenario. This does not mean, however, that exporting activities do not shift among non-Arctic countries. The value of gas exports increase basically everywhere to compensate for the Russian embargo (Figure 72). Only in Eastern Europe (EEU) export values of natural gas drop significantly (Figure 72) as well as the value of other goods (Figure 73). Since natural gas exports by the Eastern EU countries are, however, small to begin with, the immense drop in export value in relative terms does not translate to a large decrease in levels. In the countries of the Former Soviet Union (FSU) drop in domestic prices increase the export value of non-gas products.

Overall, export values increase; especially in the countries producing Arctic natural gas, for Russia and the FSU countries. The EEU countries are the main losers in terms of changes in export values (Figure 74).

Panel a:



Panel b:

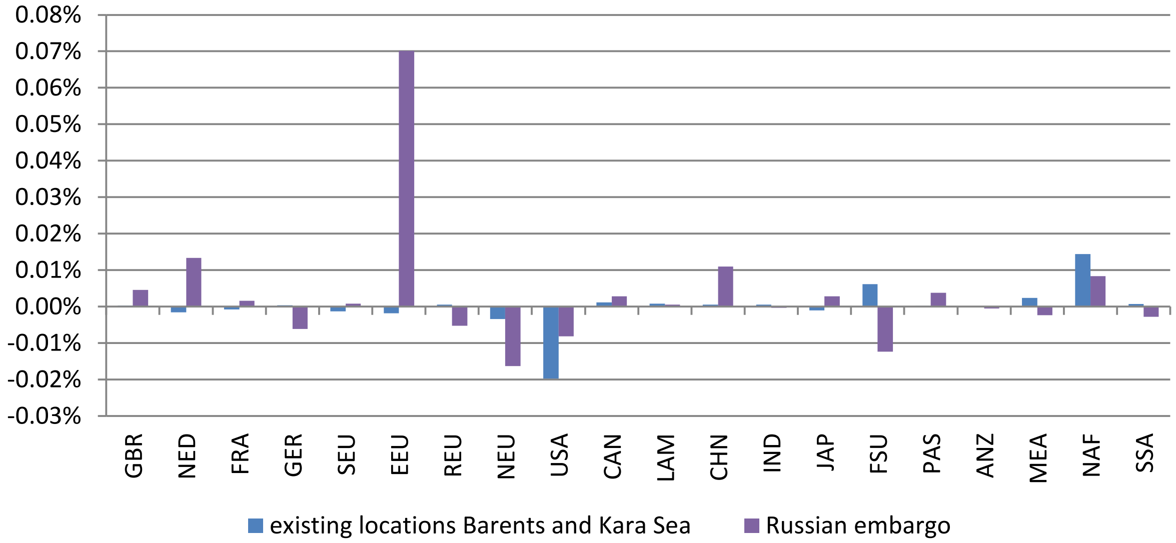


Figure 68: Change in terms of trade in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

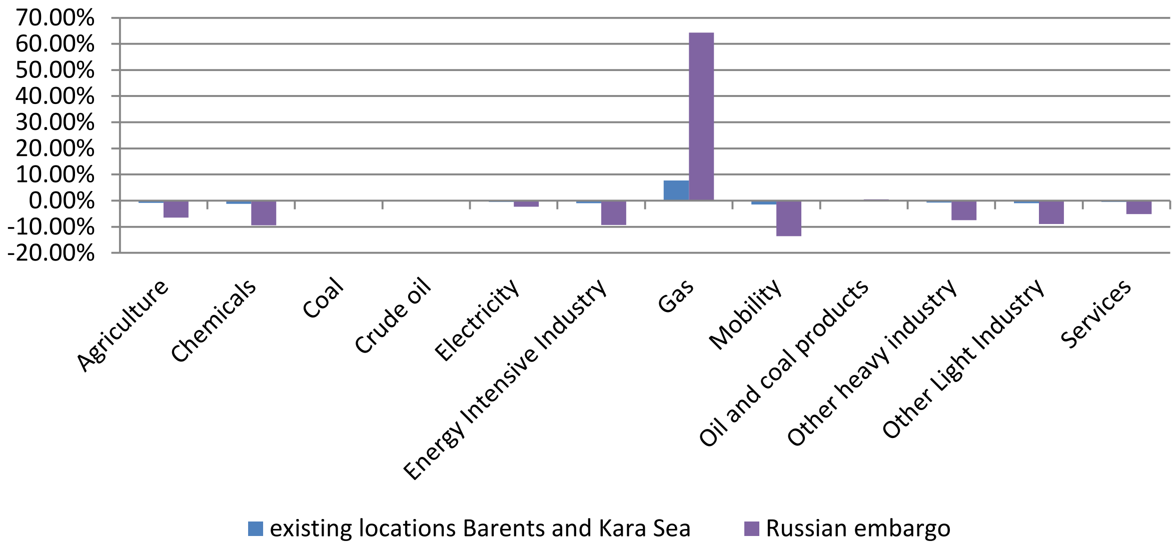


Figure 69: Change in the value of Norwegian exports in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

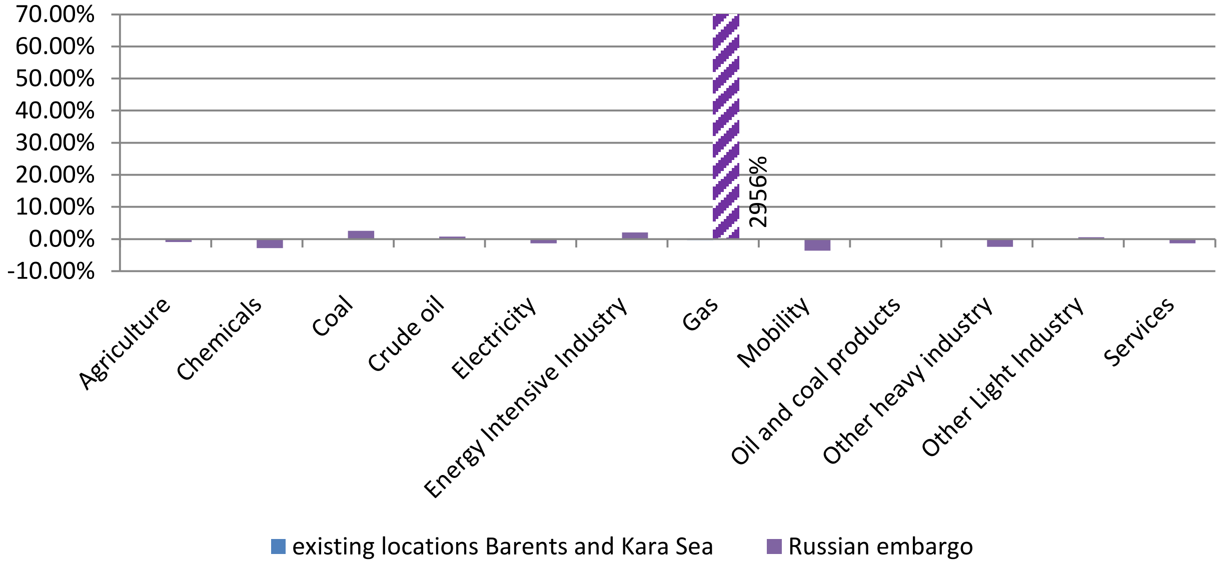


Figure 70: Change in the value of Danish exports in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

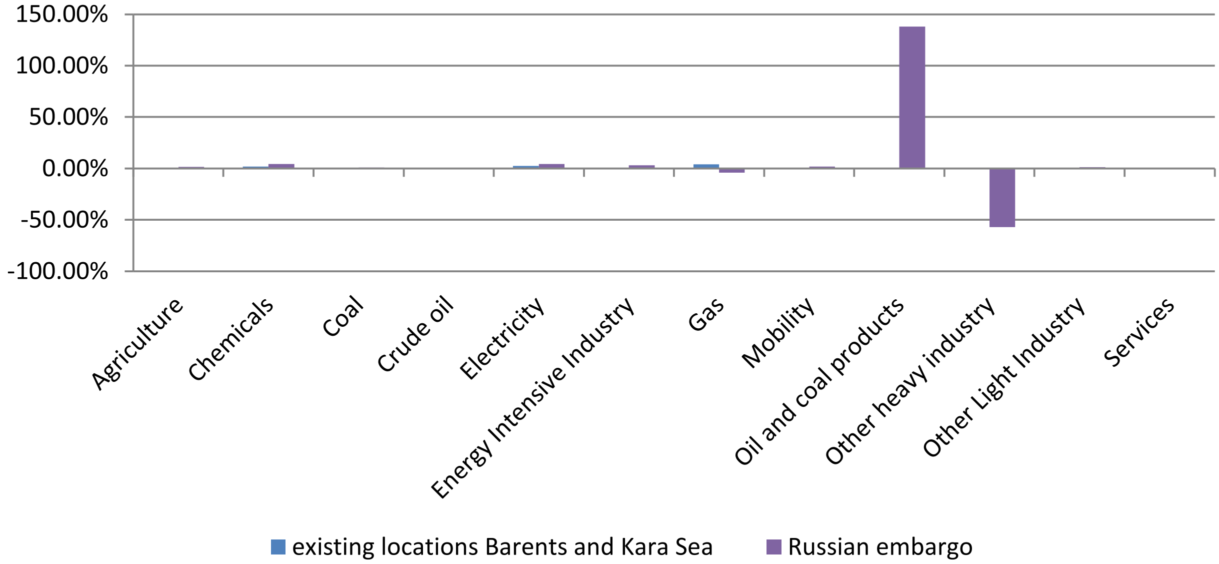


Figure 71: Change in the value of Russian exports in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

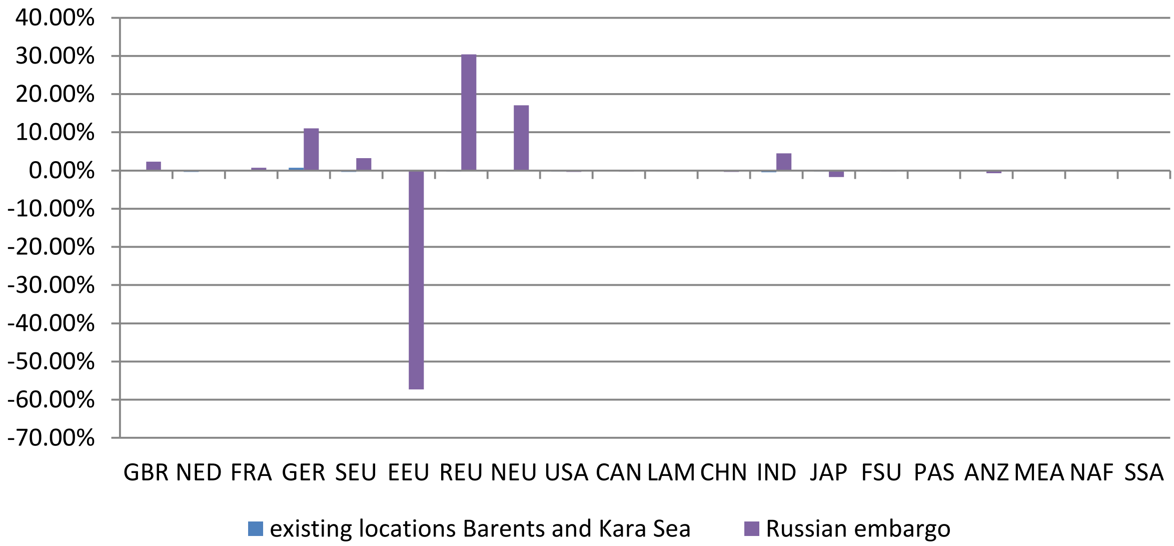


Figure 72: Change in the value of gas exports of non-Arctic countries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

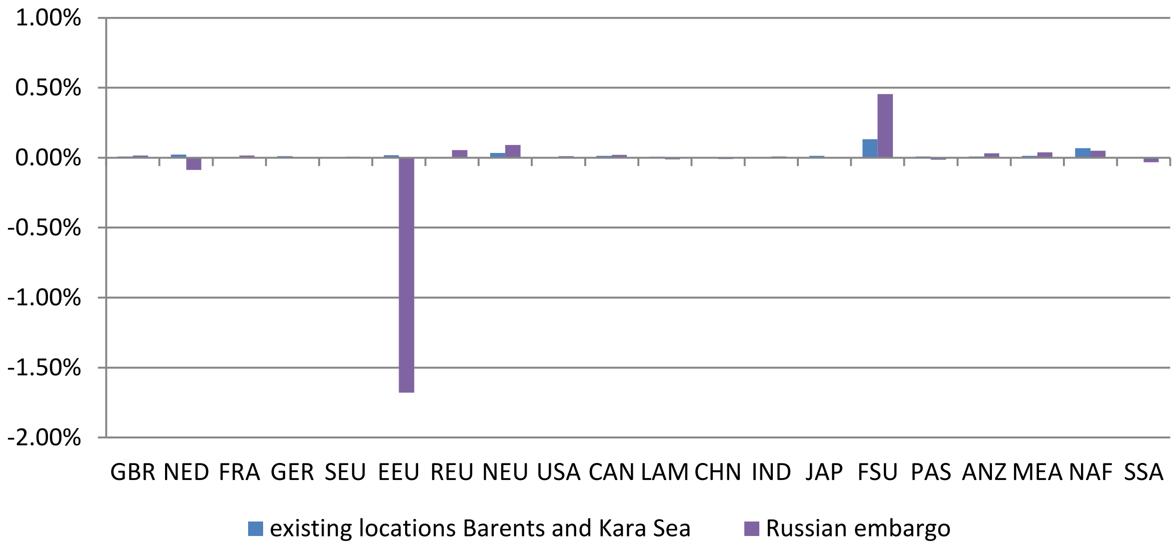
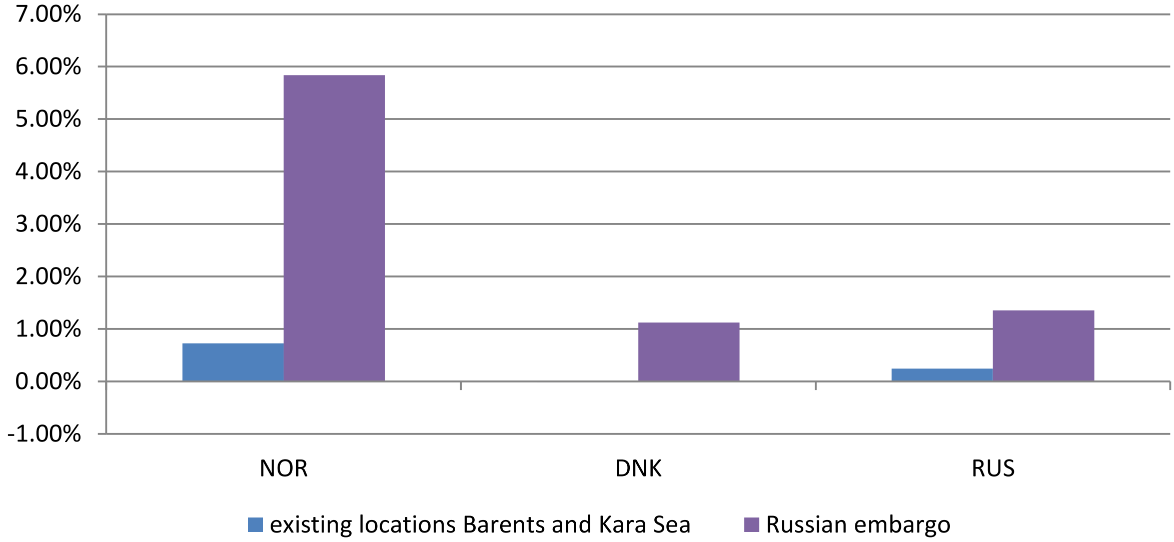


Figure 73: Change in the value of non-gas exports of non-Arctic countries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

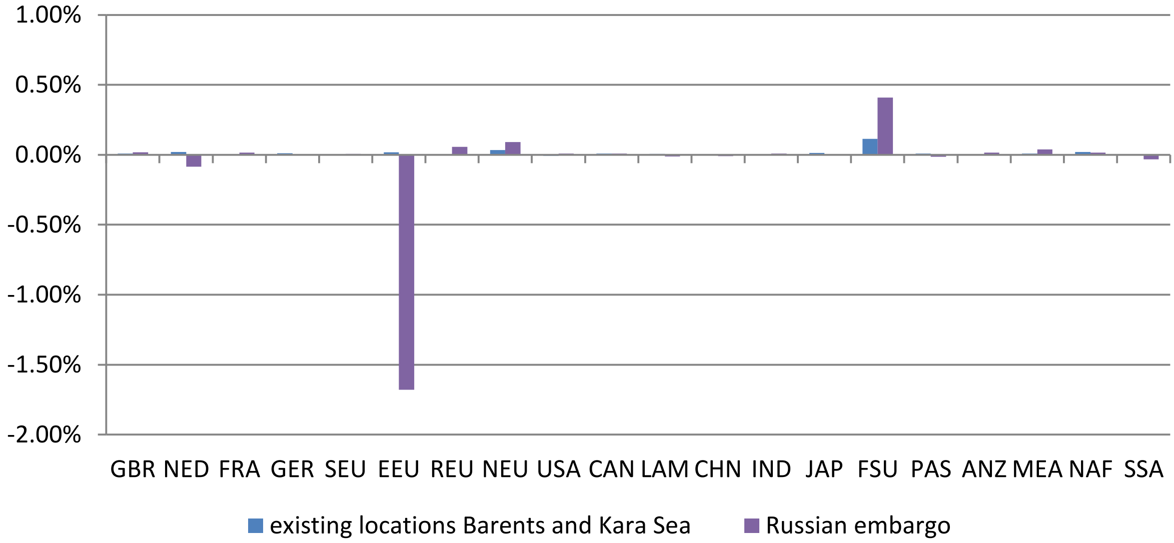
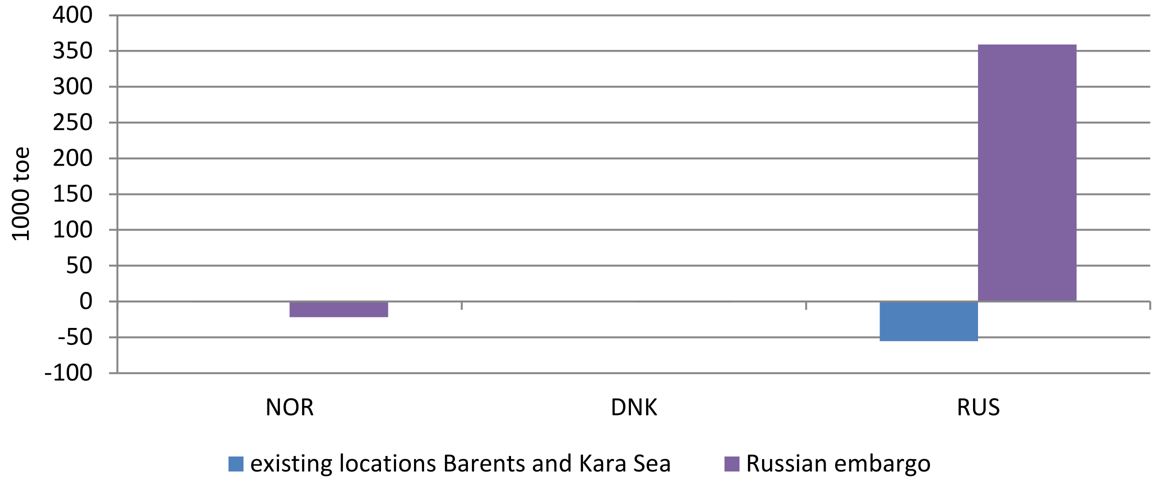


Figure 74: Change in the value of total exports in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.12.5. Impact on the production of other fuels

We find only modest effects on the production of other fuels. Neither coal (Figure 75), nor crude oil production (Figure 76), nor production of oil and coal products (Figure 79) are significantly affected by the embargo compared to the Reference Scenario. Also, perhaps surprisingly, we find no significant increase in the production of non-Arctic natural gas (Figure 77). The expansion in the Netherlands (NED), for example, amounts to 85 000 toe, a mere 0.22 % of gas production relative to the Reference Scenario. The only fuel where we do find significant effects, again, for the Eastern EU (EEU), is electricity (Figure 78). There, electricity production, largely depending on gas as an input factor, drops by 25 mtoe (19 %) in 2040, adding to the economic distress in the EEU imposed by the Russian embargo.[12]

Panel a:



Panel b:

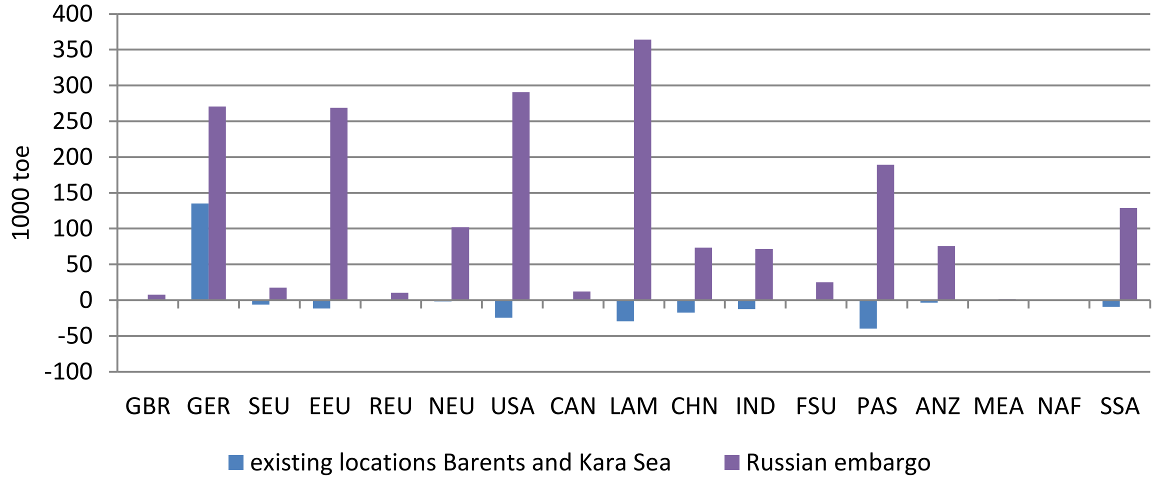
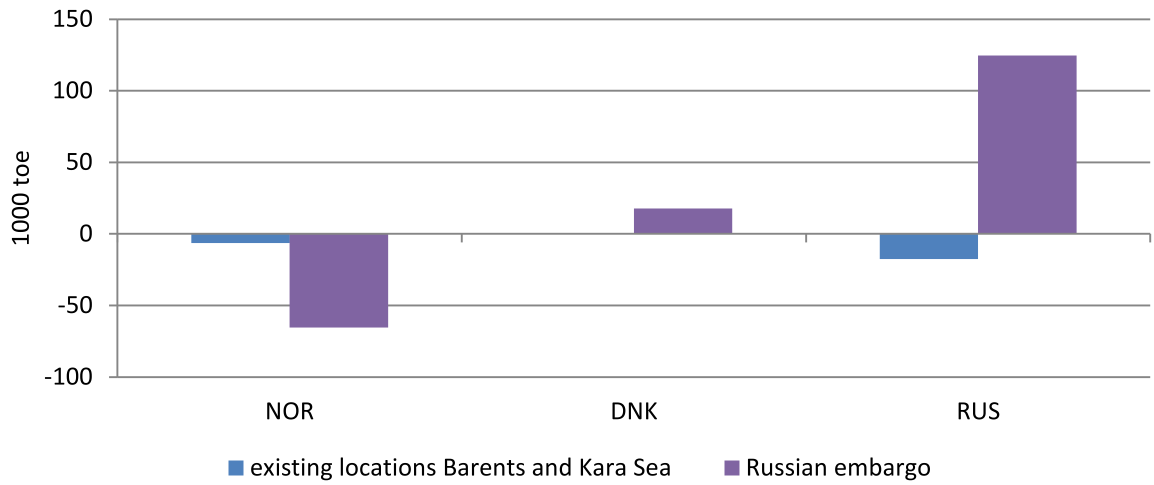


Figure 75: Change in production of coal in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

[12] Electricity, as any other form of energy, can be measured in tonnes of oil equivalent, since a tonne of oil equivalent is a general energy unit, standardized using the energy content of crude oil. A tonne of oil equivalent is equivalent to approximately 42 GJ.

Panel a:



Panel b:

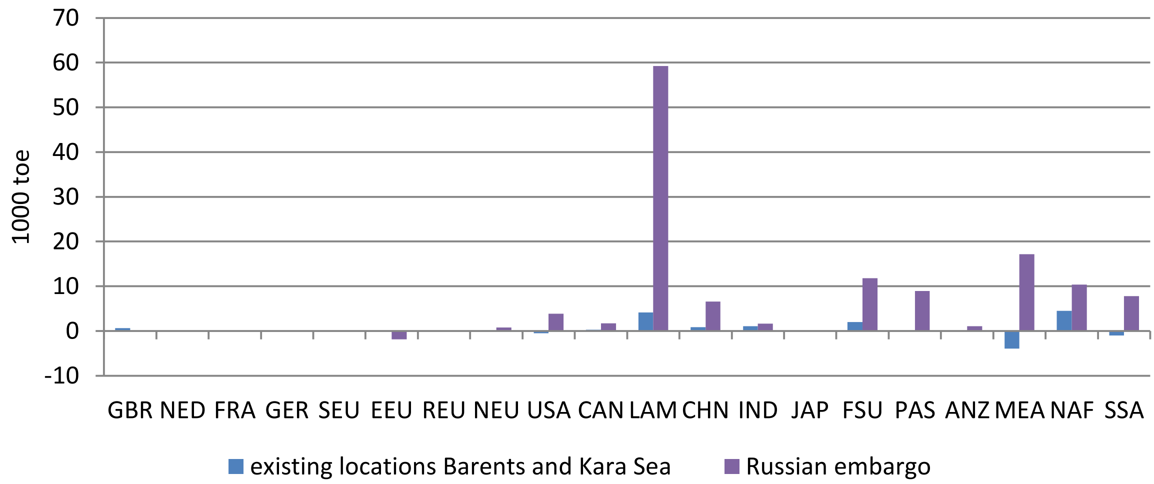
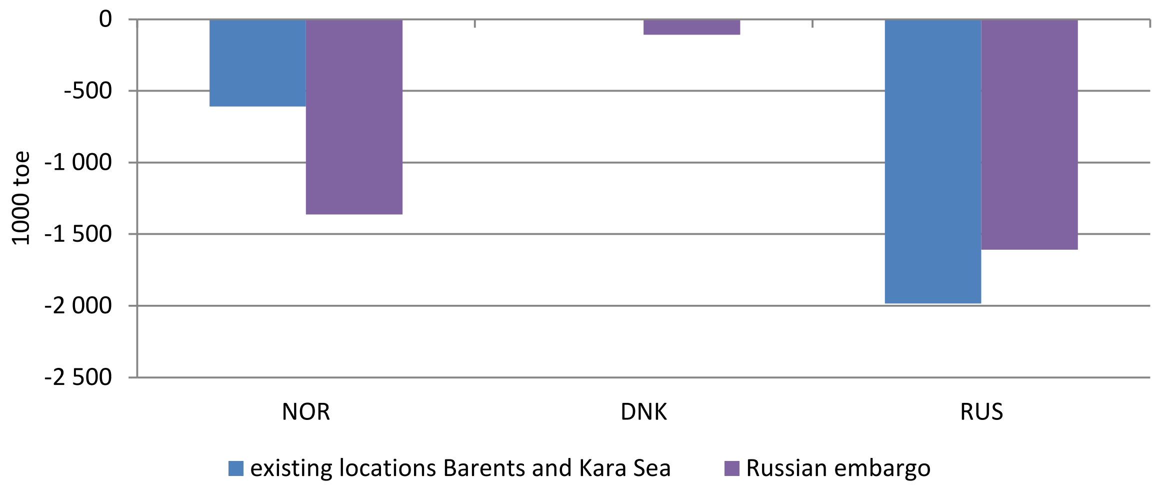


Figure 76: Change in production of crude oil in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

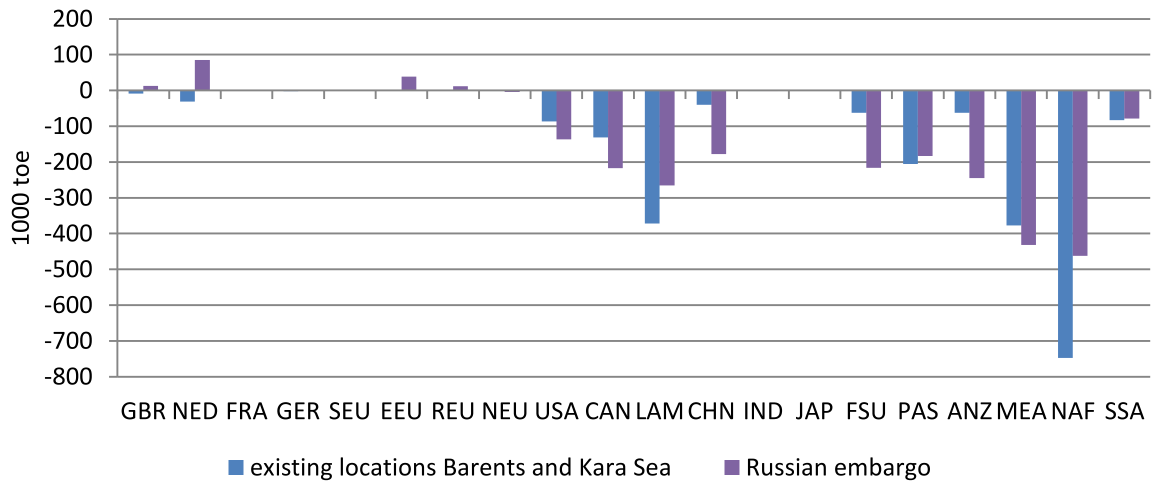
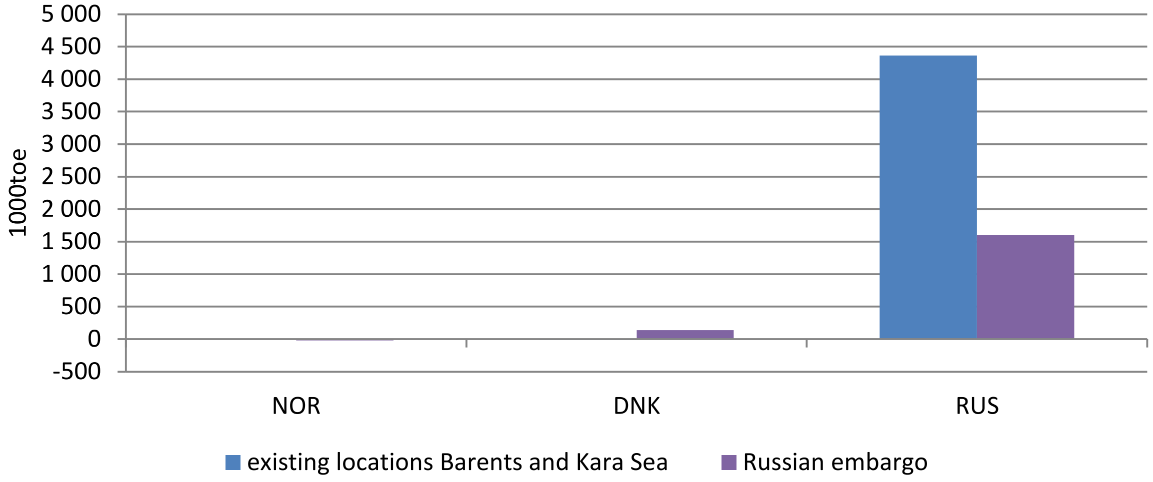


Figure 77: Change in production of non-Arctic natural gas in 2040, absolute difference to Reference Scenario (1000 toe) Source: Own presentation based on DART model results.

Panel a:



Panel b:

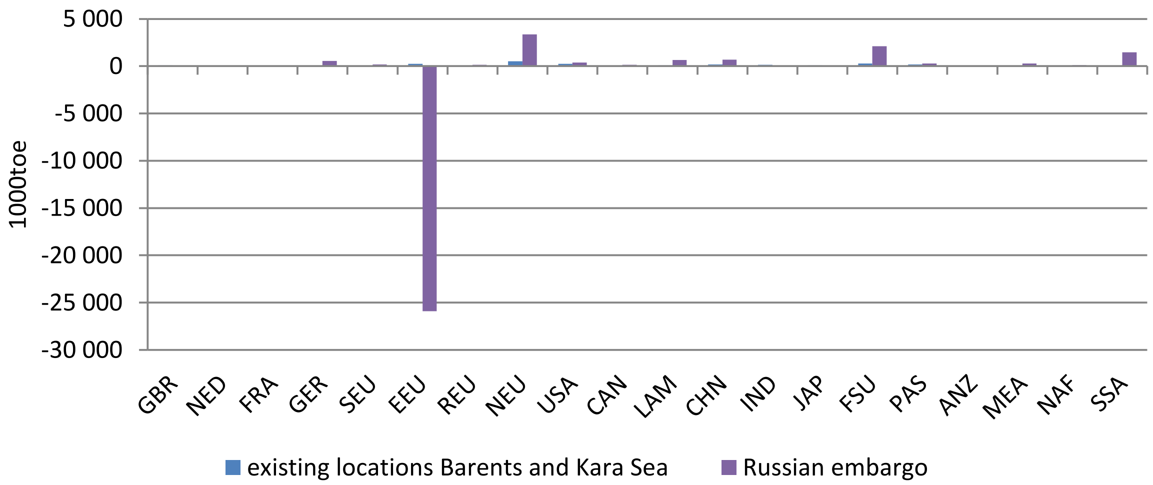
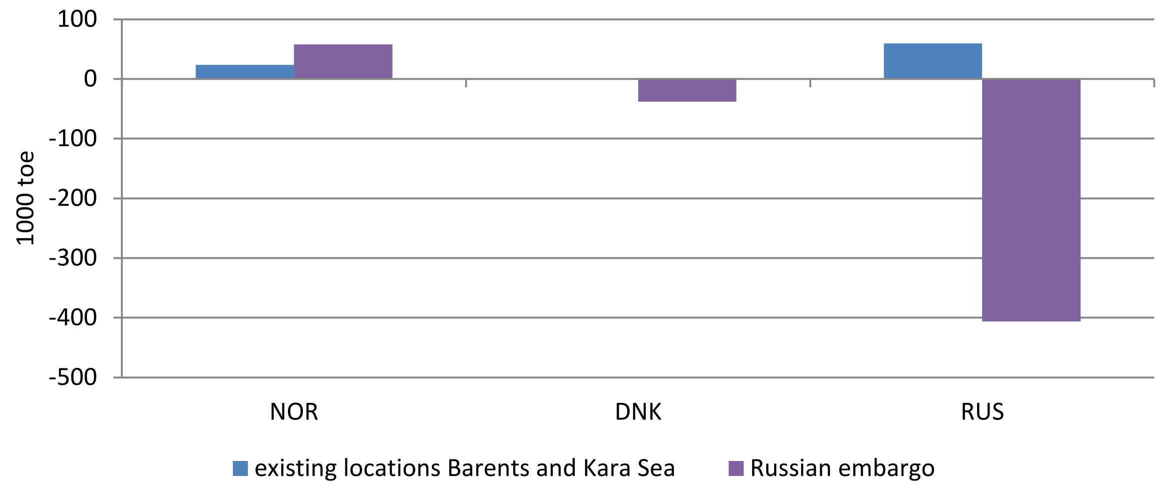


Figure 78: Change in production of electricity in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

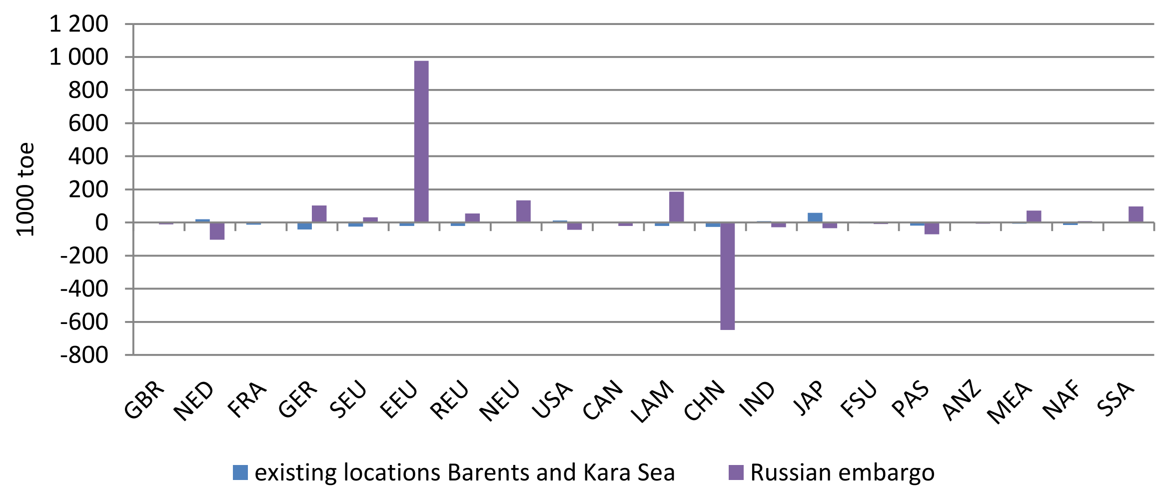


Figure 79: Change in production of petroleum and coal products in 2040, absolute difference to Reference Scenario (1000 toe)
Source: Own presentation based on DART model results.

7.12.6. Impact on other sectors

Additional production in Norway and Denmark as well as shifting prices trigger a number of changes in the economic structure both in Russia and beyond. In Norway, the increase in natural gas production is crowding-out production in other sectors (Figure 80). The value of output in these sectors drops throughout the economy, but especially in manufacturing. The chemical industry is the largest loser with value losses of over 8 % relative to the Reference Scenario. In Denmark, losses from crowding-out are partly balanced by decreasing energy costs (Figure 81). Even though the output value of the chemical industry decreases by 2.7 %, other manufacturing sectors gain. In Russia, lower energy prices lead to widespread gains in the value of output, too (Figure 82). Here output values in the chemical industry increase by 3.7 %, and also other manufacturing sectors gain.

Triggered by changes in energy prices the output of the chemical industry in other countries is heavily affected as well, with losses in output values of 10.7 % in the Eastern EU (EEU) and gains of 3.7 % in the Former Soviet Union countries (FSU) changes (Figure 84). Energy intensive industries in the two regions are affected in the same way, although lower in the magnitude of the change (Figure 85). Other sectors are only mildly affected, see Figure 83 for agriculture, Figure 86 for transport, Figure 87 for other heavy industries, Figure 88 for other light industries, and Figure 89 for services.

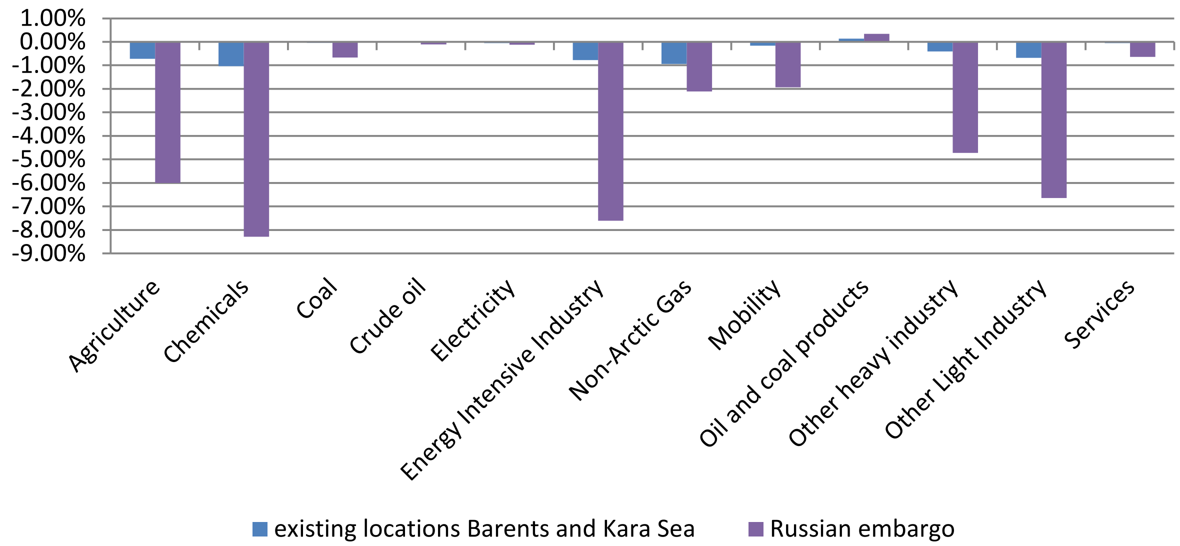


Figure 80: Change in output value per sector (Norway) in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

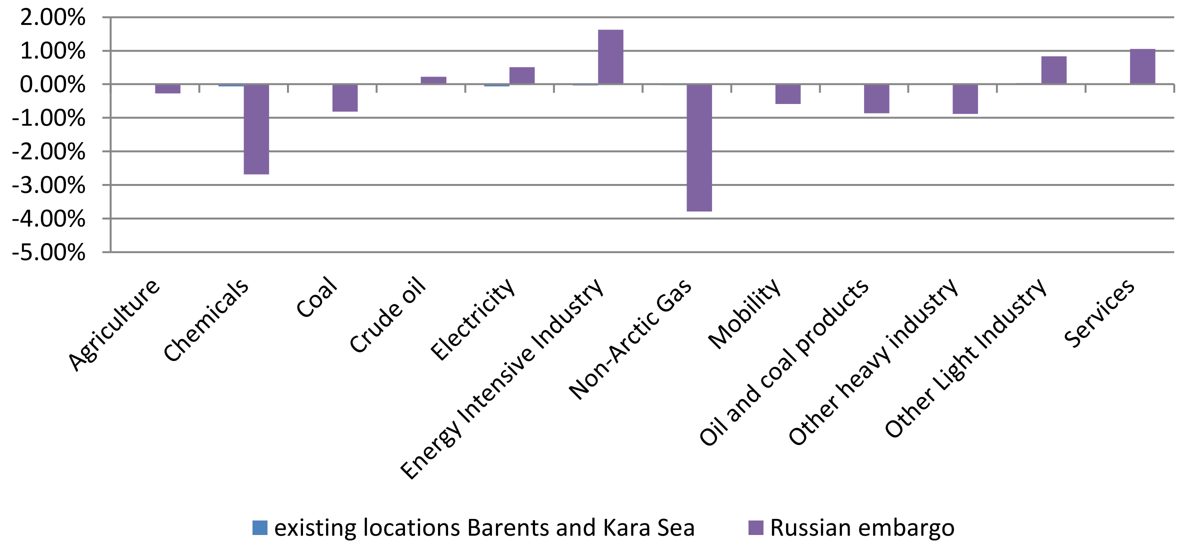


Figure 81: Change in output value per sector (Denmark) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

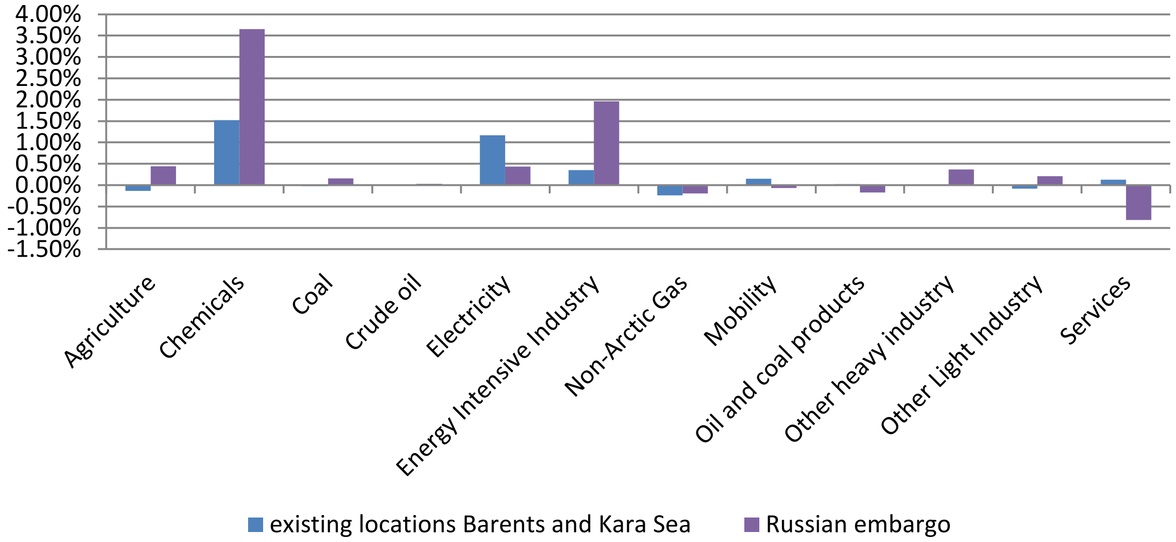


Figure 82: Change in output value per sector (Russia) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

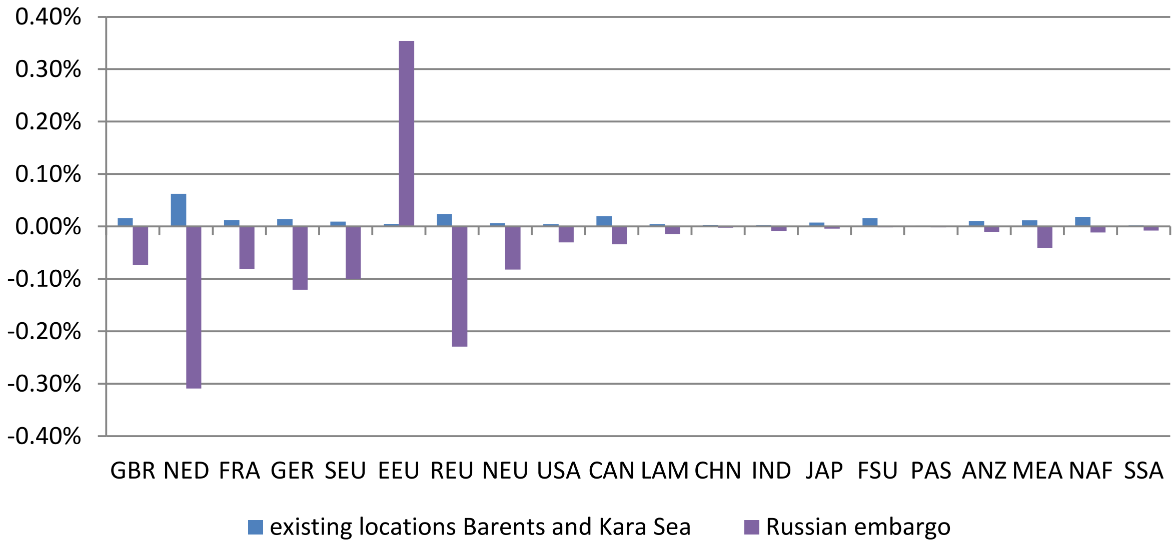


Figure 83: Change in the agricultural output value in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

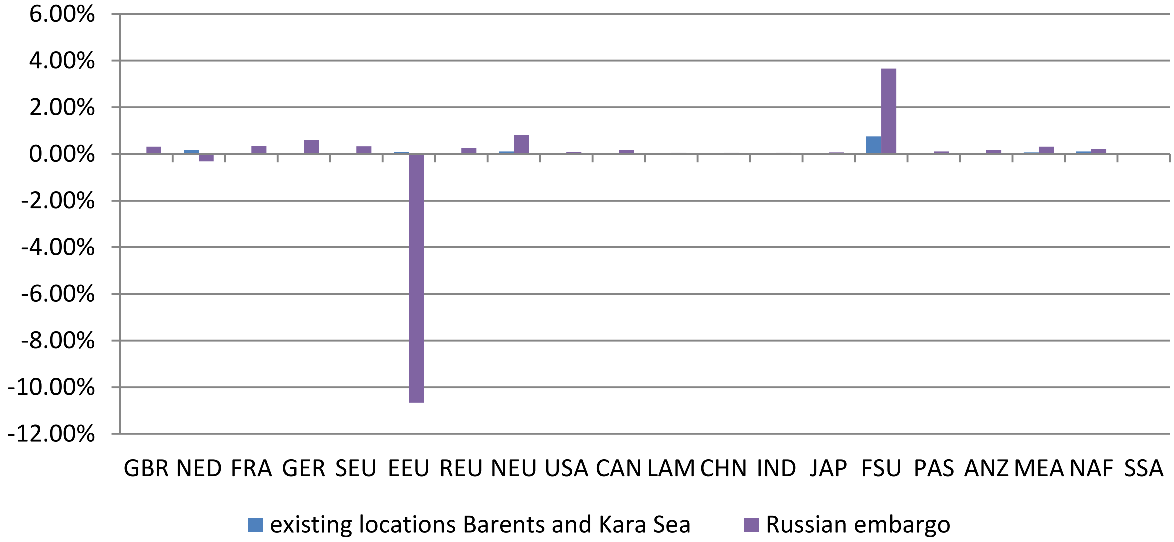


Figure 84: Change in the output value of chemical products in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

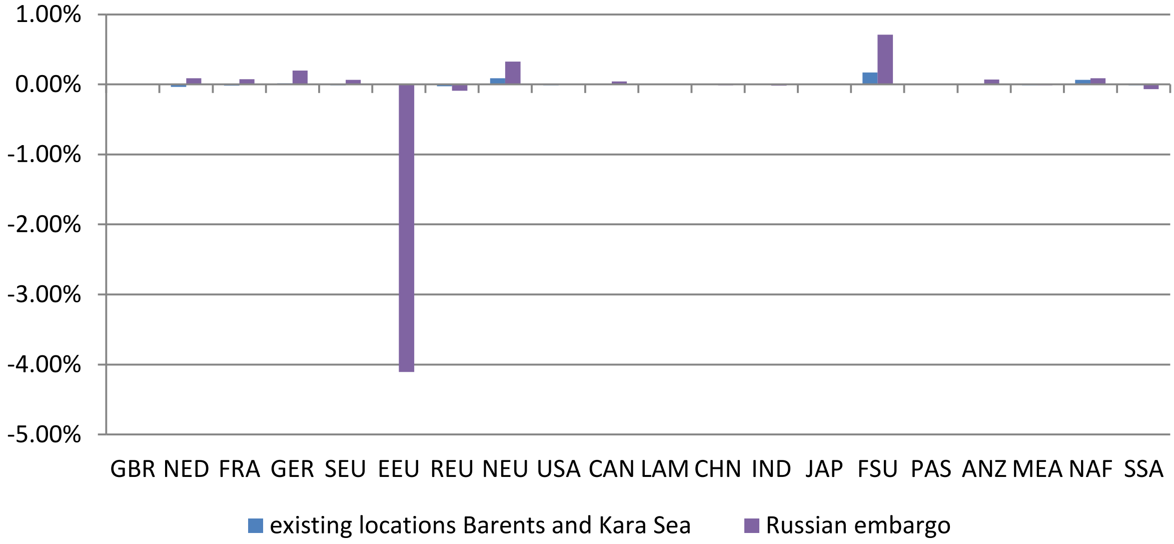


Figure 85: Change in output value of energy intensive industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

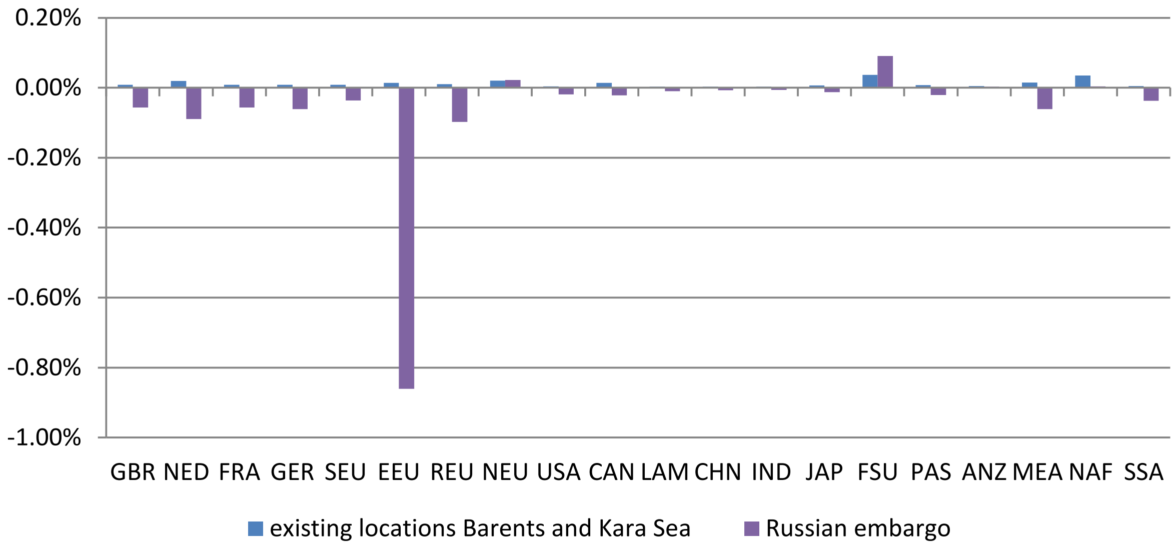


Figure 86: Change in output value of Mobility in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

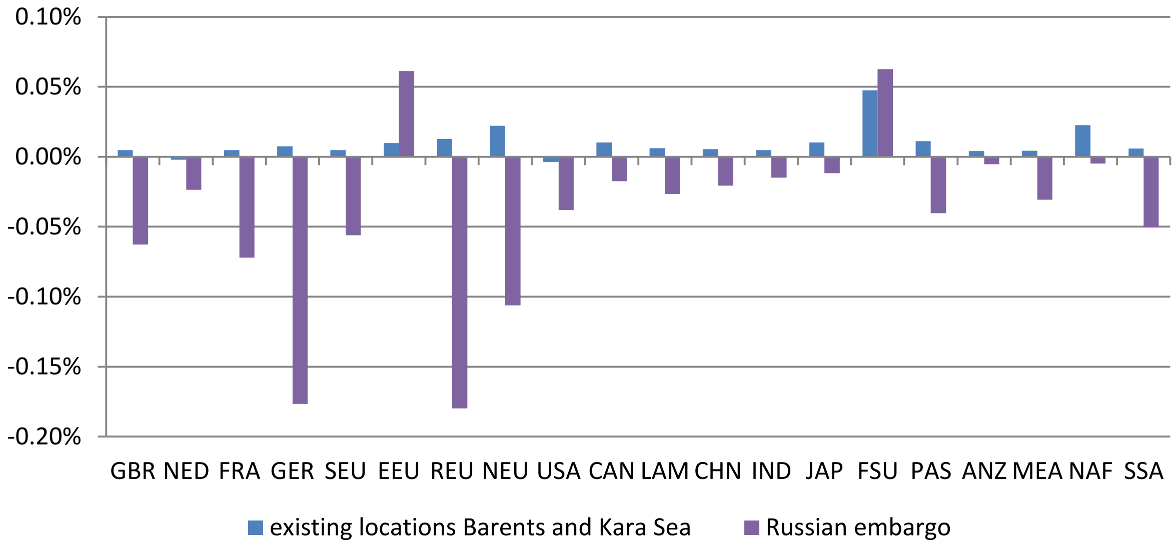


Figure 87: Change in output value of other heavy industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

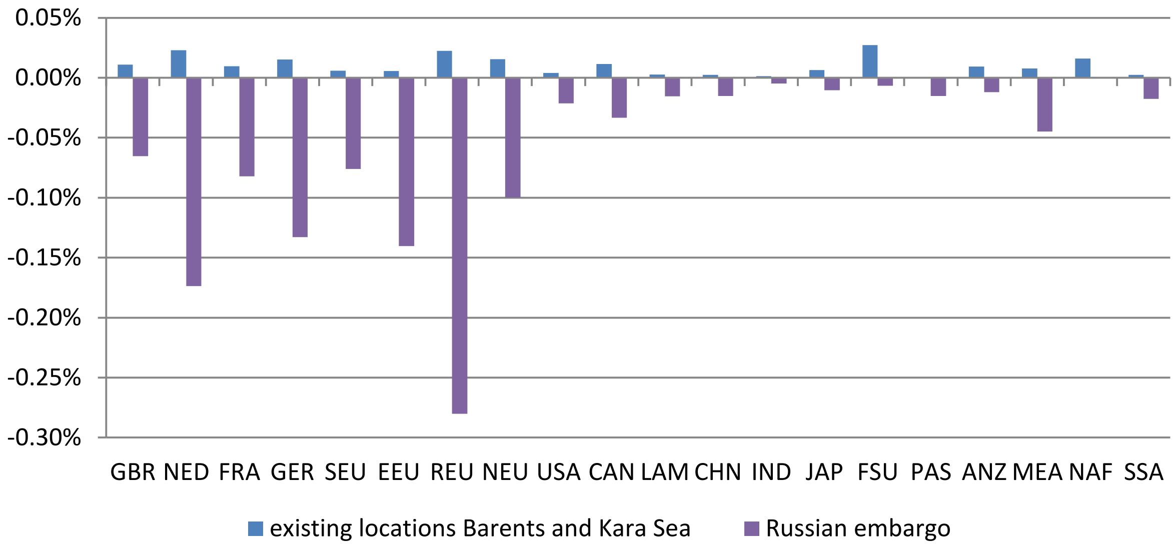


Figure 88: Change in output value of other light industries in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

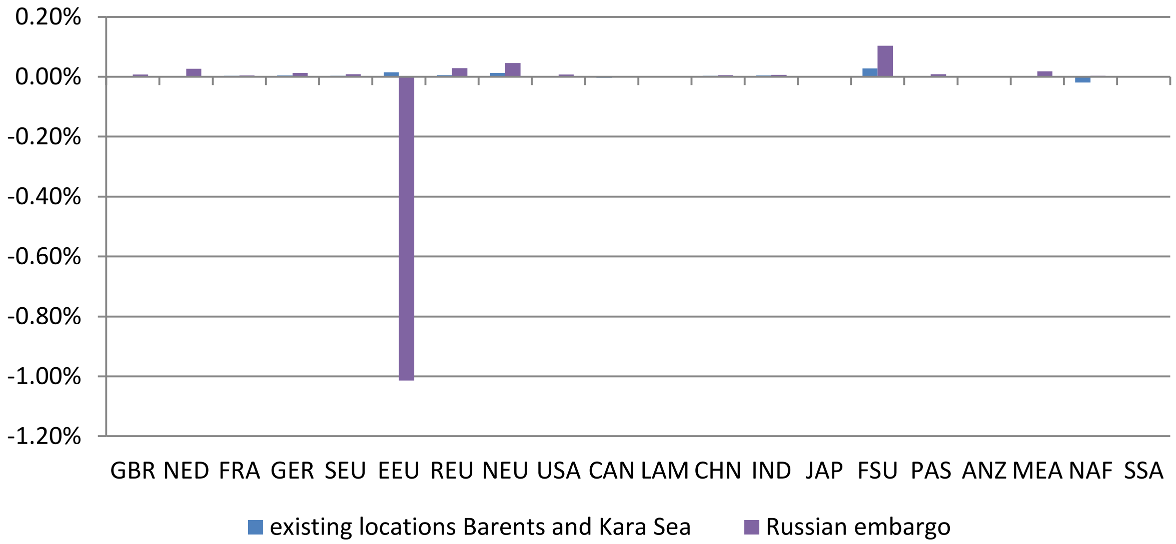


Figure 89: Change in output value of the service sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.12.7. Impact on the labour market

The sectoral shifts depicted in Section 7.12.6 are reflected in the labour market, too. Both in Norway (Figure 90) and in Denmark (Figure 91), employment shifts from practically all other sectors to the natural gas sector as gas production increases. In Russia, meanwhile, both the chemical and energy intensive industry sectors attract labour input from other sectors as energy prices decrease. Employment in the Russian chemical industry increases by 3.9 % compared to the Reference Scenario.

In countries of the Eastern European Union (EEU), importers of natural gas from Russia before the embargo, employment shifts between sectors based on energy intensity, too.

Employment moves out of the chemical (Figure 95) and energy intensive industry (Figure 97) and into agriculture (Figure 93), the natural gas sector (Figure 98), various other manufacturing sectors (Figure 100 and Figure 102) including oil and coal products (Figure 101) and, most of all, services (Figure 103), where employment increases by more than 180 %.

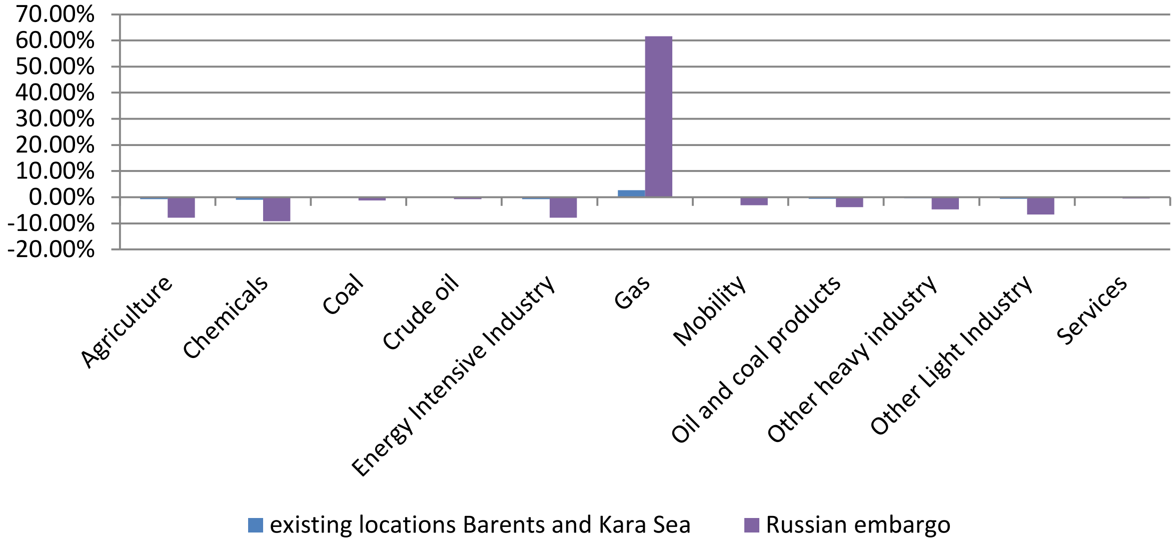


Figure 90: Change in labour input value per sector (Norway) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

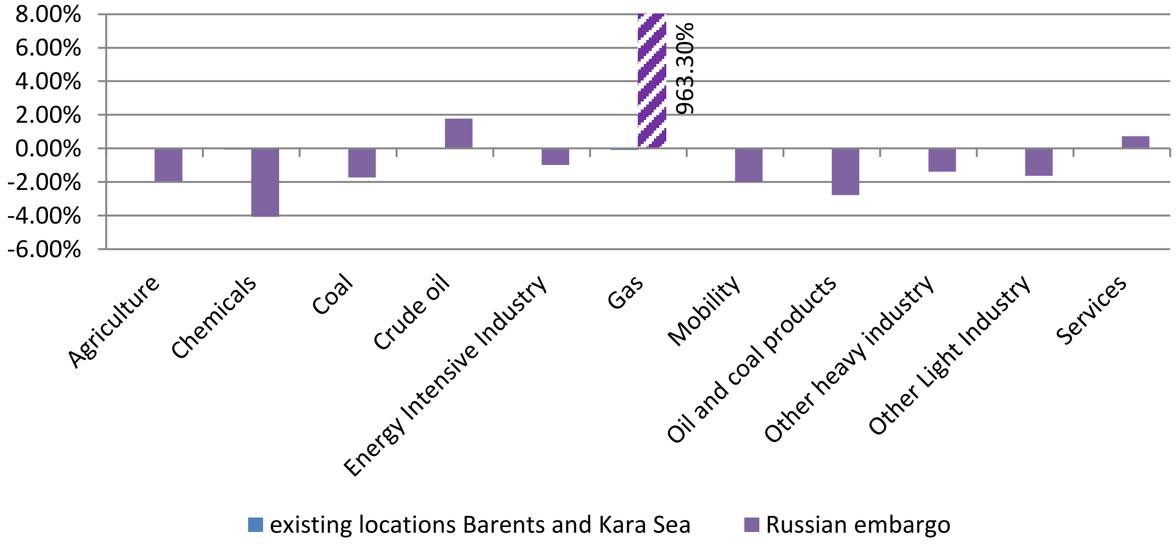


Figure 91: Change in labour input value per sector (Denmark) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

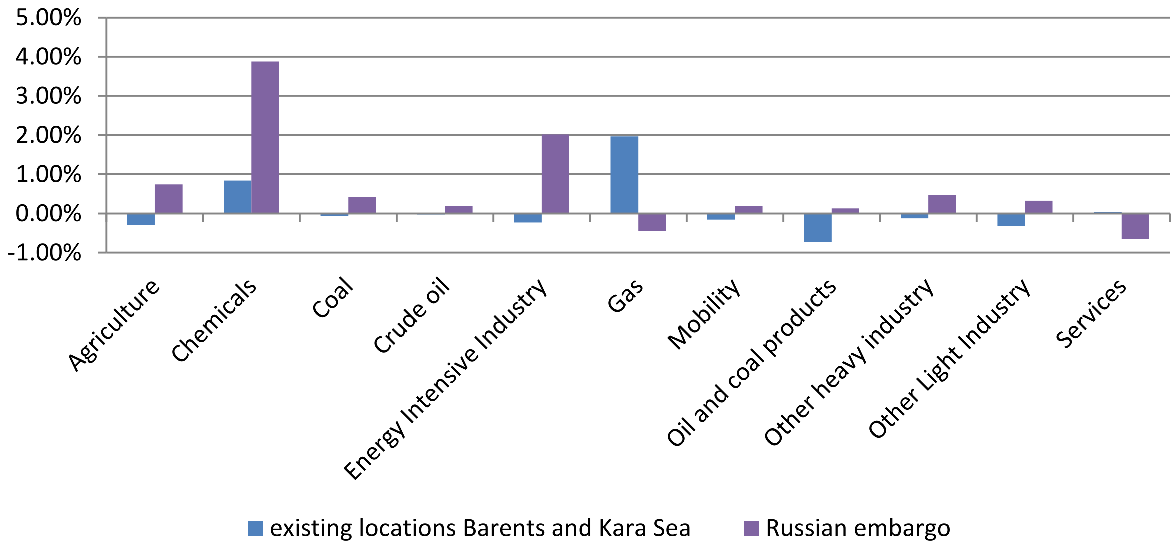


Figure 92: Change in labour input value per sector (Russia) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

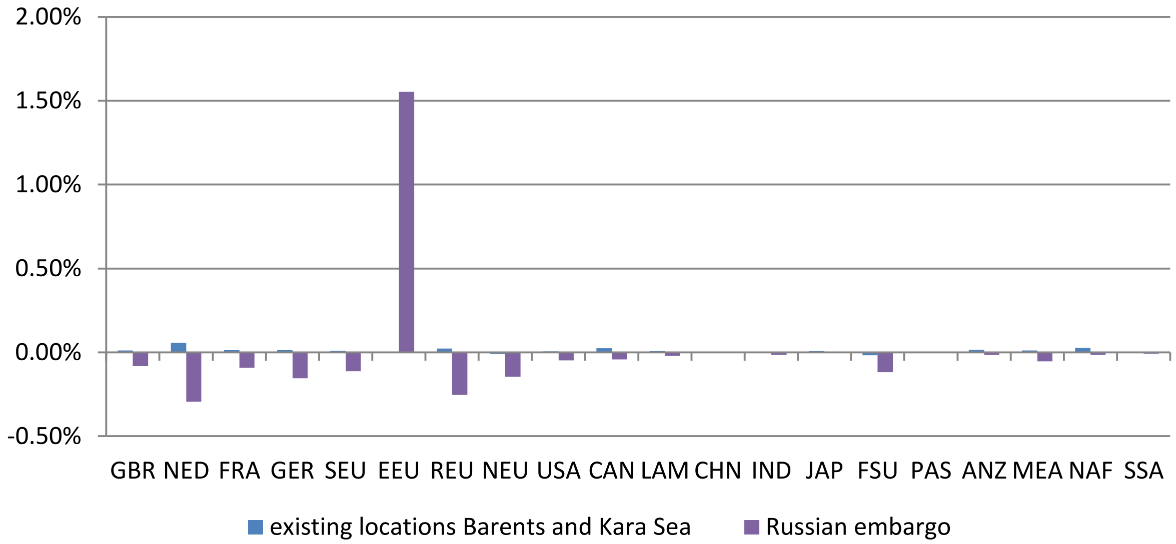


Figure 93: Change in labour input value in agriculture in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

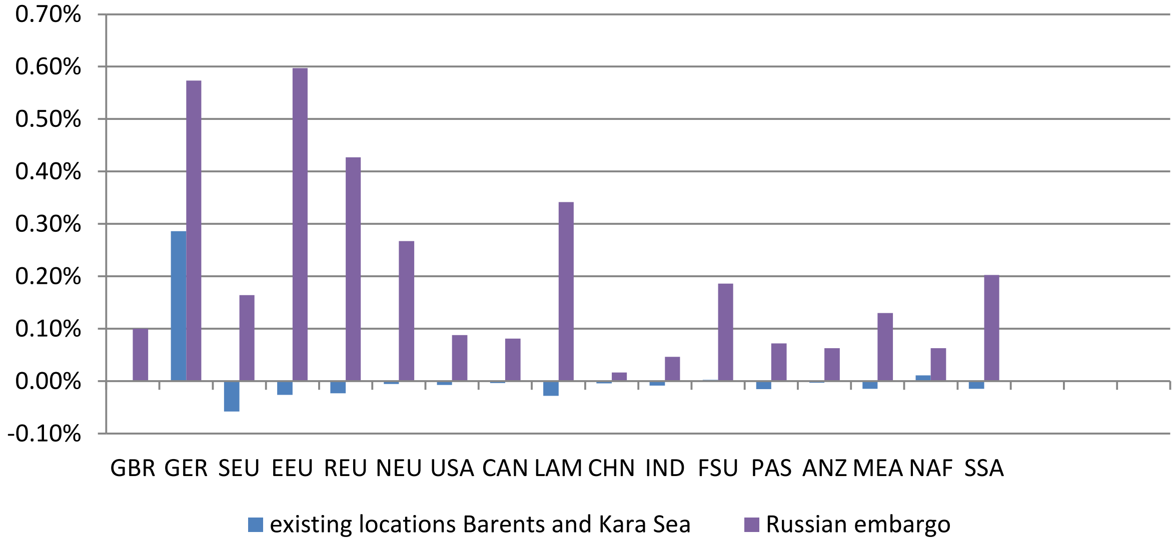


Figure 94: Change in labour input value in the coal sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

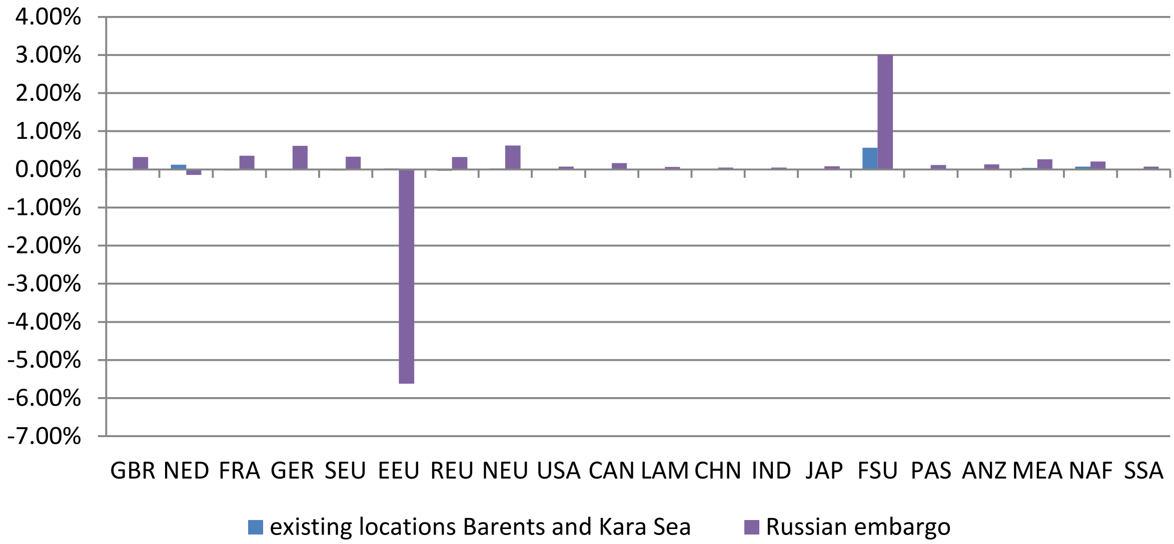


Figure 95: Change in labour input value in the chemical products sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

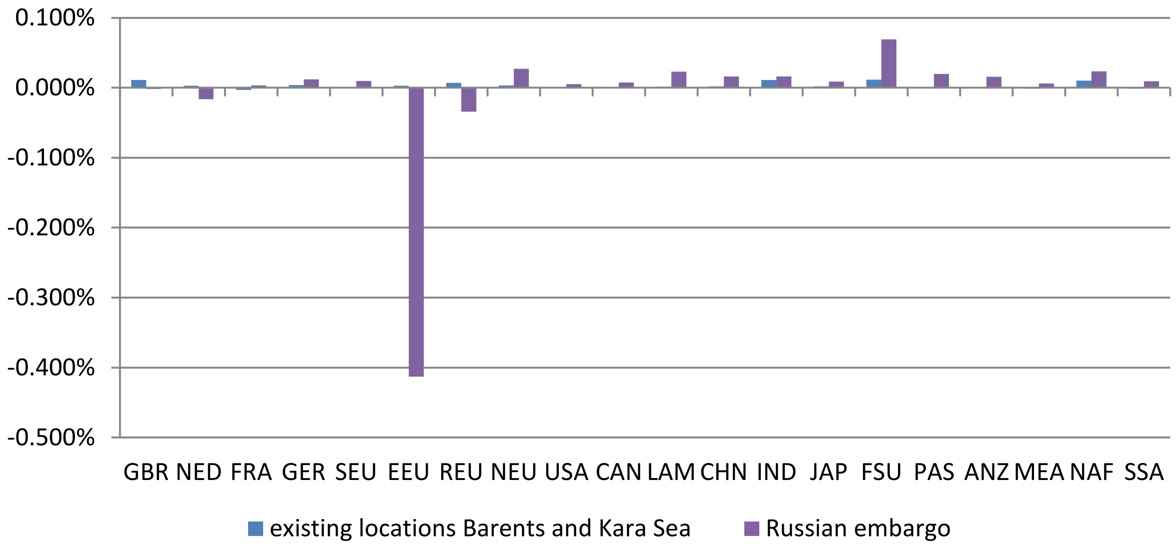


Figure 96: Change in labour input value in the crude oil sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

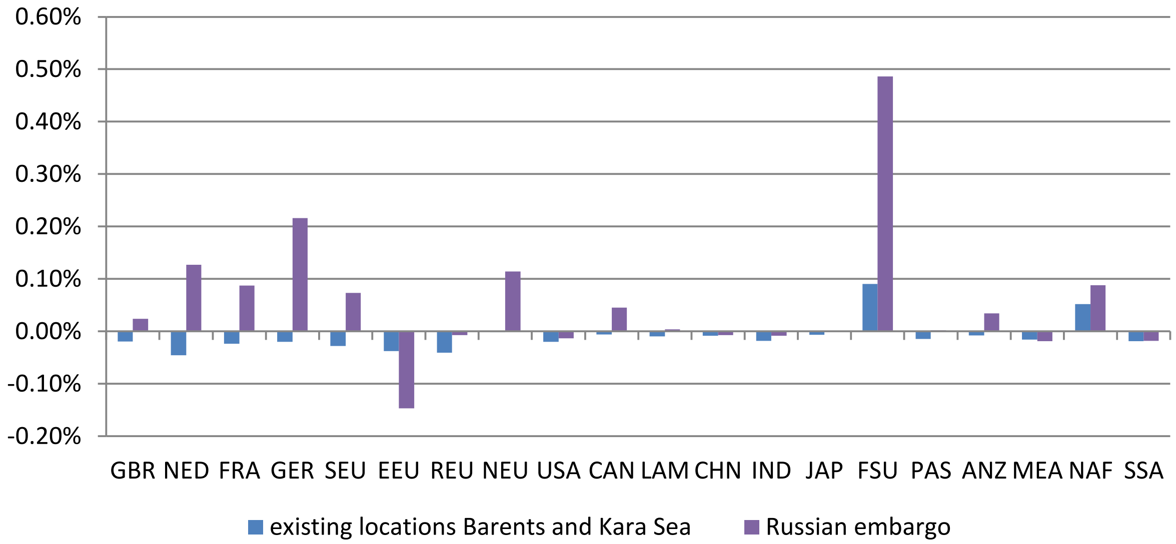


Figure 97: Change in labour input value in the energy intensive industries sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

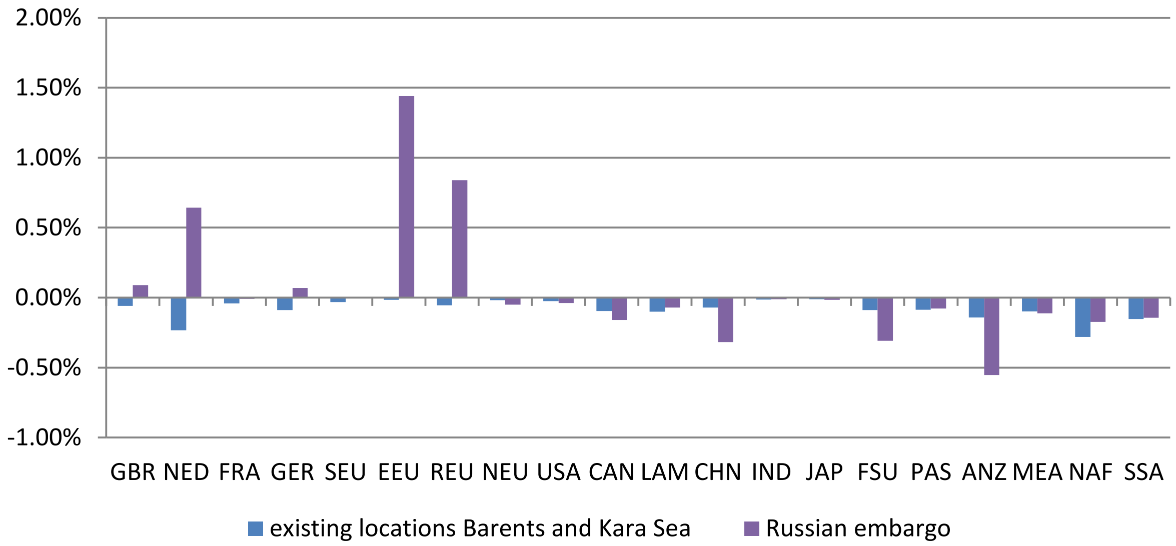


Figure 98: Change in labour input value in the natural gas sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

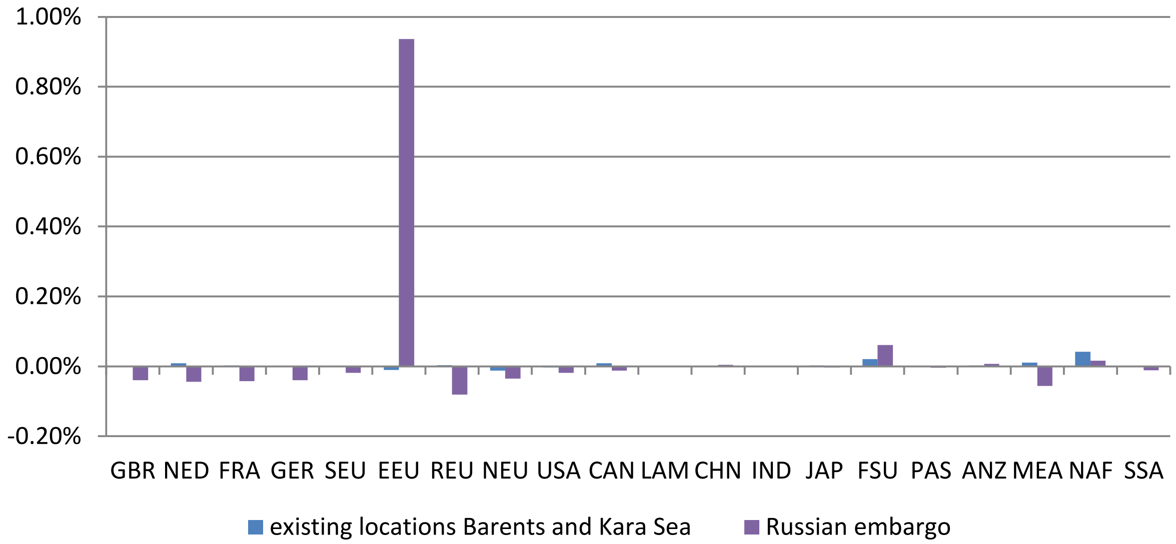


Figure 99: Change in labour input value in the mobility sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

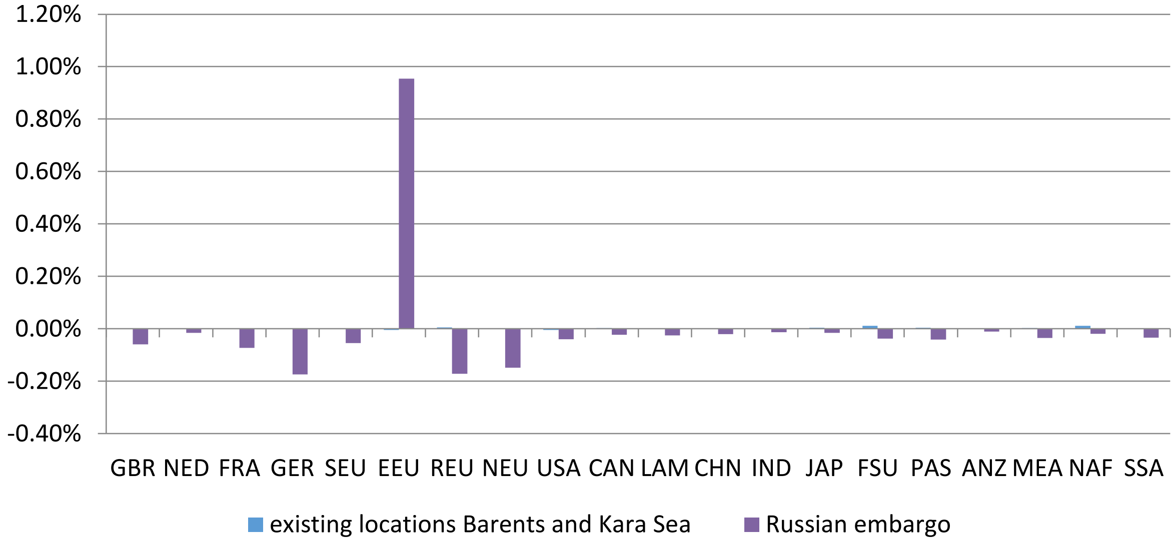


Figure 100: Change in labour input value in the other heavy industries sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

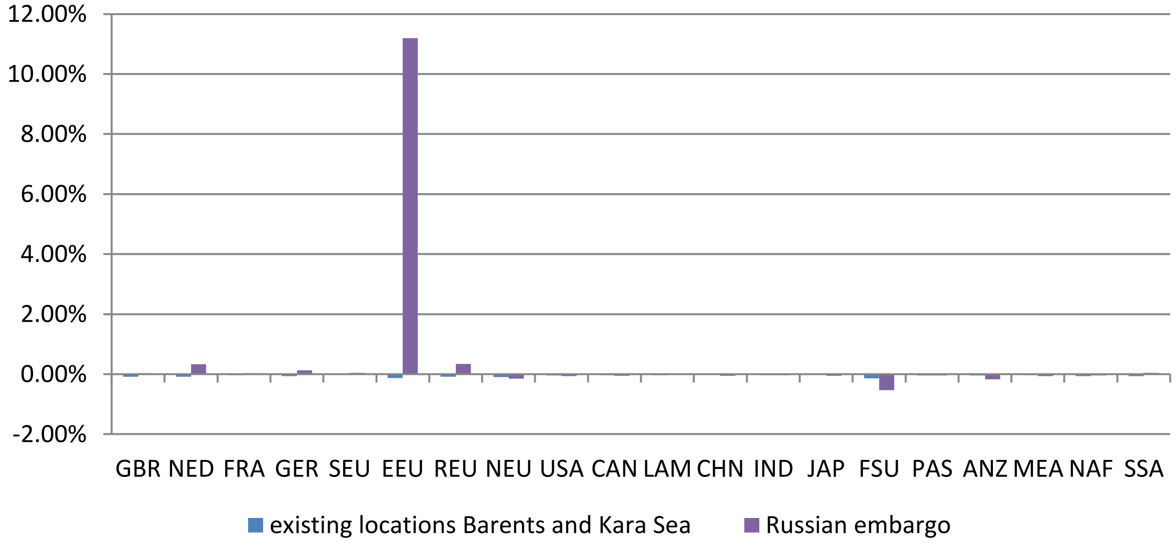


Figure 101: Change in labour input value in the petroleum and coal products sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

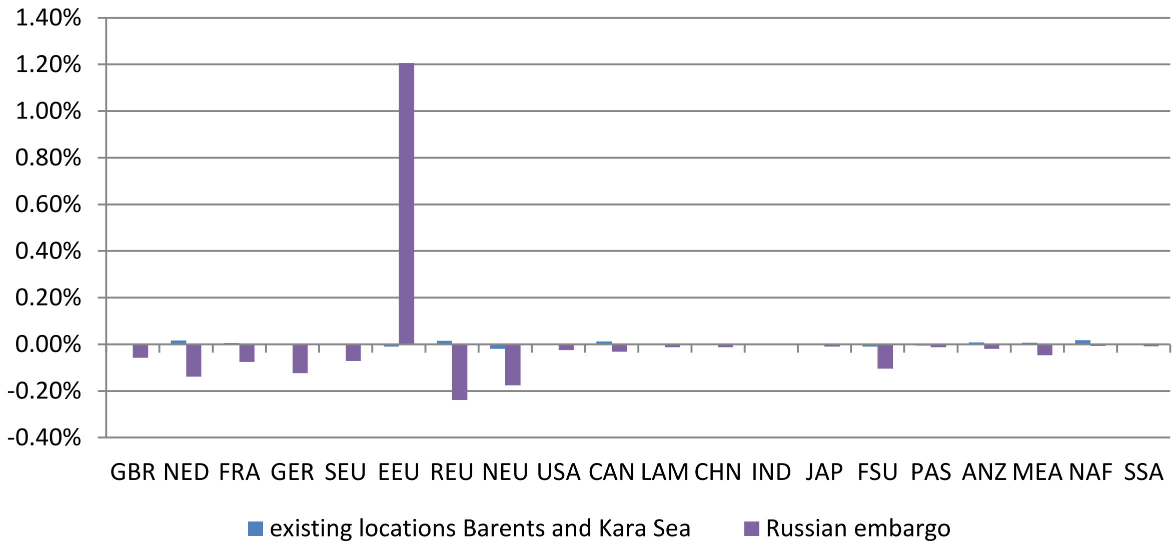


Figure 102: Change in labour input value in the other light industries sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

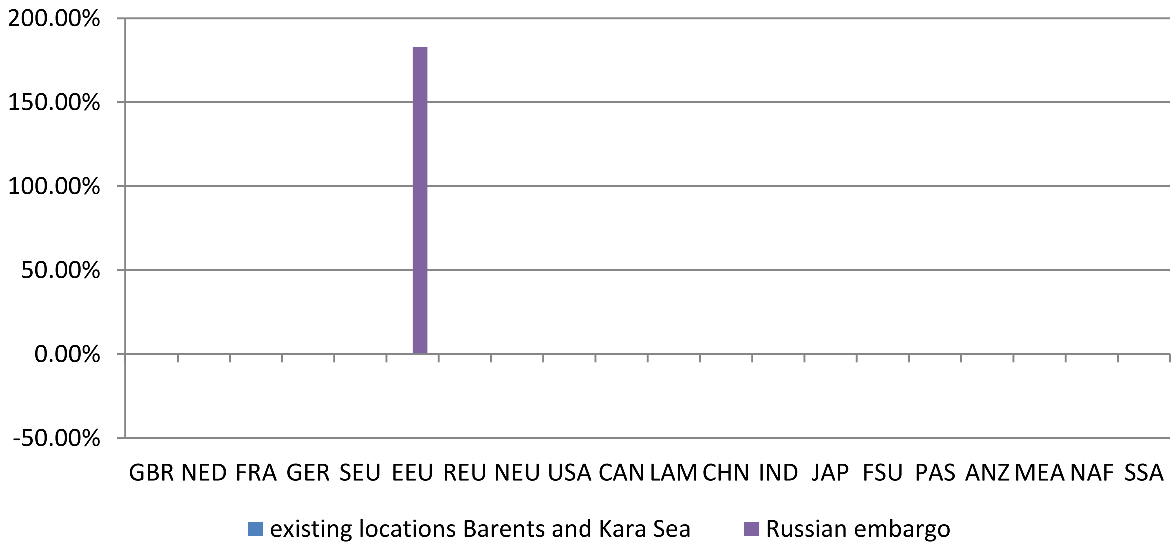


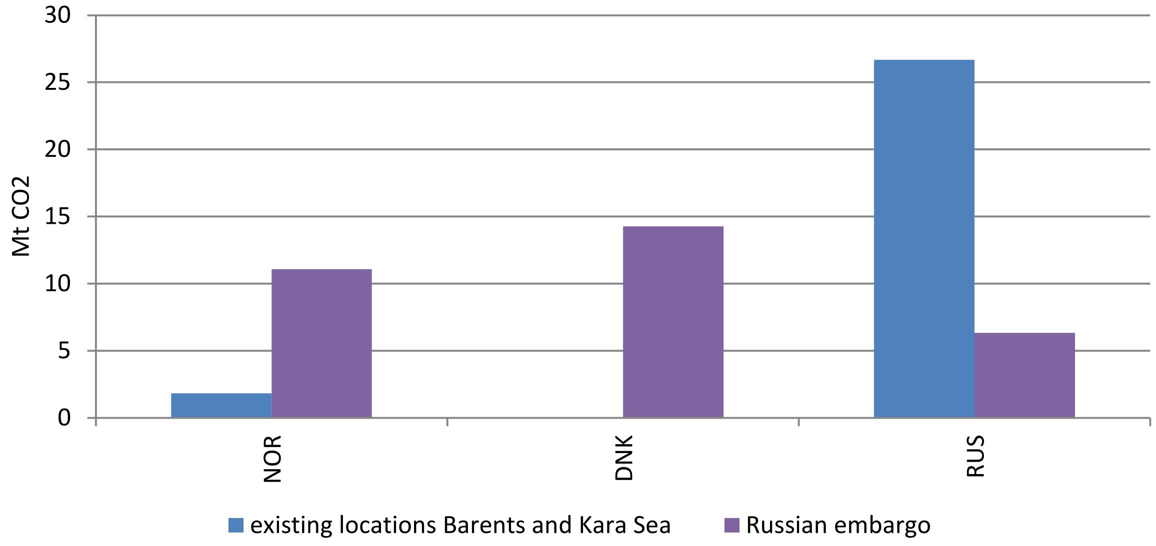
Figure 103: Change in labour input value in the services sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.12.8. Impact on decarbonisation efforts

While a Russian embargo has detrimental consequence for the economies in Russia and Eastern Europe, it serves at the same time as an involuntary climate protection program. CO_2-emissions from burning fossil fuels decrease worldwide by more than 24 mt in 2040, relative to the Reference Scenario. These emission savings are realized almost entirely in Eastern Europe (EEU), where CO_2-emissions drop by more than 110 mt (10 %). These large savings in the EEU are offset by increasing CO_2-emissions elsewhere, most notably in non-

EU Europe (NEU), the countries of the Former Soviet Union (FSU) as well as Russia, Norway and Denmark.

Panel a:



Panel b:

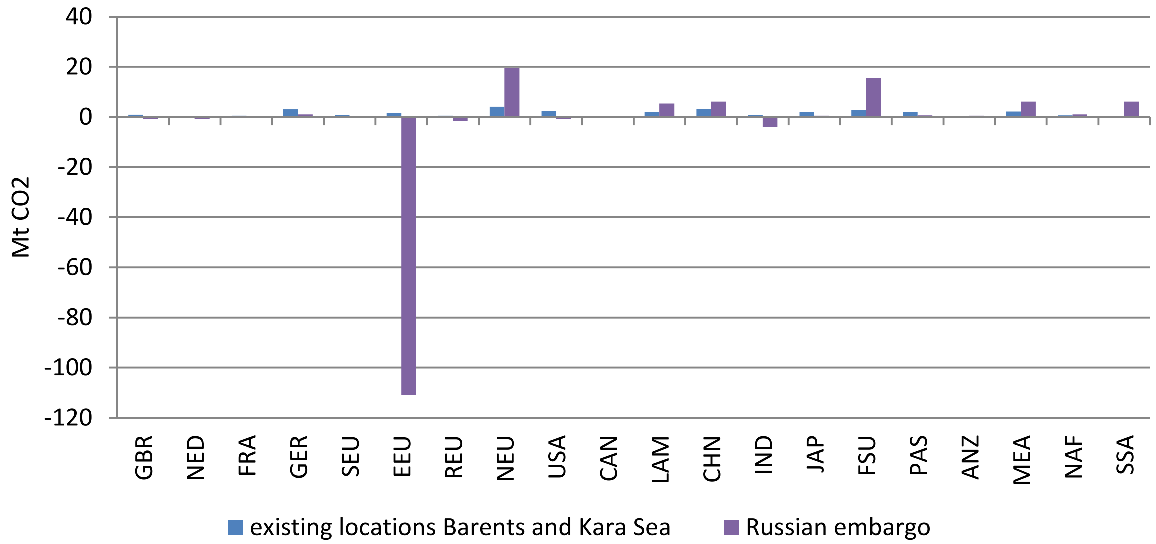


Figure 104: Changes in CO2-emissions from coal, gas, oil (Mt CO2) in 2040, absolute difference to Reference Scenario (%)
Source: Own presentation based on DART model results.

7.12.9. Summary of the effects of a Russian natural gas embargo

A Russian export stop of natural gas to Europe leads to a sizeable increase in European Arctic natural gas production and a correspondingly larger share of European gas in the European import portfolio. However, the consequences of the export stop are wider than the direct effect on European Arctic gas production.

Economic activity, measured as GDP, is most negatively affected in Russia and the countries of the Eastern European Union (EEU) since their economy heavily depends on natural gas from Russia in the Reference Scenario. On the flipside, the economic activities especially in

Norway and Denmark increase, as the two countries produce Arctic natural gas to fill the vacuum on the EU's gas. Somewhat surprisingly, effects on economic activity in Western Europe are negligible in the long run.

A similar picture emerges regarding the development of the natural gas price; this development initiates a number of second round effects. The Eastern European (EEU) countries witness severe price increases and are more affected than others, while the rest of Europe is almost unaffected by price changes.

The price changes drive a number of other developments, including shifts in the labour market in Russia, Norway, Denmark, and the Eastern European (EEU) countries. In Norway and Denmark employment is shifted from almost all other sectors into the gas producing sector. In Russian production of natural gas exports are redirected to other trading partners. Again, Eastern European (EEU) countries are most affected by price effects leading to a significant drop in terms-of-trade and export values as compared to the Reference Scenario. As an unintended side effect, global CO_2-emissions decrease substantially, following the economic downturn in Eastern Europe.

8. Concluding remarks on the impact of Arctic natural gas

This analysis has focused on the effects of additional natural gas production in the Arctic, with a special focus on Europe. In general, the effects are very moderate. This is due not only to the small *existing* European Arctic natural gas production capacities which, taken together, will amount only to 28.6 bcm in 2018. It is also due to the fact that only few locations in the European Arctic are economically viable in the current gas market environment. We study additional production in the Norwegian and Russian Barents Sea, at existing Russian Kara Sea facilities and off of the West coast of Greenland. Of these locations, only production in Greenland and the expansion of existing production facilities in Norway (Snøhvit) and Russia (Yamal) are economically viable. More challenging environments in the Barents Sea, e.g. offshore locations with higher step-out distances, are not economic in the current environment. This highlights the importance of existing infrastructure for economic development in the High North, which serves as a catalyst restricting future development.

With Asian demand steadily increasing, the vast majority of Arctic gas production will be shipped to Asia in the long run. Hence, the European supply portfolio is not going to be significantly altered by Arctic production from existing facilities, even if production volumes increase significantly. Only hypothetical LNG production in Greenland is shipped to Europe where it partly replaces US LNG.

We also find that accelerating climate change in the Arctic, looked at as the year-around passage option vie the NSR, does not have a significant effect on deliveries, since even in the case of limited availability of the NSR in the Reference Scenario (we assume availability of the NSR from June to September), almost all gas is shipped to Asia (not requiring the NSR).

Still, additional Arctic gas production has some indirect impacts on Europe and beyond. Obviously, the gas producing countries are most affected. This is especially true for Greenland/Denmark, where we find an increase in GDP of 1.3-1.4 % and spillovers to some manufacturing sectors in 2040 if natural gas is produced in the off the coast of Greenland. Overall, economic impacts on Norway and Russia are smaller, although we find significant reactions in downstream sectors in both countries. The rest of the Norwegian economy is mostly negatively affected by Arctic gas production in the country, with values of output decreasing especially in the chemicals and energy intensive industry sectors. These sectors suffer twice from extended gas production, (1) because of increased competition about qualified labour and (2) because of Dutch Disease effects. The Russian downstream economy, especially the chemicals and electricity sectors, partly profits from lower prices for natural gas and realizes production increases. Nevertheless, increased competition for qualified labour can be seen also in Denmark and Russia, and to a smaller extend also in other natural gas producing economies, including The Netherlands and countries in North Africa.

Even though overall effects outside the Arctic may be small, we do find some effects in selected non-Arctic countries. Especially countries in Eastern Europe and those of the Former Soviet Union, all located in close proximity to Russia, are affected. Again, the chemicals and energy intensive industry sectors increase their output because of reduced natural gas prices.

On the global goods and services markets, our results indicate that reactions are mostly limited to the producing countries. Terms-of-trade decrease by around 1 % in 2040 for Denmark and Norway, as are export values in the Norwegian manufacturing sectors. Potential reasons for these losses are Dutch Disease effects as well as increased competition on factor markets, including the labour market. Despite reduced terms-of-trade, some Danish manufacturing sectors increase their export values as they profit from lower natural gas prices. The same is true for the Russian chemicals and electricity sectors.

Also, the production of other fuels is not significantly affected by additional Arctic gas production, apart from some special cases, such as the Russian electricity and non-Arctic natural gas sectors. Production of Arctic natural gas is, however, detrimental to reaching European and global climate protection goals. As global CO_2-emissions from burning coal, gas and oil increase in the order of magnitude of several dozen mt, the hope that natural gas might replace even more carbon intensive fuels such as coal or oil seems not to realize.

As a general conclusion, the production of natural gas in the Arctic, while having some modest regional effects, is certainly not a game changer for Europe. The effects on import diversification are miniscule as economic possibilities on competing markets, especially Asia, are more tempting for natural gas producers. Also, the impulses for economic development remain small and confined to the producing countries or selected energy intensive sectors.

Part III: Economy-wide impact of Arctic oil production

9. Status quo on Arctic oil production

Even though USGS estimates in their 2008 circum-Arctic resource appraisal (CARA, Gautier et al. 2009) that the Arctic Ocean holds around 90 bn undiscovered barrels of oil, there has not been too much oil exploitation activity in the European Arctic. Many technological and environmental complexities lead to exceptionally high costs and make it tough for Arctic oil to compete with other energy sources, including non-conventional ones.

Unlike than the regionalized, still pipeline-driven gas markets, the market for oil is globalized, which means that Arctic sources have to compete worldwide. Nevertheless, the Arctic oil may be competitive in the future, as oil prices have been rising again lately, even though the all-time high of just before the financial crisis has not yet been reached. The level of this, up to today, all-time high might be what Arctic oil needs for economic production. At the same time, international oil companies are attracted by the relatively unrestricted access to Arctic reserves, at least outside Russia. The future will show whether the companies' attraction extends to actual production. While offshore oil production has a long history in the shallow, close-to-shore fields of Prudhoe Bay in Alaska, there has not been much offshore oil development in the European Arctic. The most prominent example is the Russian Prirazlomnaya oil field on the Pechora sea shelf, where the first oil has been shipped to markets as late as early 2014 (see Gazprom 2014). Because of the late start of actual production and the uncertainties associated with the project before the start of production, oil from Prirazlomnaya is not included in the reference scenario for oil, but rather covered using an additional scenario.

10. The reference scenario

In the sections to come, we will express developments induced by additional production of Arctic oil mainly as deviations from a state without offshore oil production in the European Arctic. In this state of production the countries we will focus on in the following include Norway, Denmark, and Russia.

Using the DART model to determine the volume of oil production (excluding offshore Arctic oil production) for these countries until 2040, the numbers are displayed in Figure 107 (for every five years starting in 2015). Russia is by far the largest producer of oil among the three countries, with a projected production of 454 mtoe in 2040. Norwegian oil production in this year is still substantial, with 57 mtoe, while production in Greenland with just below 8 mtoe is small. Accordingly, an additional unit of production of Arctic offshore production will have a much larger relative impact in Greenland than in Norway or even Russia. For all three countries the DART model calculates a continuous but small decline over the coming decades for non-Arctic oil production, as existing oil fields deplete.

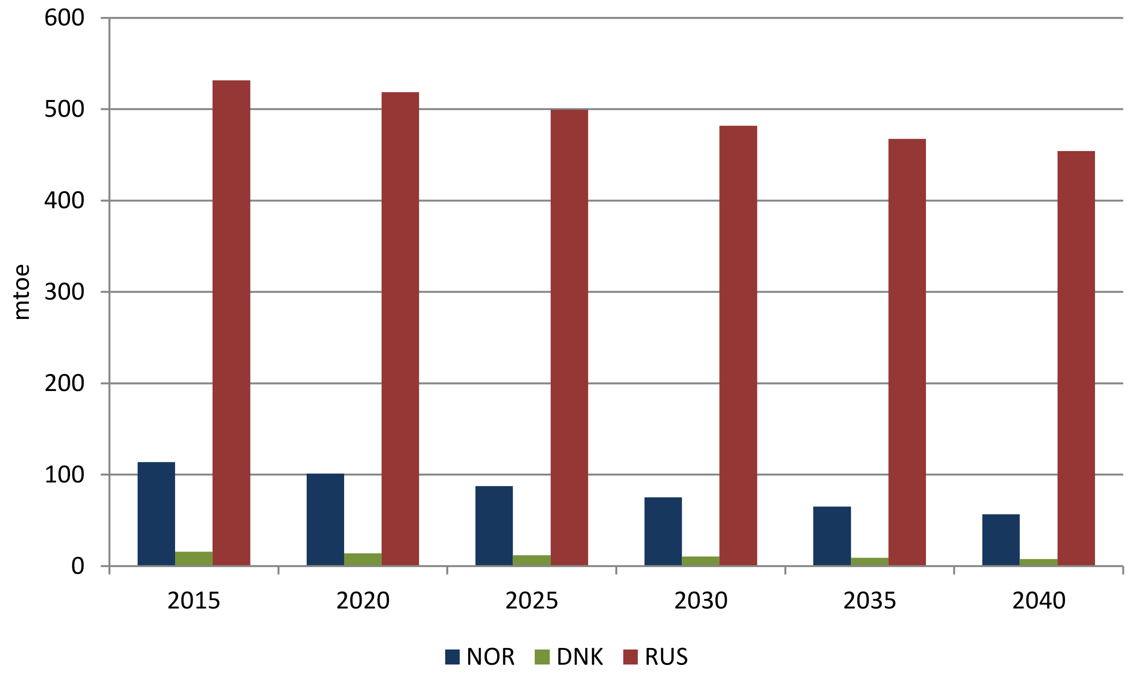


Figure 105: Total production of crude oil (mtoe), Reference Scenario
Source: Own presentation based on DART model results.

11. Motivation and description of alternative scenarios

In order to test the sensitivity of the results relative to the Reference Scenario we specify a set of alternative scenarios. This generates a more robust corridor of the economic potential of Arctic oil and assessment of the economy-wide implications. Since offshore crude oil production in the European Arctic is less developed than in the case of natural gas, future development is less certain. To acknowledge this we specify four general scenarios, each with a number of sub-scenarios.

According to the assumptions used for the scenario analysis of additional Arctic natural gas, we assume that up to two standard production units of 2.3 mtpa each, as taken from IMPaC (2012), are a realistic development size for a non-developed region. An exception is the scenario 1b1 (details are provided below),We specify one scenario for each relevant country in which two standard production units start production in 2020. This should allow sufficient time for installation. An additional scenario is added that analyses simultaneous production in all regions (Scenario 4). Whether the complete capacity is utilized depends on the economic framework, as determined by the DART model.

The resulting list of scenarios is as follows:

- Scenario 1: “Model-driven investment in the Russian Arctic Ocean”
- Scenario 2: “Model-driven investment in the Norwegian Arctic Ocean”
- Scenario 3: “Model-driven investment in Greenland”
- Scenario 4: “Model-driven investment in Russia, Norway, and Greenland”

Each scenario is comprised of two sub-scenarios. Sub-scenario a assumes the installation of a subsea production unit with on-shore processing, while scenario b assumes the installation of an FPSO. We add an additional sub-scenario to Scenario 1 to take into account the recent start of production at the Prirazlomnaya field, which is an FPSO that exceeds our prespecified production capacity. The Prirazlomnaya field went into production after most of the modelling work for our analysis on the economy-wide impact of Arctic oil supply was completed. However, to account for this recent development we scenario 1b1 which estimates the impact of a large, Prirazlomnaya-style, FPSO of 6.6 mtpa production capacity (Sevmash 2011).

The production costs used in our assessment of Arctic offshore oil production are displayed in Table 8. For use in DART, production costs are first converted into mark-ups relative to conventional oil production in the respective country. Conventional cost estimates are taken from a compilation of various sources (Aguilera et al. 2009) and converted to 2012 EUR. In a second step, we convert the mark-ups from EUR into inputs from the rest of the economy by using the input structure of conventional production. In order to account for the differing composition of inputs between FPSO, subsea, and average conventional technology, we calculate the mark-ups distinguishing between capital (mark-up calculated based on fixed development costs), labour (mark-up based on variable production costs), and intermediates (mark-up based on a mixed calculation between the two reflecting total cost). Given the different cost-structures between different countries, the mark-ups differ between Norway, Russia, and Greenland.

Table 8: Cost Assumptions for Arctic offshore oil consumption (EUR/bbl/a)

	Development Cost	Production Cost
Floating Production Unit with Floating LNG	17.84	17.63
Subsea Production Facility and onshore LNG	27.27	16.83

Source: Own calculations based on IMPaC 2012.

The following table contains a summary of the scenario outline.

Table 9: Scenario Overview Arctic oil

Scenario			Description
Reference Scenario		No offshore oil production in the European Arctic.	
Scenario 2	**a**	FPSO facility	This scenario allows for offshore production of Arctic oil in the Russian Arctic Ocean. It is divided in three sub-scenarios. In scenarios 2a and 2b, up to two standard trains of 2.3 mtpa each can be added in 2020. In scenario 2c, a capacity of up to 6.6 mtpa can be installed to simulate a Prirazlomnaya-style development. All other parameters are those of the Reference Scenario.
	b	Subsea facility	
	c	Large FPSO facility	
Scenario 3	**a**	FPSO facility	This scenario allows for offshore production of Arctic oil in the Norwegian Arctic Ocean. It is divided in two sub-scenarios. In scenario 3a and 3b, up to two standard trains of 2.3 mtpa each can be added in 2020. All other parameters are those of the Reference Scenario.
	b	Subsea facility	
Scenario 4	**a**	FPSO facility	This scenario allows for offshore production of Arctic oil in Greenland. It is divided in two sub-scenarios. In scenario 3a and 3b, up to two standard trains of 2.3 mtpa each can be added in 2020. All other parameters are those of the Reference Scenario.
	b	Subsea facility	
Scenario 5		This scenario models simultaneous Arctic offshore production in Russia, Norway, and Greenland, using FPSO technology. As before, up to two standard trains of 2.3 mtpa each can be added in 2020 in each country. All other parameters are those of the Reference Scenario.	

12. Economy-wide impact of Arctic oil production: Results

12.1. Arctic oil production

12.1.1. Scenario 1 ("Model-driven investment in the Russian Arctic Ocean")

Russia, as the largest oil producer in the European Arctic at present, is also on the forefront of future Arctic offshore production. The DART model calculates that Russian offshore oil production in the Arctic would be economic from the earliest possible, predefined year in 2020 (for subsea as well as FPSO production; Figure 106 and Figure 109, respectively). The overall production cap imposed by the upper bound of two standard trains of 2.3 mtpa each is approached fairly quickly, even though a general caveat is that the adaptation paths generated by the model might not necessarily reflect the actual business economics of individual fields.

As overall oil demand is limited and oil prices fall with supply increases, non-Arctic Russian oil production falls, although by a far smaller amount (Figure 107). Also, production losses in non-Arctic oil production in Russia decrease over time. Even more negligible production losses occur in Norway.

As opposed to Norway and Denmark, Russia experiences an overall expansion of oil production by almost the complete amount that is produced offshore in the Arctic (Figure 108). The increase in production is even quicker if FPSO technology is used, and the production losses in non-Arctic Russia as well as Norway and Greenland are slightly larger (Figure 109 to Figure 111).

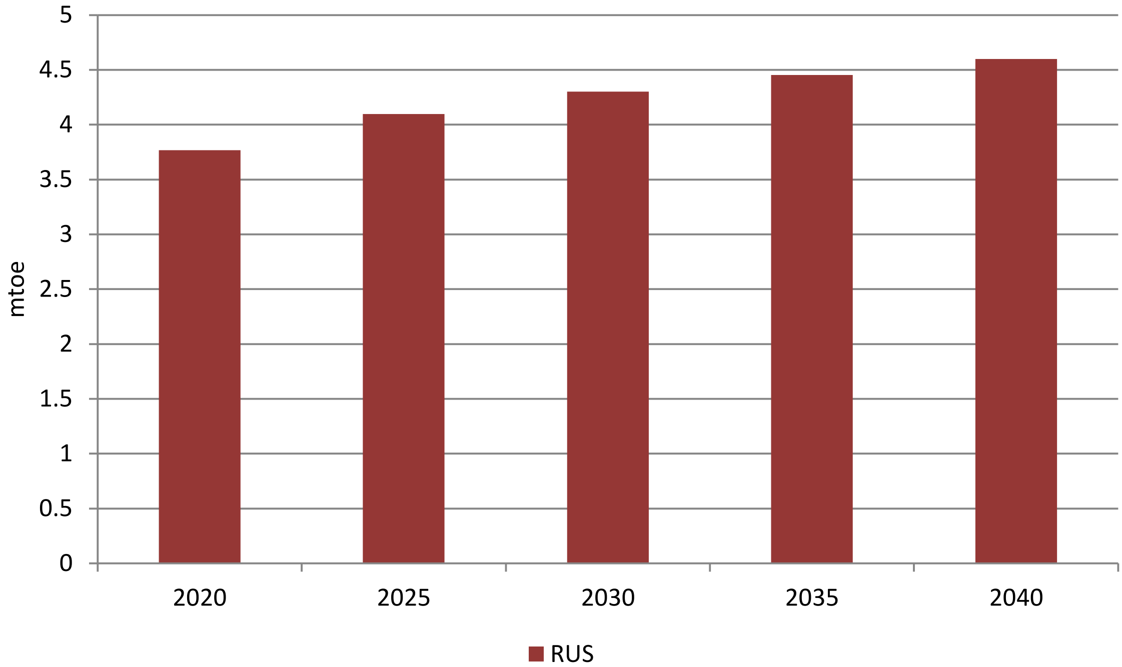


Figure 106: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (subsea)"
Source: Own presentation based on DART model results.

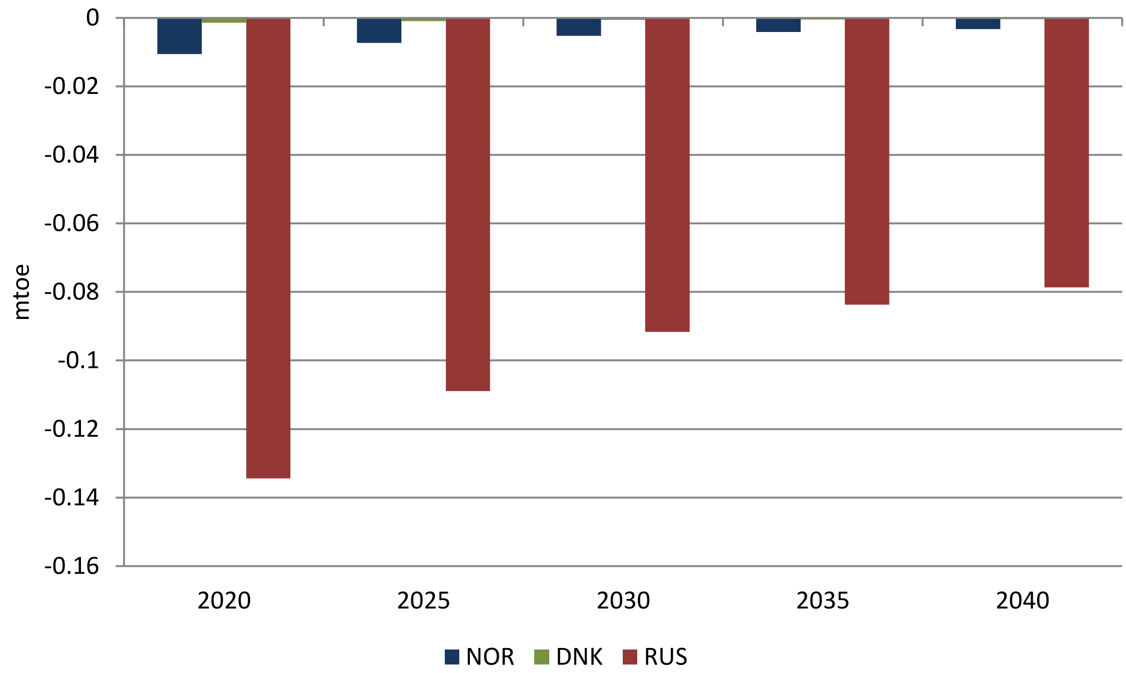


Figure 107: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (subsea)"
Source: Own presentation based on DART model results.

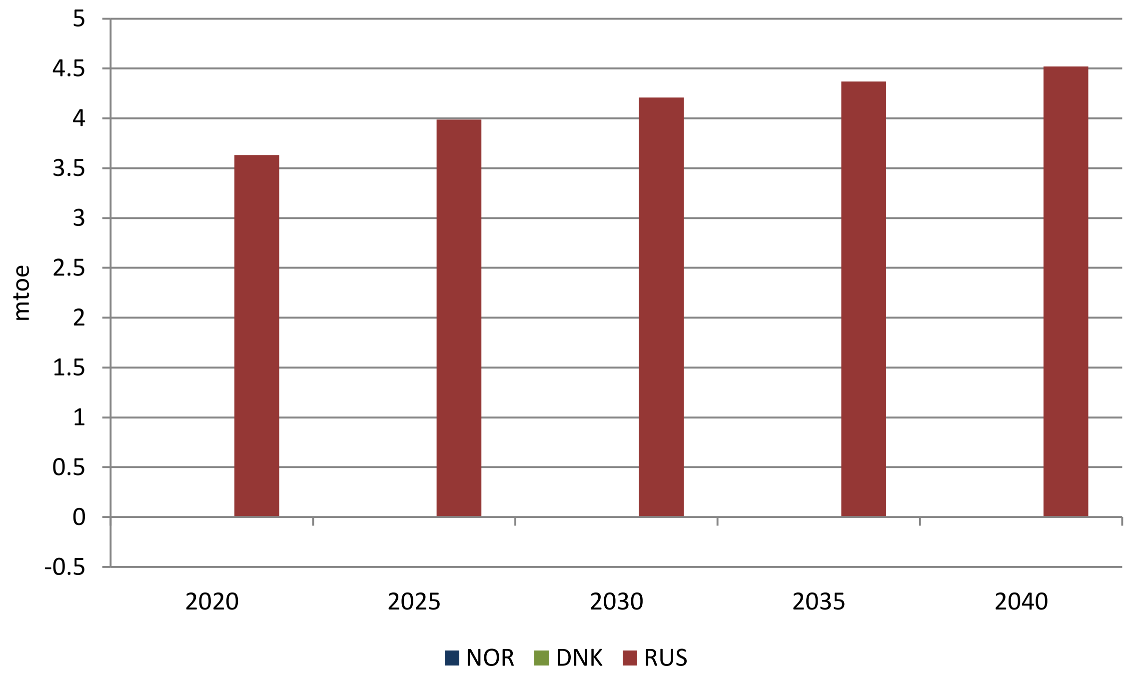


Figure 108: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (subsea)"
Source: Own presentation based on DART model results. Values for NOR and DNK are smaller than 0.002 in absolute terms.

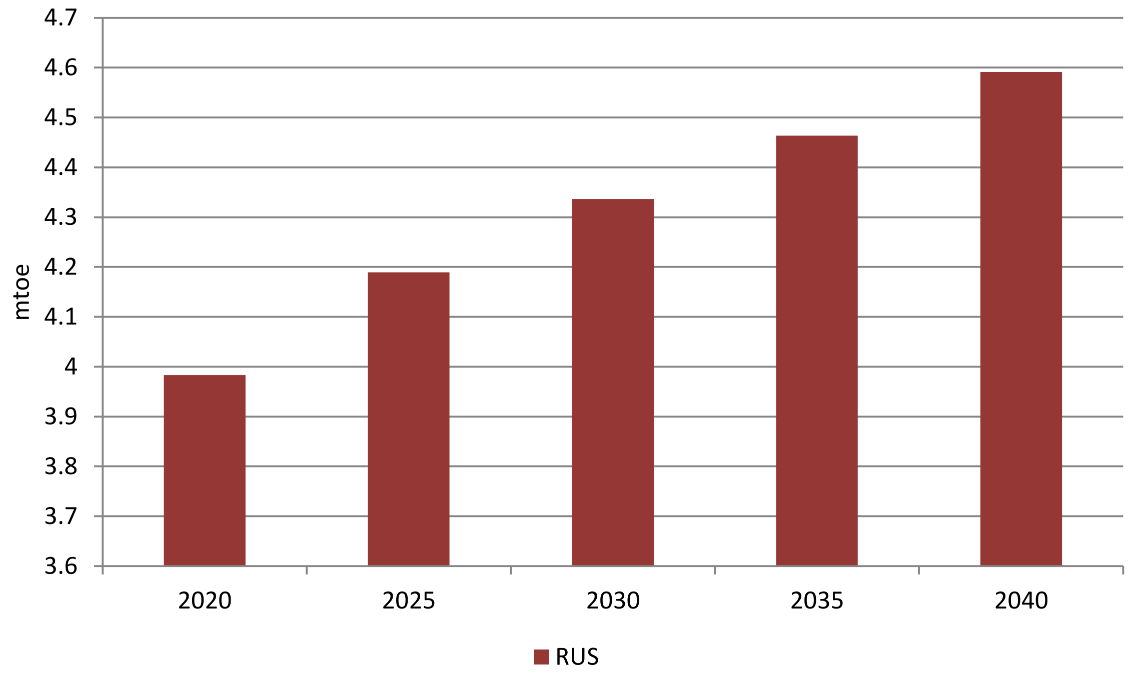


Figure 109: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (FPSO)"
Source: Own presentation based on DART model results.

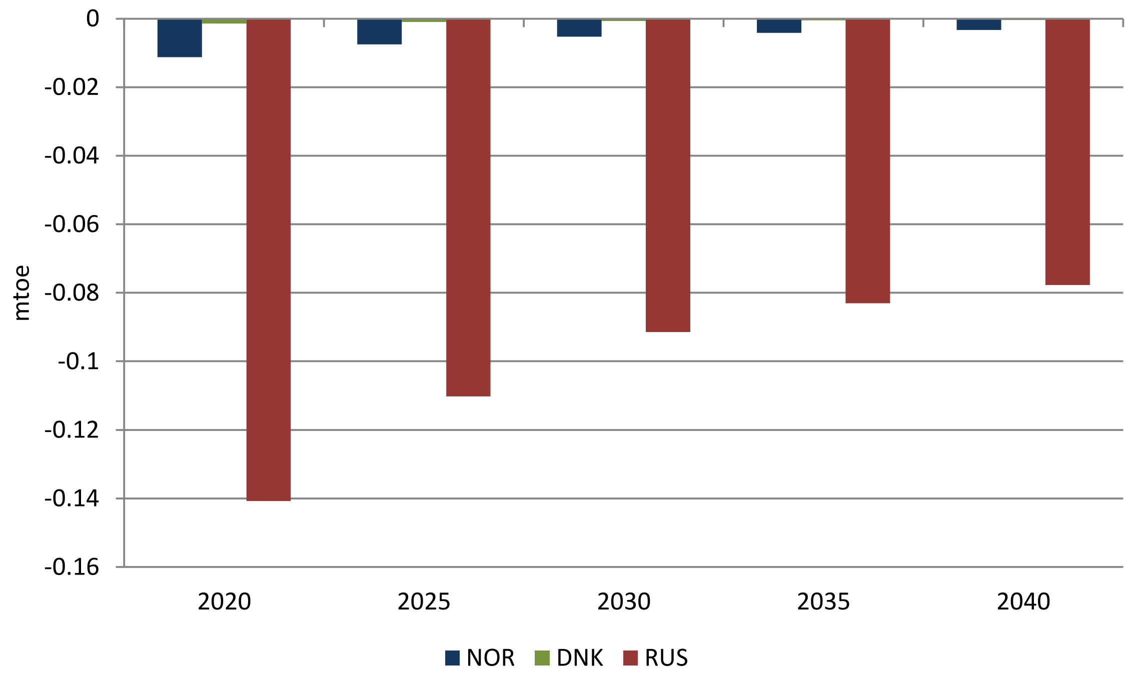


Figure 110: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (FPSO)"
Source: Own presentation based on DART model results.

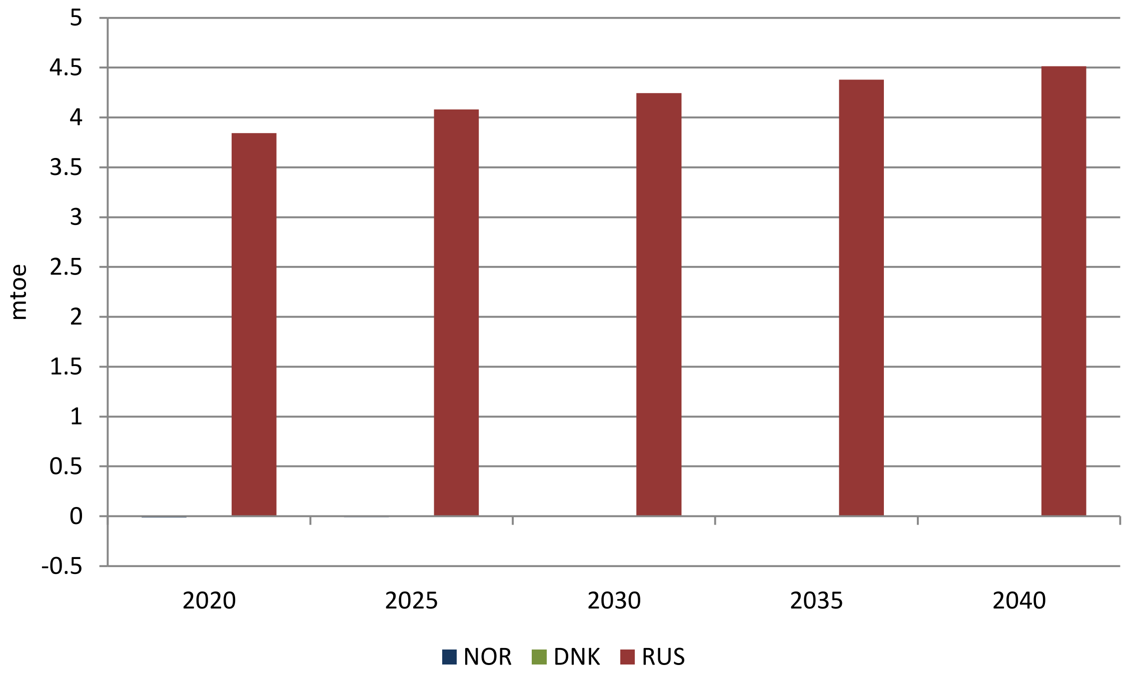


Figure 111: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (FPSO)" Source: Own presentation based on DART model results. Values for NOR and DNK are smaller than 0.002 in absolute terms.

As mentioned before, Russia is the only Country in Europe that has started the commercial offshore production of crude oil in the Arctic. The Prirazlomnaya oil field went into production in 2014, after the implementation of this analysis. As production volumes of Prirazlomnaya are larger than our assumed volumes in the other oil scenarios, we add an additional scenario that reflects the projected size of the Prirazlomnaya field. As Figure 112 shows, results of the DART model indicate that production of these larger FPSO volumes is economically feasible, even though the overall limit of production is only reached in 2040. Oil production in other facilities is crowded out accordingly, as reflected by the results presented in Figure 113 and Figure 114.

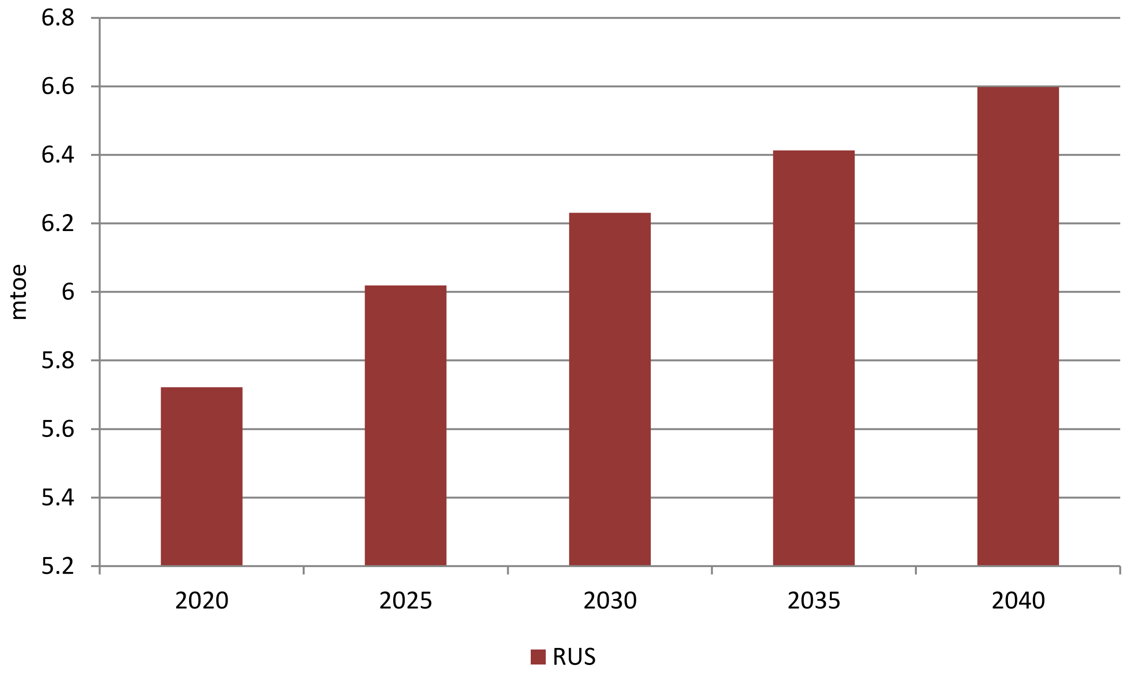


Figure 112: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (larger FPSO, Prirazlomnaya)"
Source: Own presentation based on DART model results.

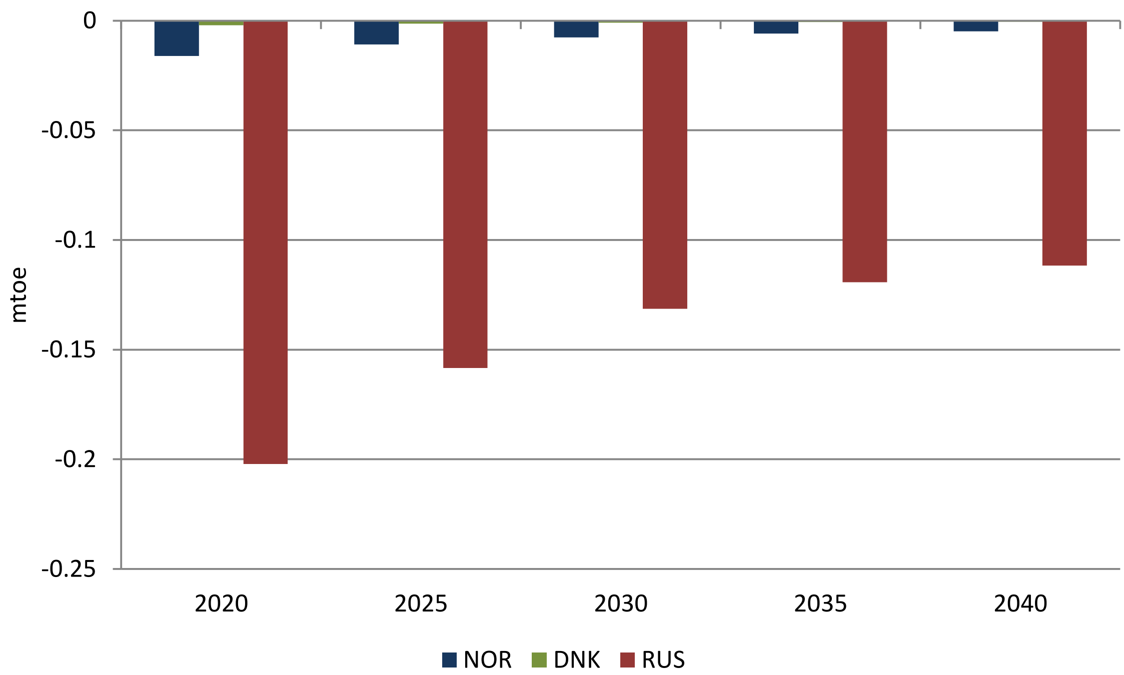


Figure 113: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (larger FPSO, Prirazlomnaya)"
Source: Own presentation based on DART model results.

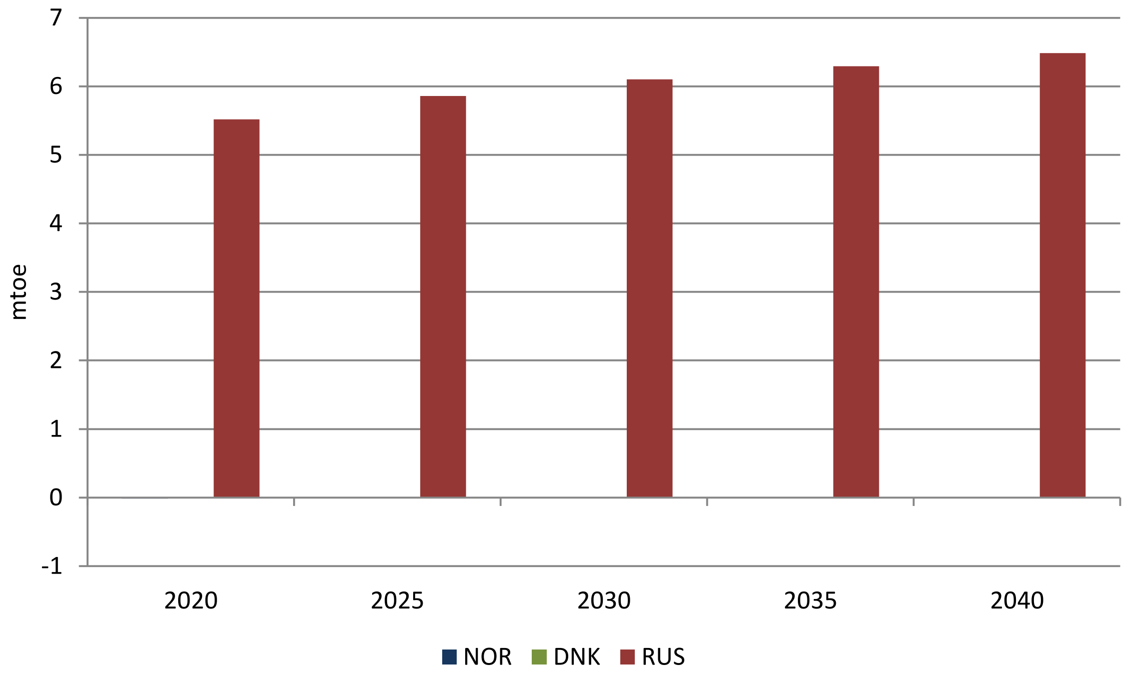


Figure 114: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Russia (larger FPSO, Prirazlomnaya)"
Source: Own presentation based on DART model results.

12.1.2. Scenario 2: "Model-driven investment in the Norwegian Arctic Ocean"

While additional production was economic in Russia early on irrespective of the technology, the situation for Norway is different. Even though FPSO technology starts producing already in 2020 (Figure 118), subsea technology, burdened with higher development and overall costs, is not economic before the mid-2020s (Figure 115).

In general, the production path accelerates more slowly than in Russia. Crowding-out is generally smaller for Norwegian non-Arctic oil but slightly larger for foreign non-Arctic oil, although the overall figure for foreign non-Arctic oil is very low in general (close to zero). Overall production losses, however, remain negligible (Figure 116 and Figure 117 for subsea production as well as Figure 119 and Figure 120 for FPSO technology).

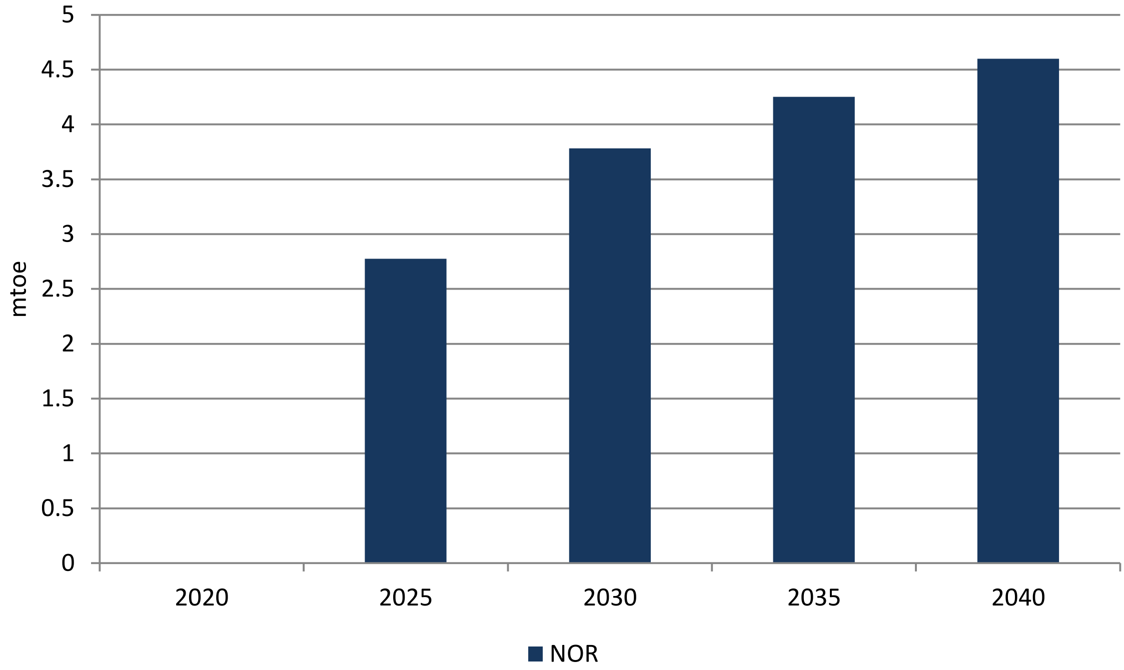


Figure 115: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (subsea)"
Source: Own presentation based on DART model results.

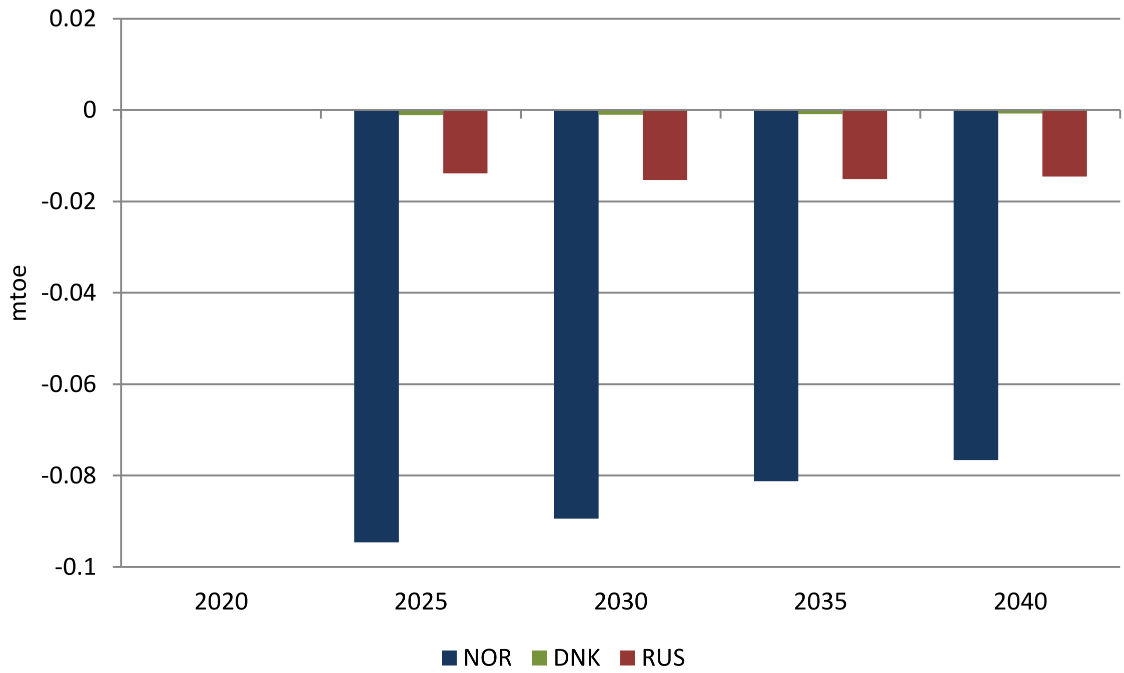


Figure 116: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (subsea)"
Source: Own presentation based on DART model results.

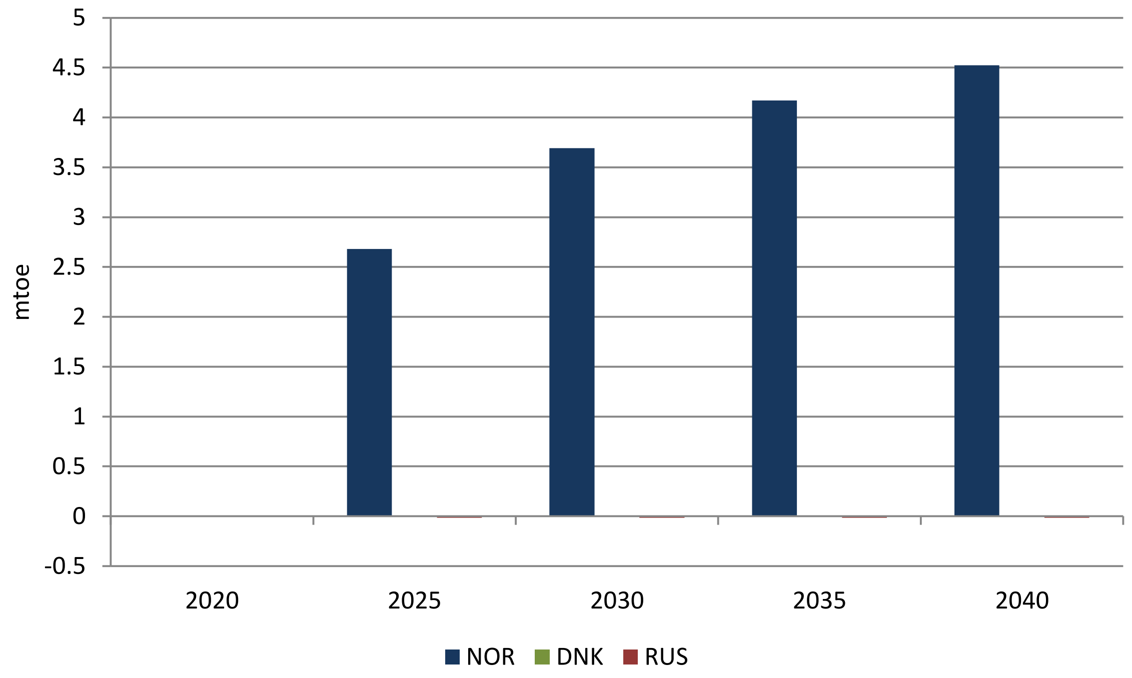


Figure 117: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (subsea)"
Source: Own presentation based on DART model results.

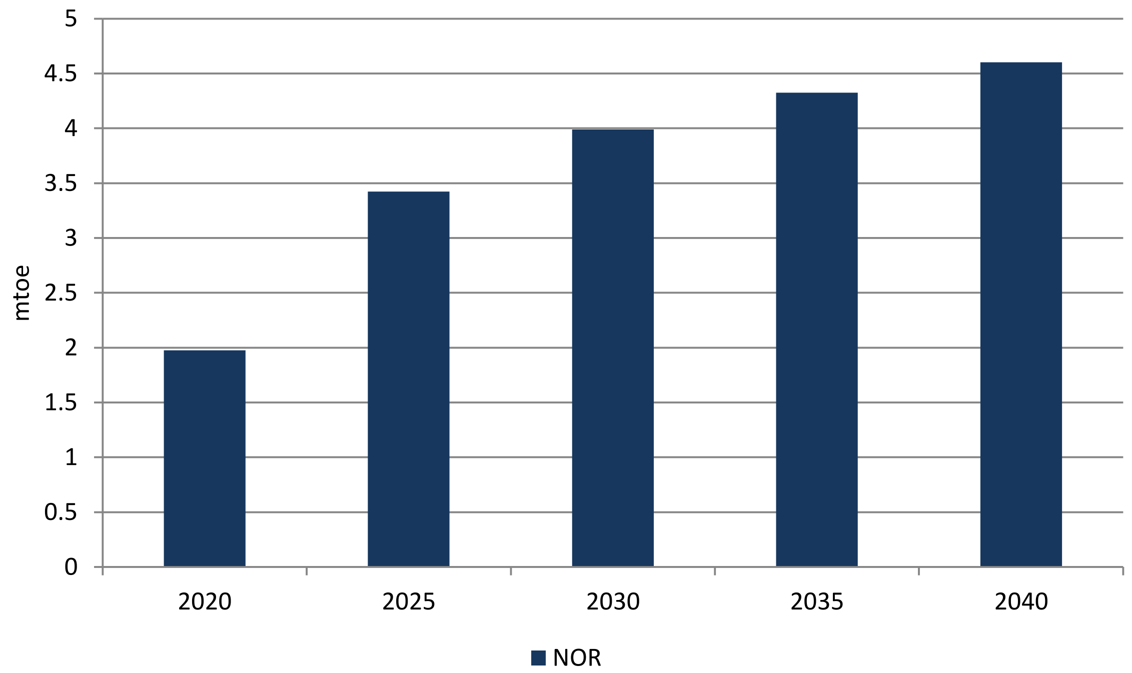


Figure 118: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (FPSO)"
Source: Own presentation based on DART model results.

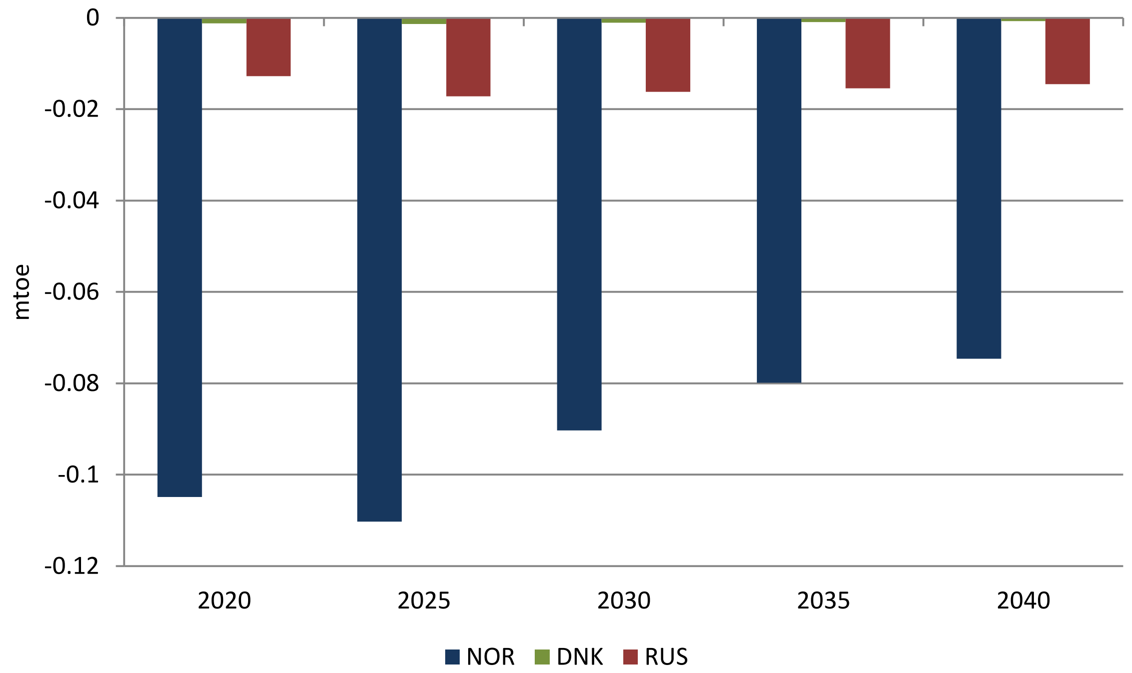


Figure 119: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (FPSO)"
Source: Own presentation based on DART model results.

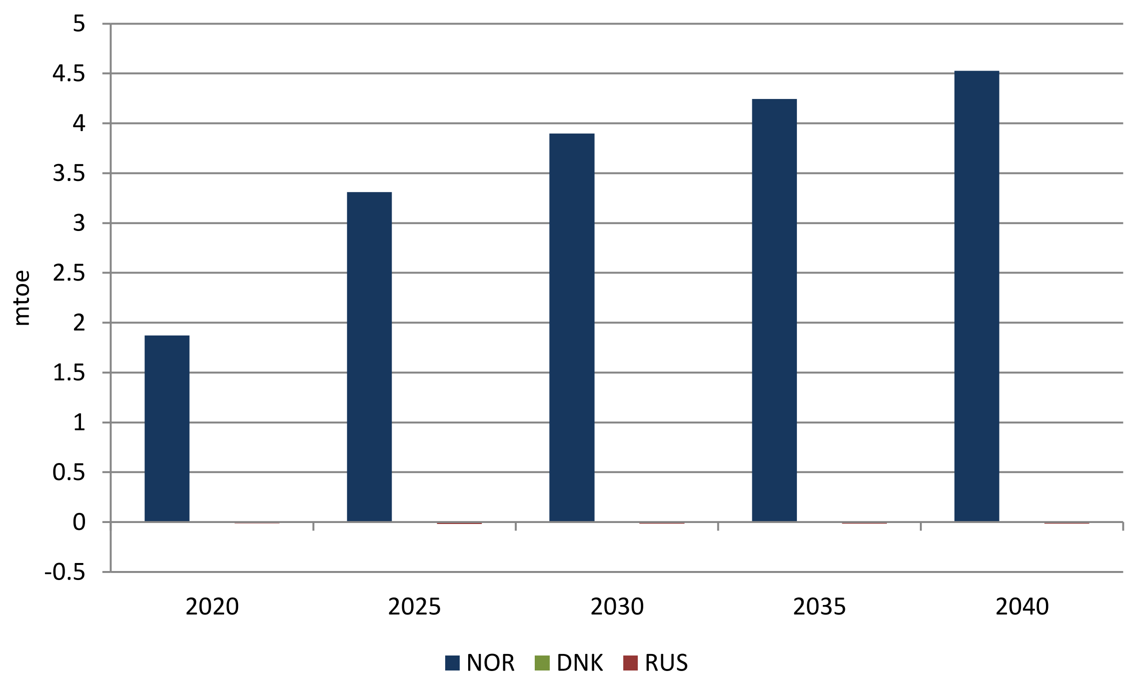


Figure 120: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Norway (FPSO)"
Source: Own presentation based on DART model results.

12.1.3. Scenario 3: "Model-driven investment in Greenland"

The development of oil production in Greenland is very similar to that of Norway. Again, FPSO production is economical from the start (Figure 124), while subsea production takes up a little later (Figure 121). Crowding-out of non-Arctic oil is occurs, but less so domestically and more in Russia compared to the Norwegian case (Figure 122 and Figure 123 for subsea production as well as Figure 125 and Figure 126 for FPSO technology).

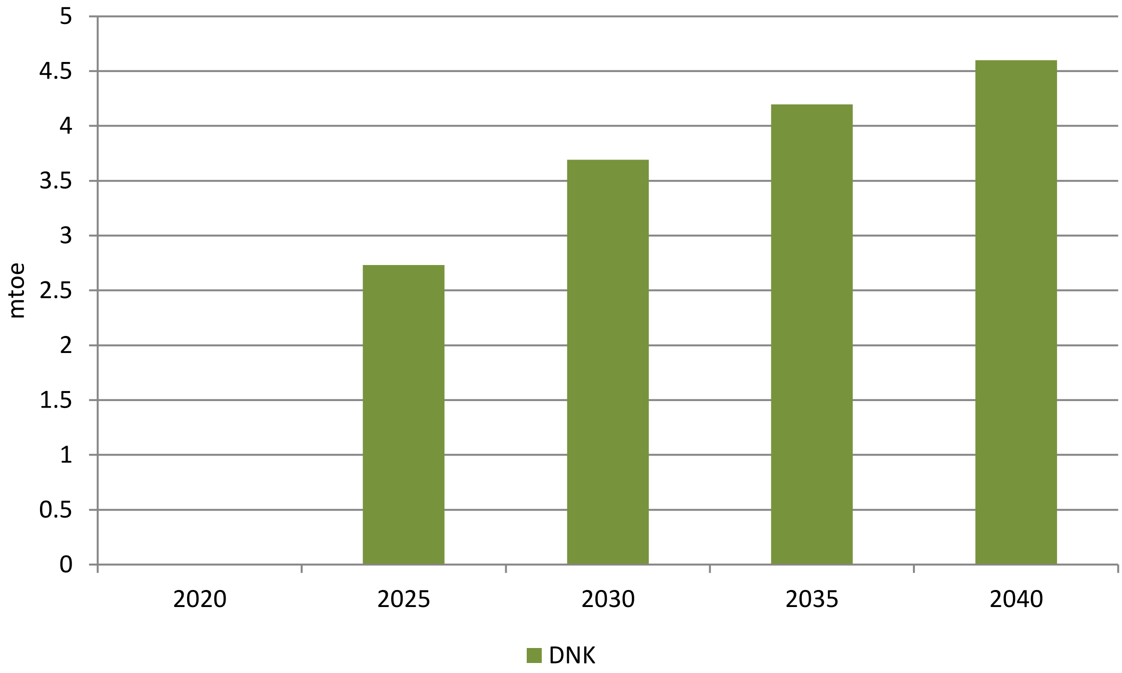


Figure 121: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (subsea)"
Source: Own presentation based on DART model results.

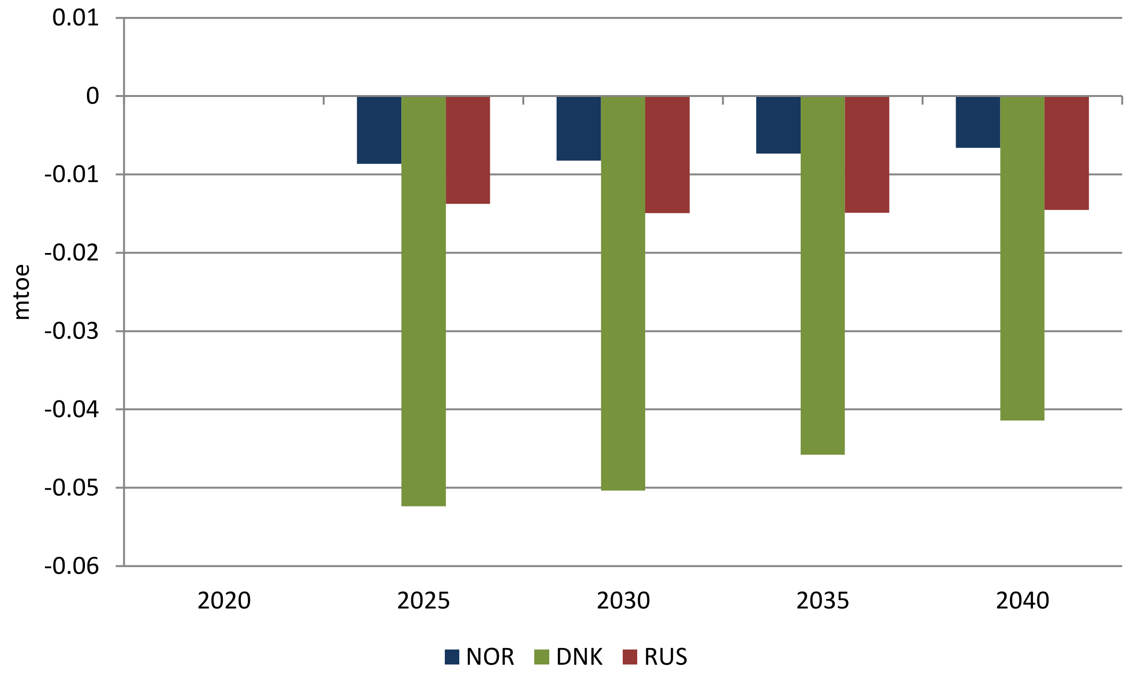


Figure 122: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (subsea)"
Source: Own presentation based on DART model results.

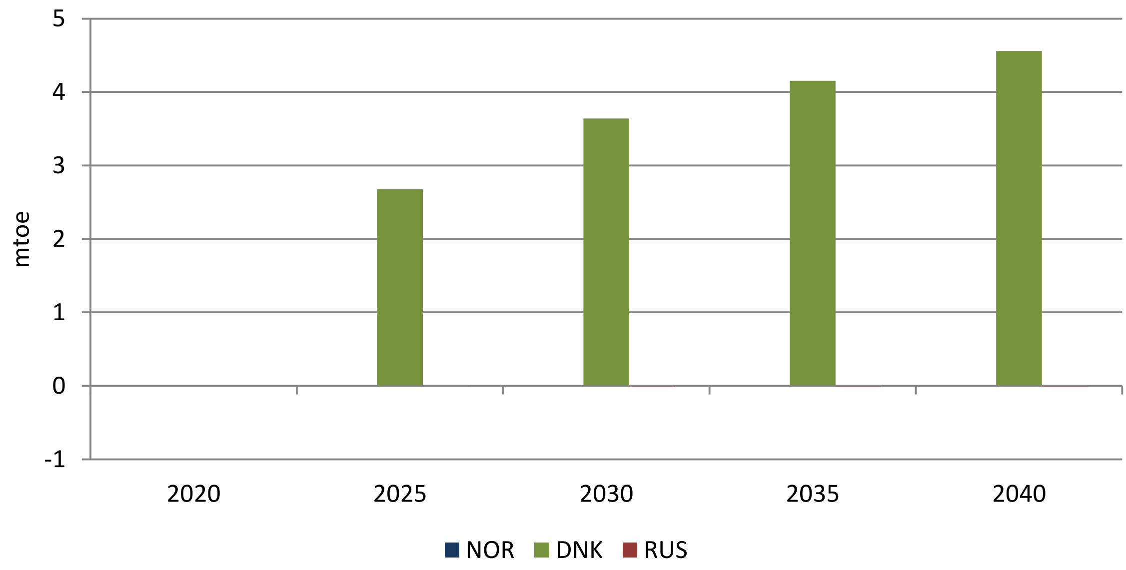


Figure 123: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (subsea)"
Source: Own presentation based on DART model results.

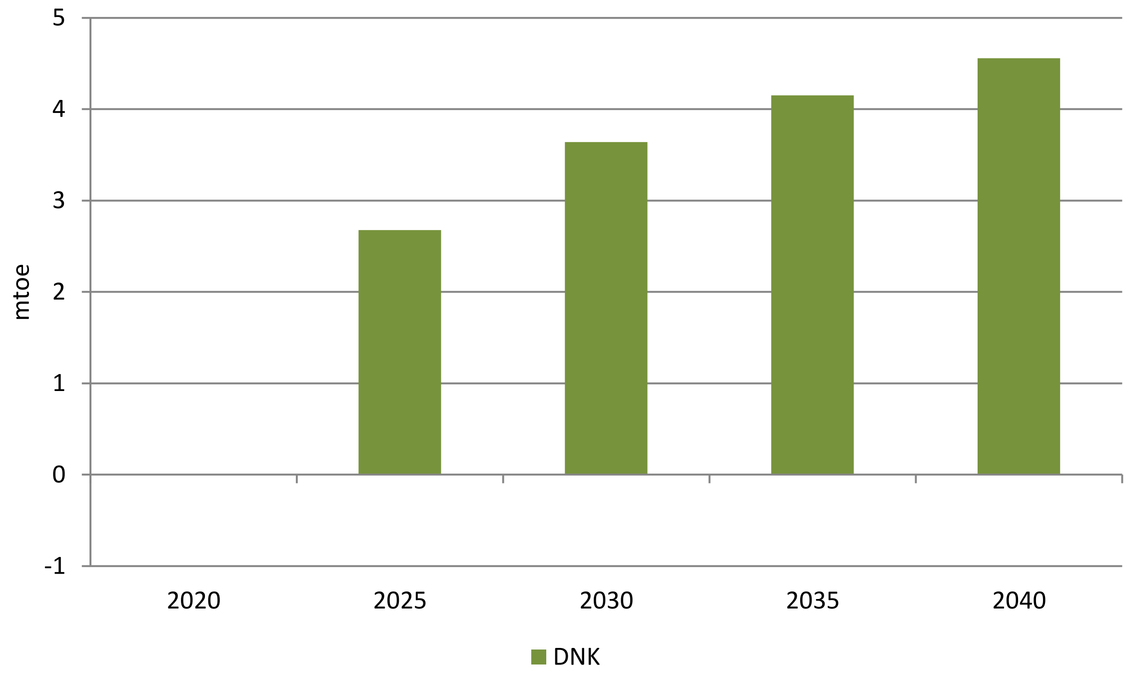


Figure 124: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (FPSO)"
Source: Own presentation based on DART model results.

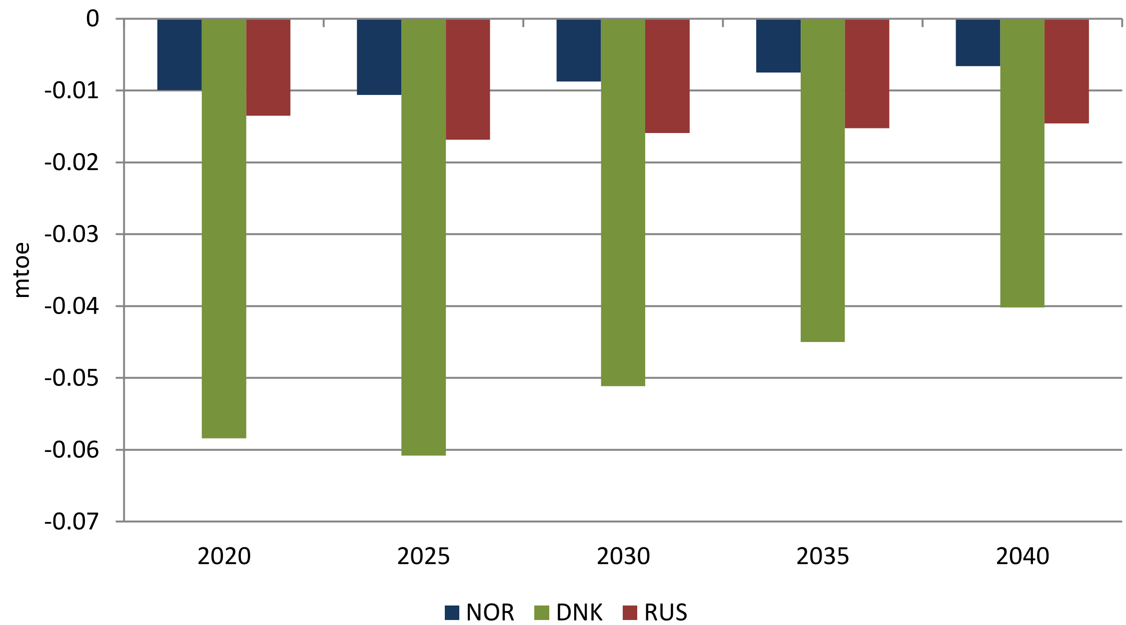


Figure 125: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (FPSO)"
Source: Own presentation based on DART model results.

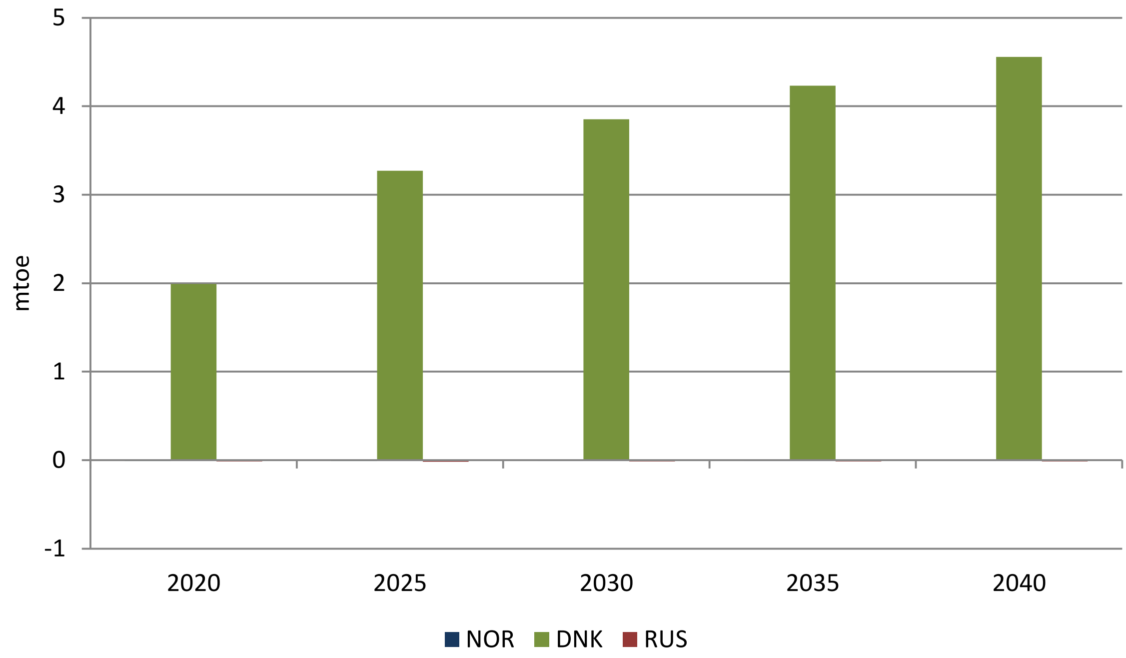


Figure 126: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in Greenland (FPSO)"
Source: Own presentation based on DART model results.

12.1.4. Scenario 4: "Model-driven investment in Russia, Norway, and Greenland"

As a final scenario, we study the implications if all three countries simultaneously allow for Arctic offshore oil production. Based on the results presented above on the economic viability of subsea production vs. FPSO, we restrict our analysis to the FPSO scenario.

The results of this scenario are similar to those presented above where the aforementioned production extension was restricted to individual countries (Figure 127). Again, production in Russia accelerates more quickly than in the other two countries and levels equalize only in 2040. As Figure 128 shows, crowding-out of non-Arctic oil is larger compared to results of Scenarios 1 to 3 for the individual countries. Because of lower levels of oil production in the Reference Scenario, the effects on non-Arctic oil are much smaller in Greenland than in Russia or Norway. This is reflected in the final figure (Figure 129).

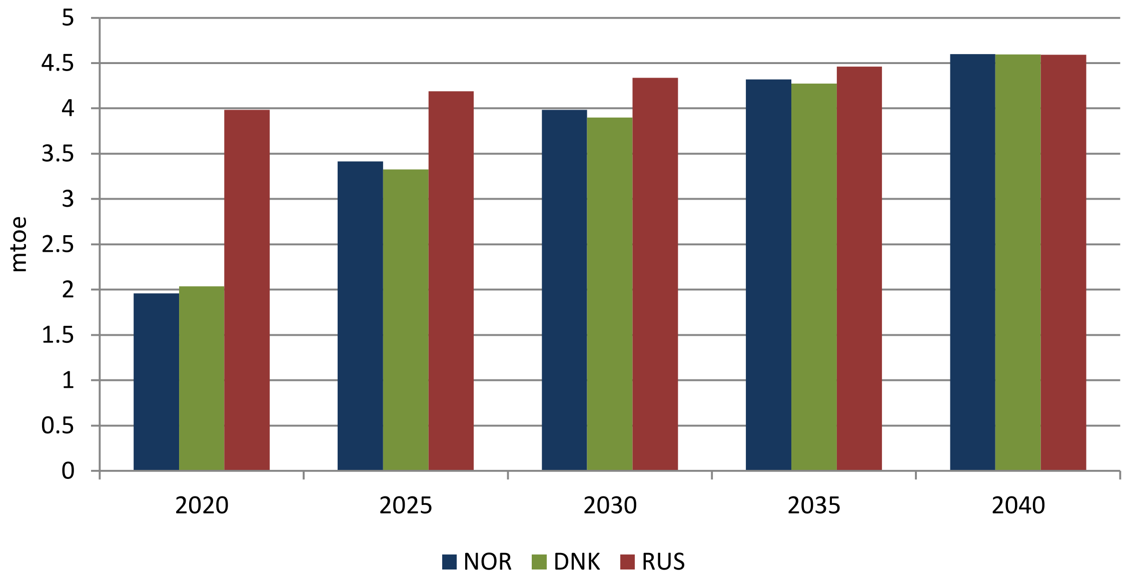


Figure 127: Change in Arctic offshore production of crude oil relative to Reference Scenario (mtoe); "extraction in all countries (FPSO)"
Source: Own presentation based on DART model results.

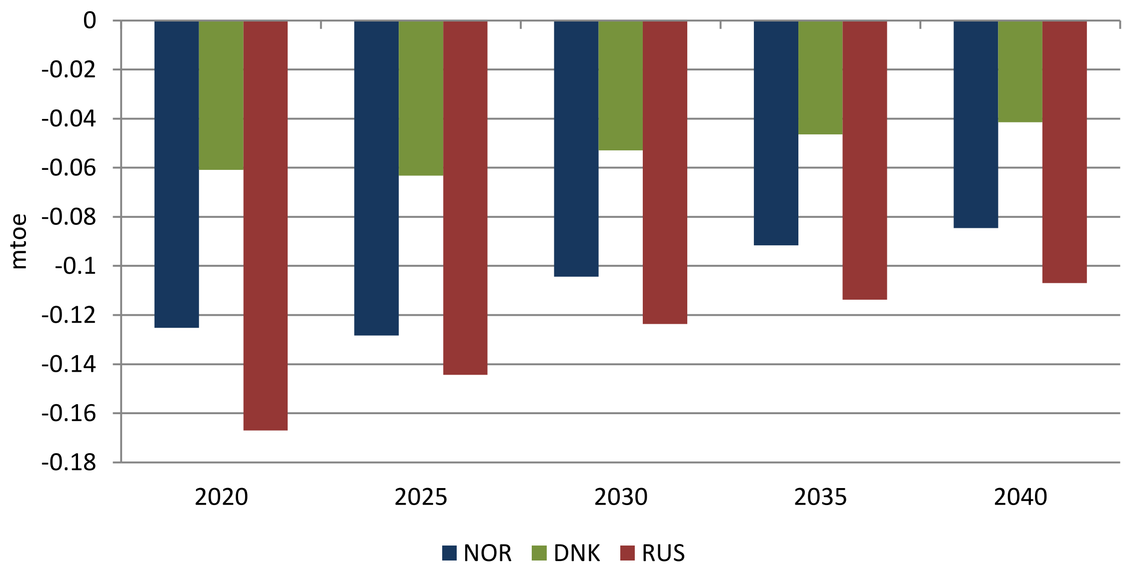


Figure 128: Change in non-Arctic production of crude oil relative to Reference Scenario (mtoe); "extraction in all countries (FPSO)"
Source: Own presentation based on DART model results.

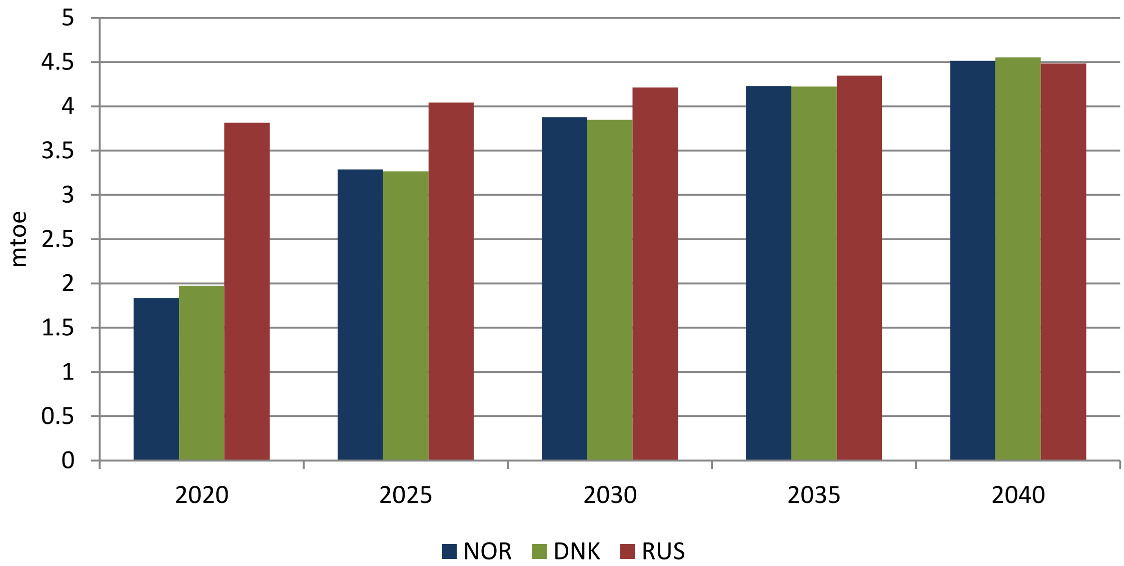


Figure 129: Change in total production of crude oil relative to Reference Scenario (mtoe); "extraction in all countries (FPSO)"
Source: Own presentation based on DART model results.

12.2. Impact on GDP and welfare

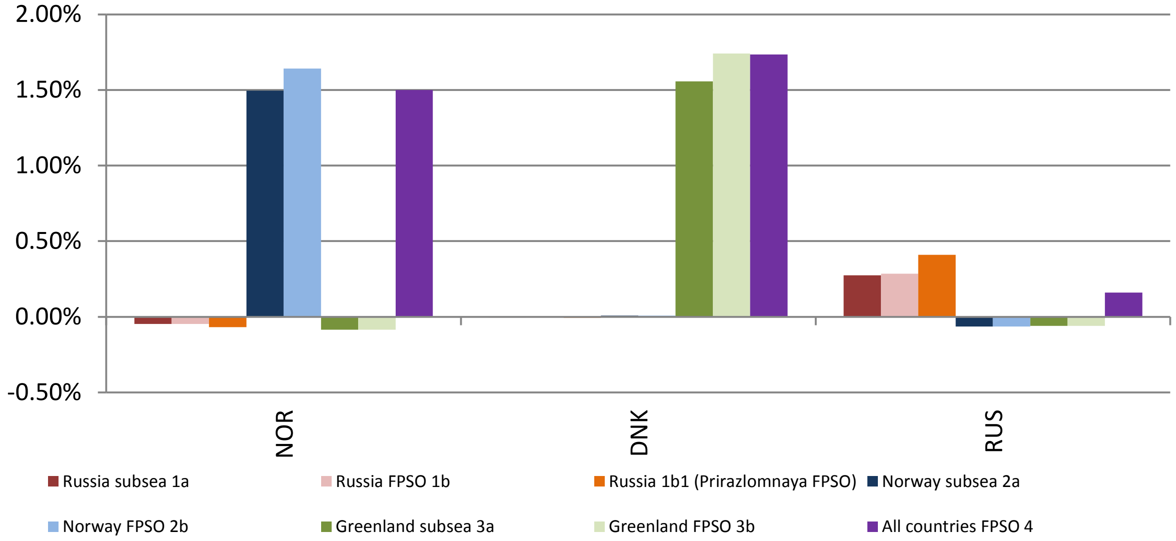
GDP is probably the most widely used indicator of economic performance. Representing the value of all traded goods and services, it is frequently used as a measure of the general economic success of an economy (even though this is simplified and rather narrow view of economic success).

In many countries, including both Norway and Russia, resource production constitutes a significant part of economic activity. Due to its position upstream of other production chains, resource extraction has, in addition to this direct effect, significant second round effects. As both, energy resources themselves and the products of downstream production chains are traded internationally, these second round effects spread to other countries that are not directly affected by additional resource production, e.g. by cheaper imports or by changing competition on export markets. Figure 130 shows the effects of additional offshore oil production in the Arctic for the three countries under study (Panel a) and for countries indirectly affected (Panel b).

The production of offshore oil in the Arctic has a significant positive effect on economic activity in the producing countries. In Norway and Denmark, GDP increases by 1.5 % for of own subsea production. For FPSO changes in GDP are even higher for both countries. Not least because of the much larger size of the economy, Russian GDP increases less, by just below 0.3 %. Unsurprisingly, Russian GDP growth is larger in the "Prirazlomnaya FPSO" scenario. Intra-Arctic competition in the "all countries FPSO" scenario drives down Norwegian and Russian GDP growth slightly, but not for Denmark/Greenland (compare "Greenland FPSO" and "All countries FPSO")

As in the case of natural gas (see Section 7.5), other oil producers suffer from increased competition on the global market for oil, namely the countries of the Former Soviet Union (FSU), the Middle East (MEA), and North (NAF) as well as Sub-Saharan Africa (SSA) (Figure 130, panel b). At the same time, though not to a similar extent, oil importing countries profit from increased production through lower oil prices. The effect is larger for countries in close proximity to the producing country or those that have existing trade ties (EEU parts of NEU in the Russia scenarios). The effect on global GDP is positive. Global GDP increases by 0.01 % in the Russia, Norway, and Greenland scenarios.

Panel a:



Panel b:

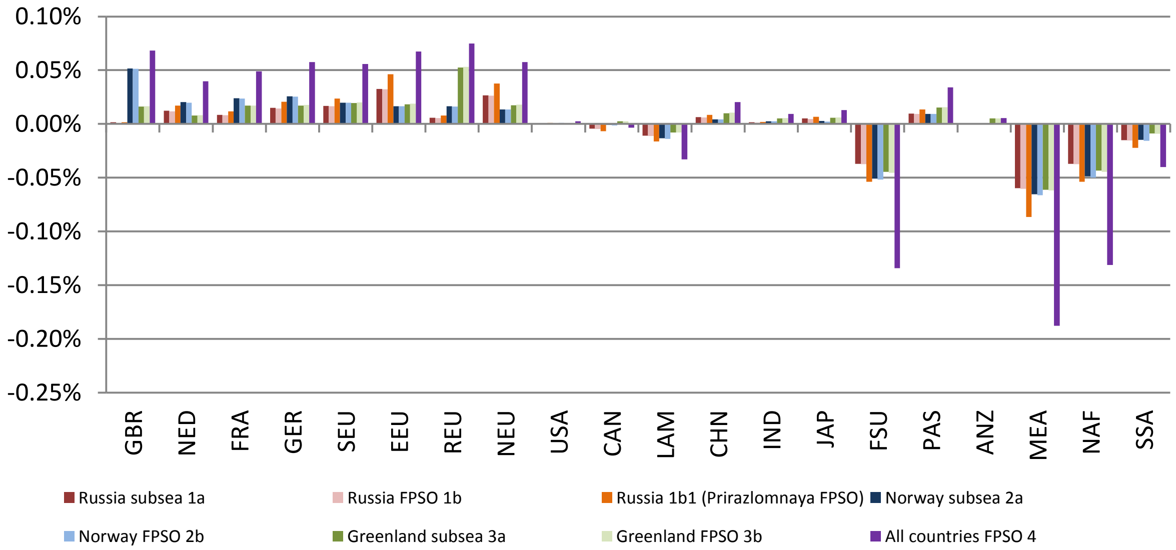
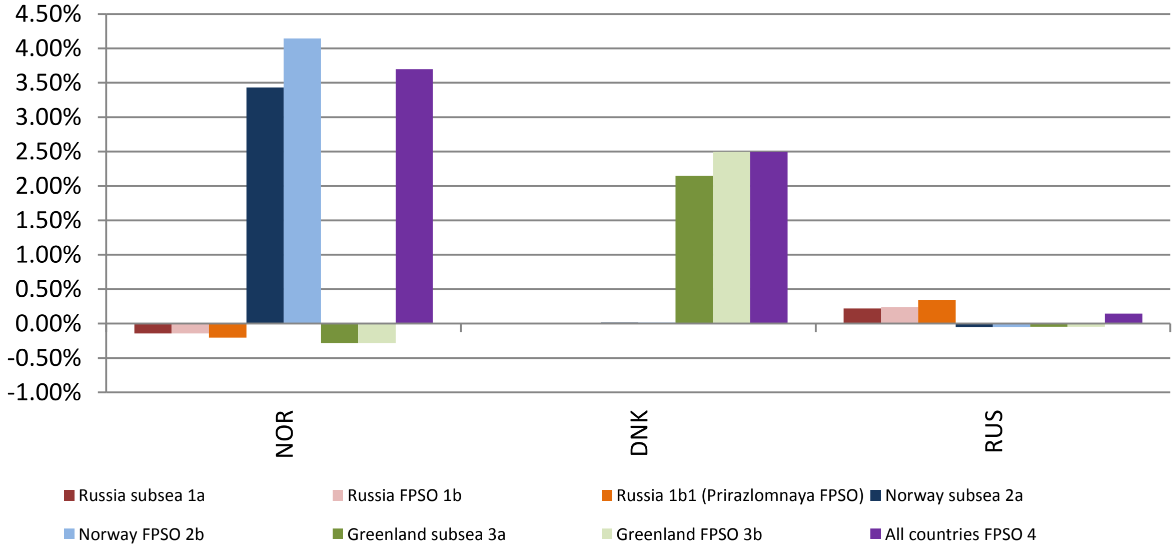


Figure 130: Change in GDP in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As mentioned above, GDP is necessarily an imperfect representation of economic activity. For this reason, we study an additional measure of economic performance, equivalent variation. Changes in equivalent variation or, more precise, Hicksian equivalent variation are defined as an income adjustment which maintains the consumer at a particular level of utility. Thus, equivalent variation is the amount of income that must be given to the consumer to forego a price decrease to leave him as well off as with the change.

Expressed in equivalent variation, benefits from resource production are considerably larger compared to GDP figures. This is true both for producing countries as well as for indirectly affected oil importing countries. For oil exporting countries relative losses are smaller. Qualitatively, the results do not change.

Panel a:



Panel b:

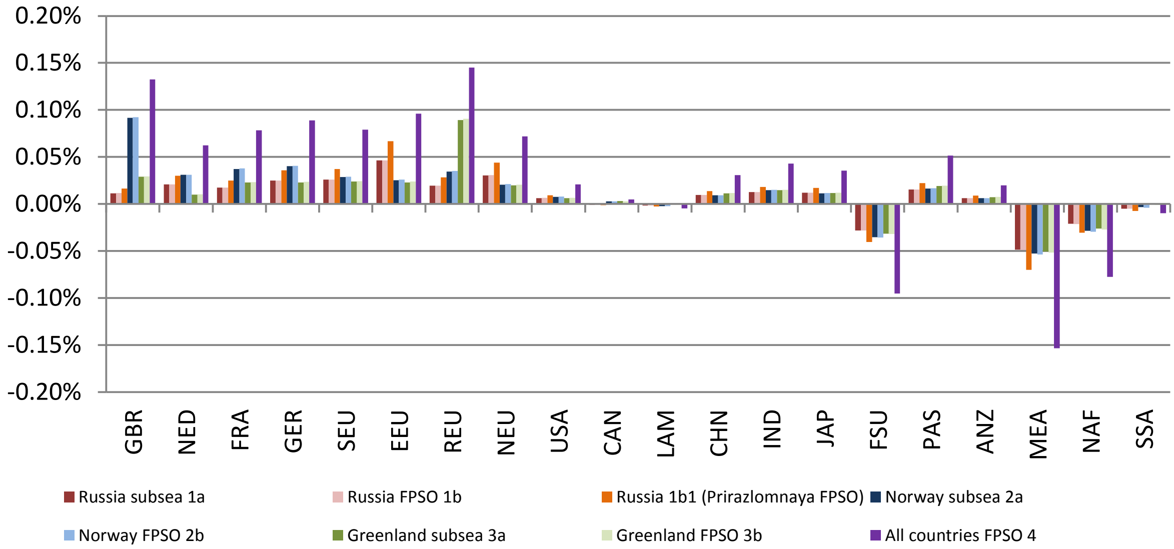


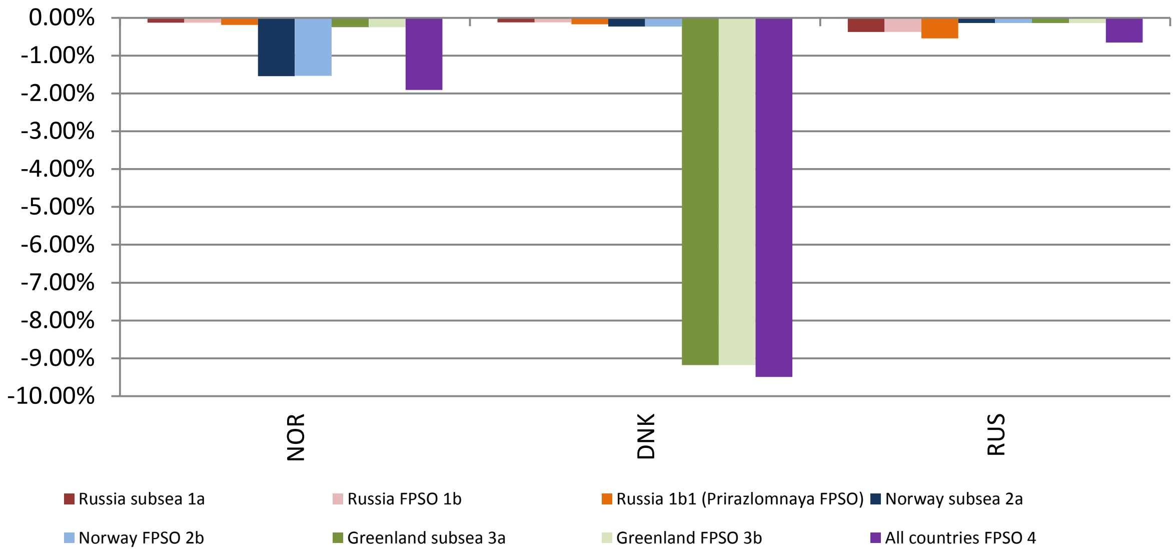
Figure 131: Change in welfare (equivalent variation) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

12.3. Impact on prices

The oil price has been an indicator of global economic prosperity since the oil crises of the 1970s. Additional production of crude oil directly affects the price level of other producing countries and indirectly other countries via the world market. The oil price itself is affected by additional production since more oil will usually lead to lower oil prices. Prices of other products may be affected in various ways;(1) either because oil is an input factor in production that becomes cheaper, or (2) because they substitute fuels compete with oil on the energy markets or (3) they compete with the oil production sector on input markets, such as the labour market. Also potential Dutch disease effects may affect prices via the exchange rate channel (see Section 12.4 for more detail). While the first channel will lead to lower prices of other goods, the other channels might lead to higher prices. Thus, the overall direction of prices of other goods is unclear and depends on concrete circumstances. In the following we study three price indices, the oil price (Figure 132), a price index for all goods other than crude oil (Figure 133) and the overall price level (Figure 134).

Additional crude offshore oil production in the Arctic leads to a decrease in crude oil prices both in the Arctic countries (panel a of Figure 132) and in non-Arctic countries (panel b). The crude oil prices in Denmark fall considerably in the case of oil production in Greenland, with reductions beyond 9 % compared to the Reference Scenario. But also in Norway (-1.5 %) and Russia (-0.3 to -0.5 %) crude oil prices fall after the start of production. Crude oil price fall in no-Arctic countries as well, especially in countries that are close to the new production facilities, such as the UK (GBR) in the case of Norwegian oil, or Eastern Europe (EEU) in the case of Russian oil.

Panel a:



Panel b:

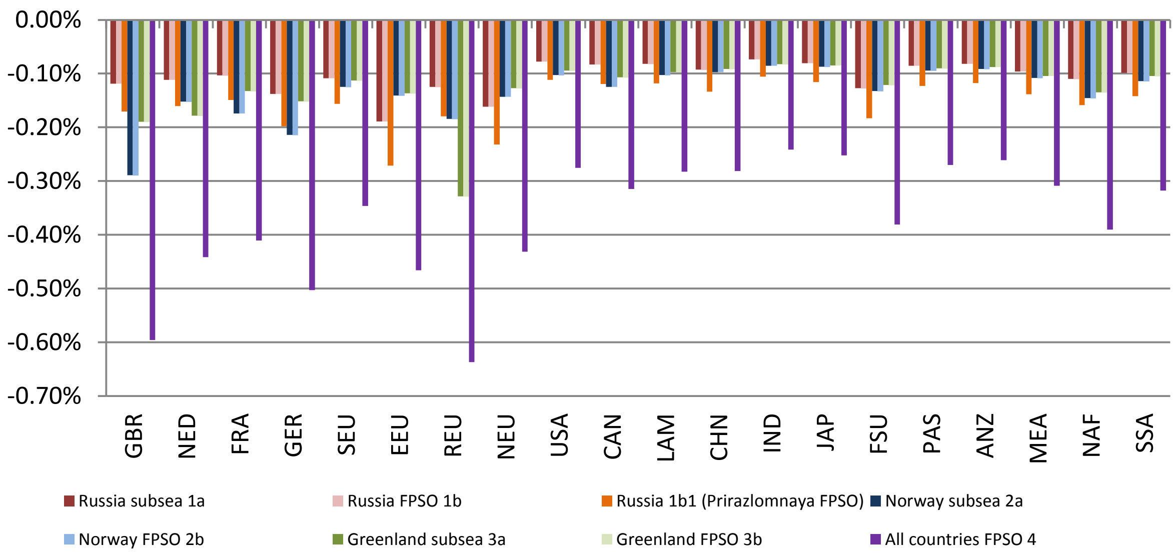
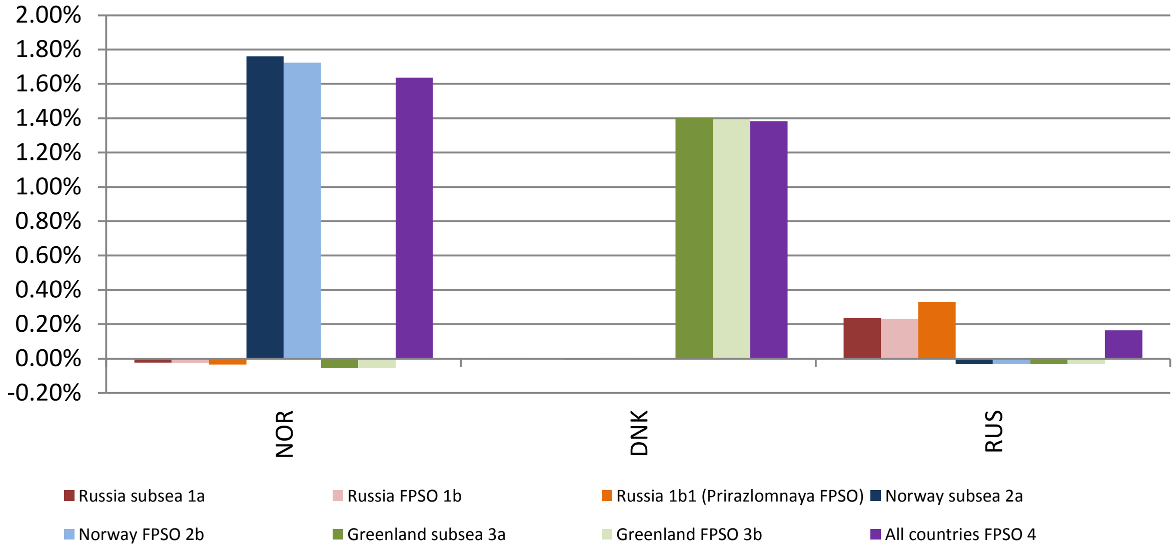


Figure 132: Changes in oil prices in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

While the crude oil price drops both in exporting and importing countries following additional offshore production in the Arctic, prices for other goods and services change as well (Figure 133). In the producing countries in the Arctic, price levels increase following additional domestic production (Panel a). For Norway the price increase is particularly large with up to 1.8 % (Norway subsea), but also Greenland/Denmark is strongly affected (+1.4 %). Again, due to the larger size of the economy, Russian prices do not increase as much. As in the case of natural gas, price-increasing effects, including Dutch Disease effects, dominate in the producing countries.

In comparison, price effects in indirectly affected countries are much smaller. Price movements differ across countries. The witnessed price decreases, presumably due to reduced input costs, are usually larger than price increasing effects (especially for FSU, MEA, NAF and SSA). In the UK (GBR) prices increase with additional production in Norway.

Panel a:



Panel b:

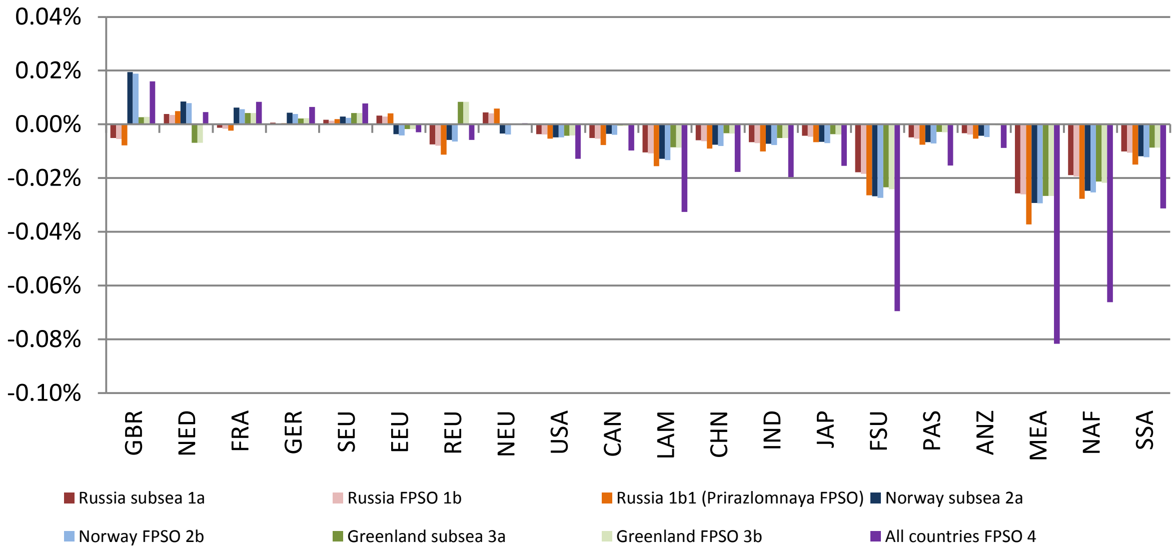
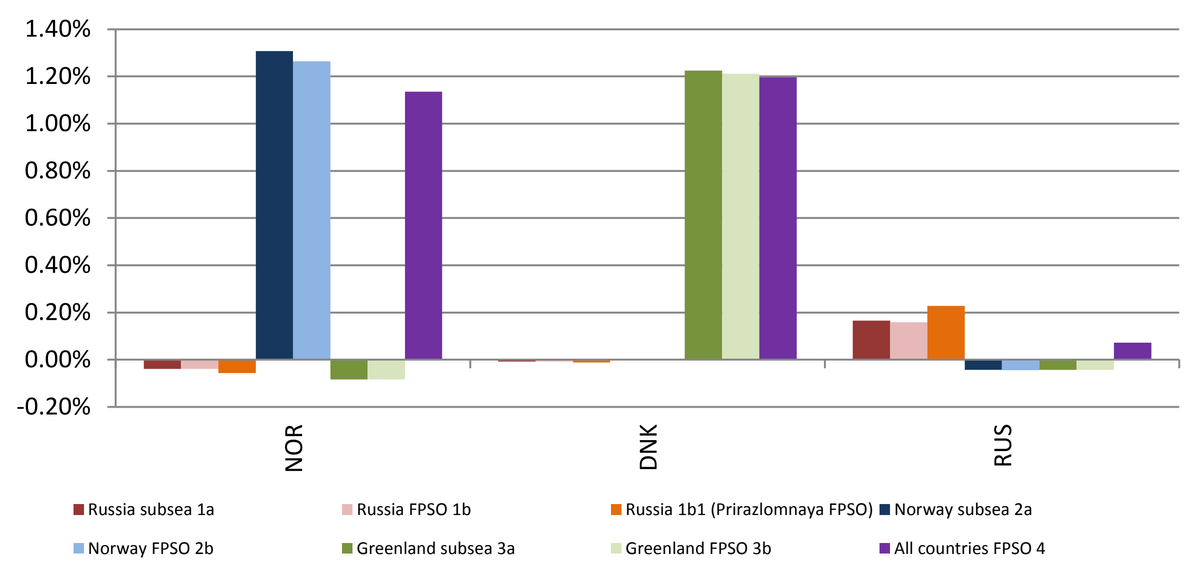


Figure 133: Changes in prices (without oil) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Looking at the effect on the aggregate price level of an economy, the large price changes in the crude oil sector are mediated by price changes in other sectors. However, overall price levels in producing countries increases noticeably, with overall price increases of up to 1.3 % in Norway and by 1.2 % in Denmark. Prices of other producers are slightly affected; exceptions are countries of the Former Soviet Union (FSU), the Middle East (MEA) and Africa (NAF, SSA). There, prices decrease, not least because of a large oil sector in these countries that suffers from reduced world prices.

Panel a:



Panel b:

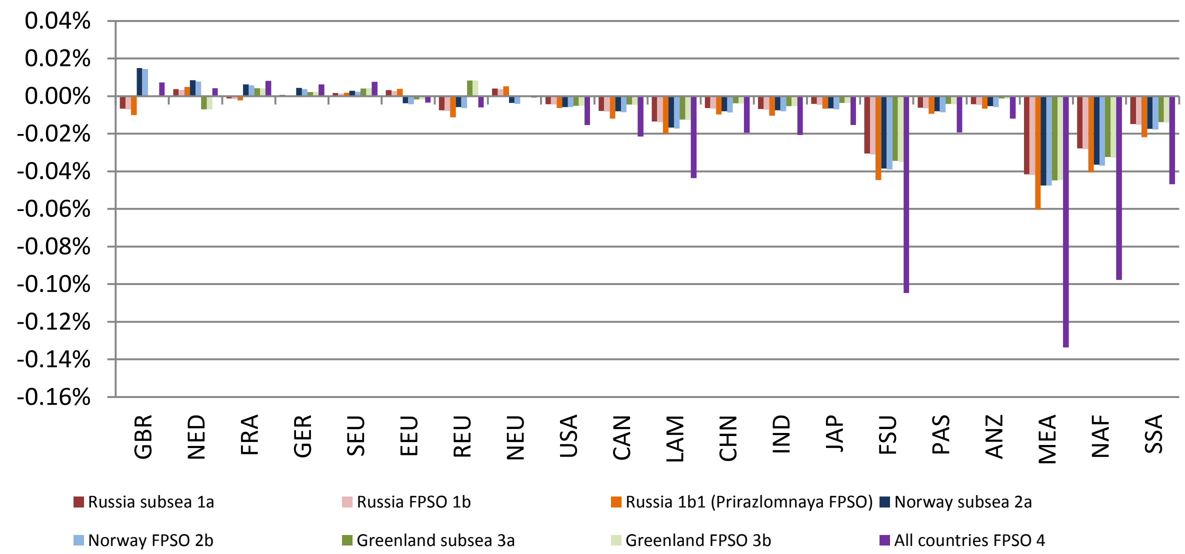


Figure 134: Changes in overall prices in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

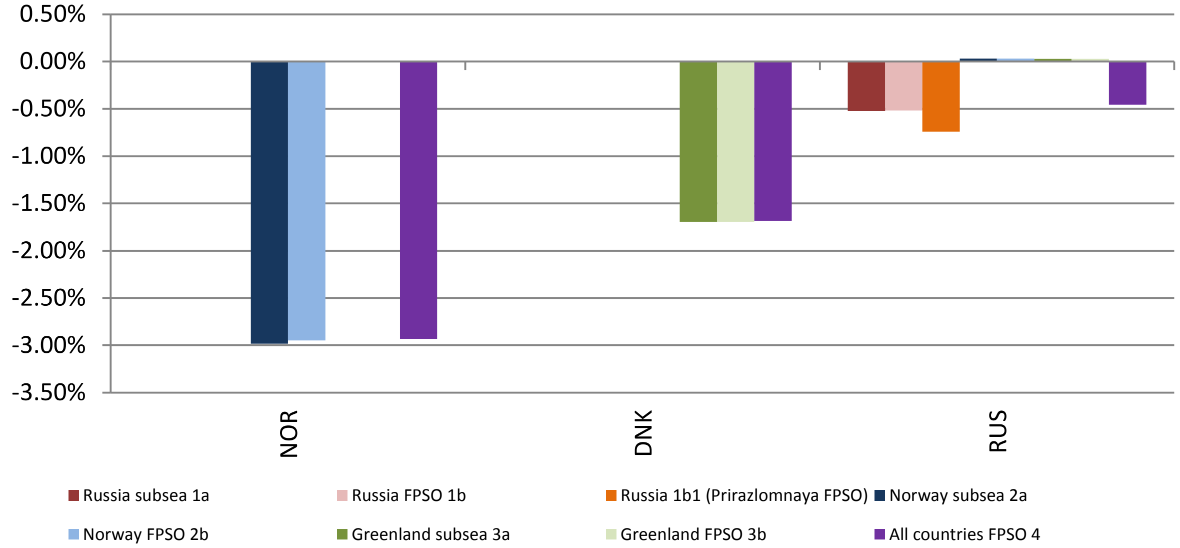
12.4. Impact on trade

Resource extraction activities usually affect the trade flows of both producing and exporting countries as well as their trading partners. Additional extraction of natural resources, such as natural gas, increase net exports of the resource, ceteris paribus increasing overall net exports of a country. At the same time, the additional (windfall) exports attract foreign capital investments and may lead to an appreciation of the real exchange rate of a countries currency. This makes it harder for other domestic sectors to export goods other than the natural resource, such as manufacturing goods or goods from the primary sector. This phenomenon is known as the “Dutch Disease”, a term coined after the Netherlands started to export North Sea natural gas in the middle of the 20th century, which led to a decline in the manufacturing sectors. Countries that face a Dutch Disease situation have a number of options to counteract its detrimental effects, most notably the setup of sovereign wealth funds which save revenues from resource extraction and reinvest them outside the domestic economy, thus balancing foreign capital inflows and, as a positive side effect, stabilizing the revenue stream from natural resource extraction. A number of Arctic countries have implemented sovereign wealth funds, most notably Norway and Russia. It should be noted that DART does not include the setup of such funds explicitly, so any effect reported here does not take into account public action to expand or set up sovereign wealth funds as a response to the extraction of offshore crude oil in the Arctic beyond the importance of these funds as of today.

In the following, we study the impact of offshore crude oil production in the Arctic on the sector-level exports of Norway (Figure 136), Greenland/Denmark (Figure 137), and Russia (Figure 138). We then present the impact of oil- (Figure 139) and non-oil exports (Figure 140) of non-Arctic countries before we look at the overall development of exports in all countries (Figure 141). However, we start our analysis by looking at the terms of trade (Figure 135). The terms-of-trade are the ratio of export prices over import prices of a country. If the terms-of-trade increase, a country is able to import more goods for the same value of export goods; domestic supply of goods improves.

Arctic offshore oil production has considerable implications for the terms-of-trade of the producing countries (Panel a of Figure 135). Crude oil is a classical export good and as the oil price decreases with increasing production, the terms-oftrade decrease. Norway is particularly strongly affected, with decreases in terms of trade of up to 3 % (Denmark/Greenland -1.7%). One reason might be that the price level in other sectors is affected relatively strongly, too (see Panel a of Figure 133). Even in Russia terms-of-trade decrease by 0.5 % or more in the case of larger production units. As in the case of natural gas, non-producing countries are almost not affected, with changes of terms-of-trade below 0.03 % even for the scenario where all three Arctic countries produce additional crude oil.

Panel a:



Panel b:

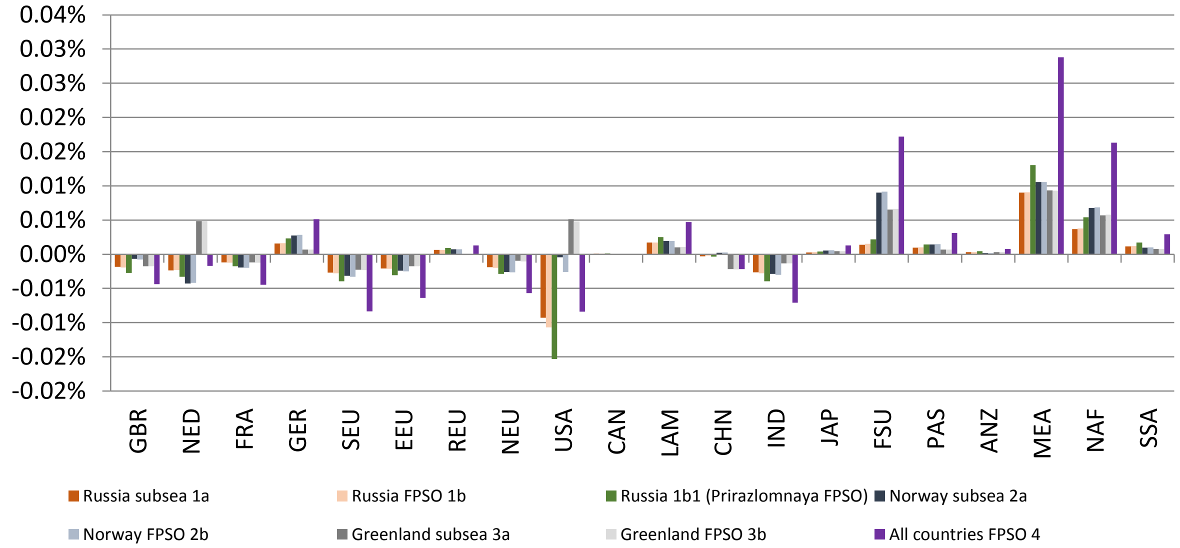


Figure 135: Change in terms-of-trade in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As in the case of natural gas, the value of exports of the three Arctic countries is affected differently. One pattern that is universal, however, is that both the value of crude oil exports and petroleum products increases.

In the case of Norway, the value of crude oil exports increase substantially by over 8 %, accompanied by a comparable increase in the export value of oil products (Figure 136). Export values of other sectors in Norway export decrease, following the drop in terms-of-trade observed in Figure 135. Losses are substantial throughout almost all sectors, but especially pronounced in the manufacturing sectors with losses of close to 3 %, including chemicals, energy intensive, heavy, and light industries. Potential reasons are competition on factor markets and Dutch Disease effects. Overall, additional oil production increases the value of Norwegian exports by 0.69-0.81 % (Panel a of Figure 141).

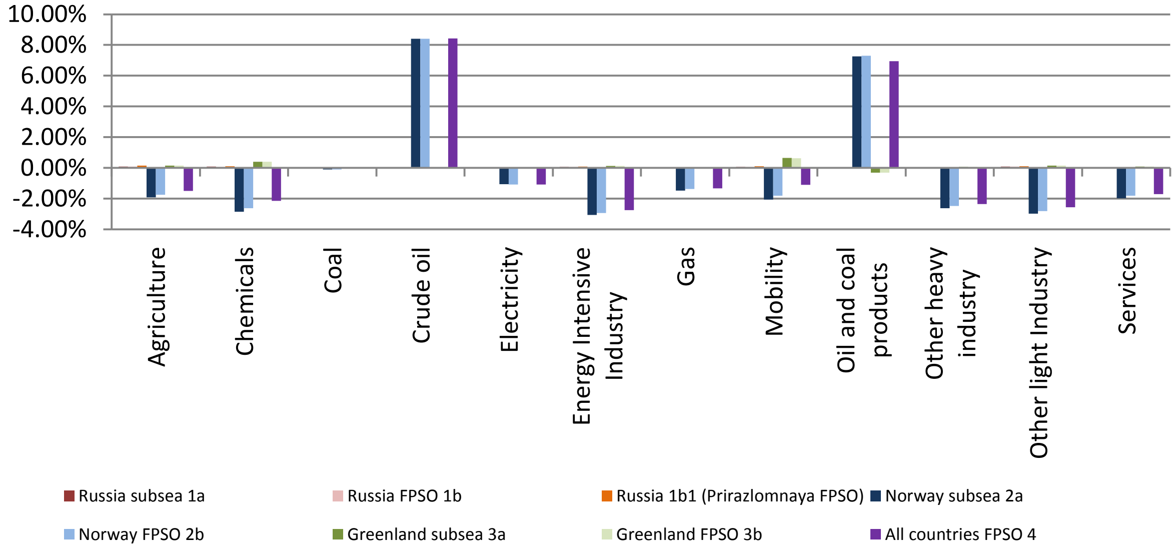


Figure 136: Change in Norwegian export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

The pattern for Denmark/Greenland is similar, but due to the small size of the oil sector in the Reference Scenario changes are more pronounced. Changes in the value of crude oil and petroleum products exports skyrocket from a low level, with rates of change of 67 % and 52 %, respectively (Figure 137). In addition, the export value of mobility services, such as shipping or air transportation increases by over 25 %. Exports values of all other sectors are affected as well. Again, this is especially the case for manufacturing sectors, where export values fall by up to 4 % in the chemicals industry. As a consequence, and as a prototypical witness of Dutch Disease, overall Danish exports decrease, despite the increase in export values of oil and oil products, by 1.3-1.5 % (Panel a of Figure 141).

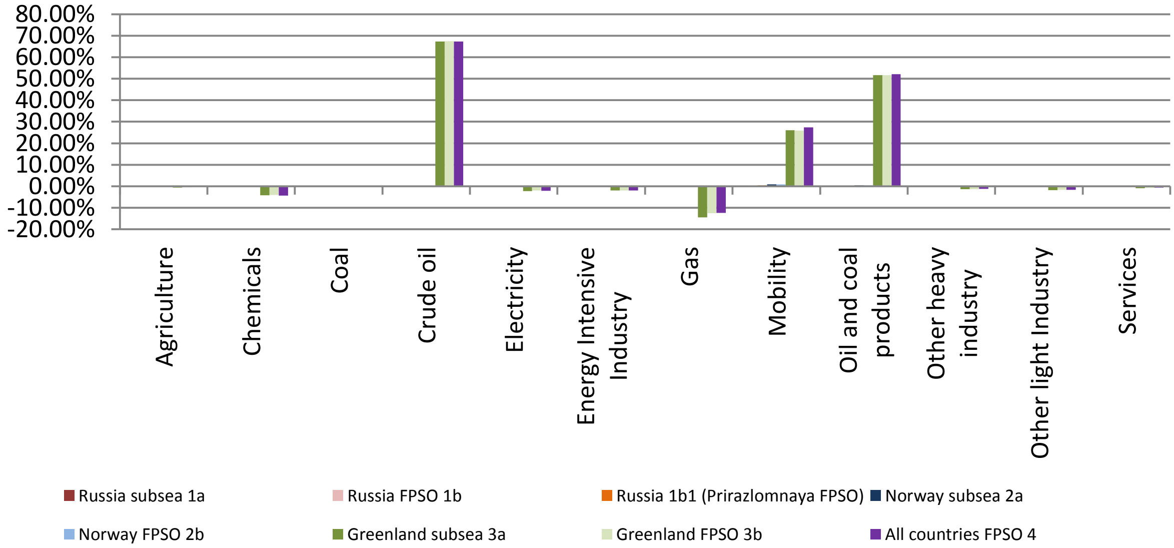


Figure 137: Change in Danish export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Unlike Norway and Denmark, Russian exports react less to a production shock from the Russian Arctic, as the larger economy is more easily able to compensate the change in production. What is most notable is that downstream sectors that depend on crude oil are affected most in relative terms, even more than the crude oil sector itself (Figure 138) The Chemicals industry and the petroleum products manufacturers increase the values of their exports by over 1.1 %, also export values of light industry products are positively affected. Together with export decreases due to the price decrease on the global oil market, this additional domestic demand for crude oil leads in total even to a slight decrease of crude oil exports by around 0.5 % in the subsea and small FPSO scenarios. Other sectors suffer from the decrease in terms-of-trade, especially the highly export oriented natural gas sector. This leads to a peculiar effect; the overall trade balance in Russia is not affected by the production of additional Arctic oil in Russia, but is affected lightly by oil discoveries in other Arctic countries (Panel a of Figure 141).

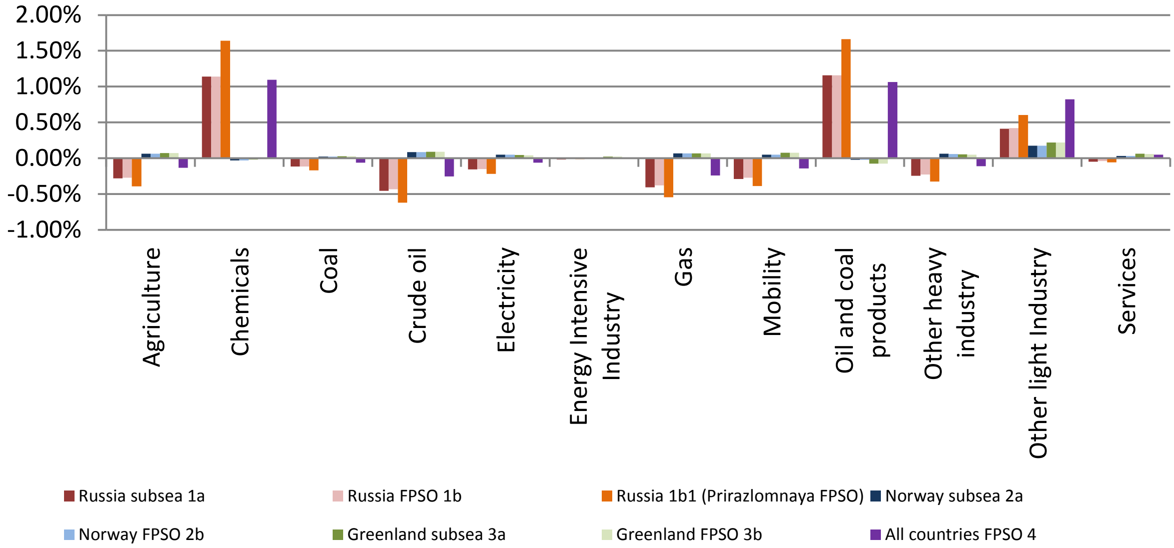


Figure 138: Change in Russian export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

The value of exports for other oil exporters usually decreases as a reaction to additional Arctic production, although only slightly in most cases. The decline in export values in the Netherlands (NED) is particularly large, but export values for the USA and a number of other exporters are smaller as well (Figure 139). The overall effect is mediated by domestic reactions, namely in the producer's petroleum products industries (see Section 12.6). The value of exports of goods and services other than crude oil increases throughout the world, following the decrease in input prices (Figure 140). These positive effects also dominate the overall development, as exports values increase throughout all non-Arctic countries (Figure 141).

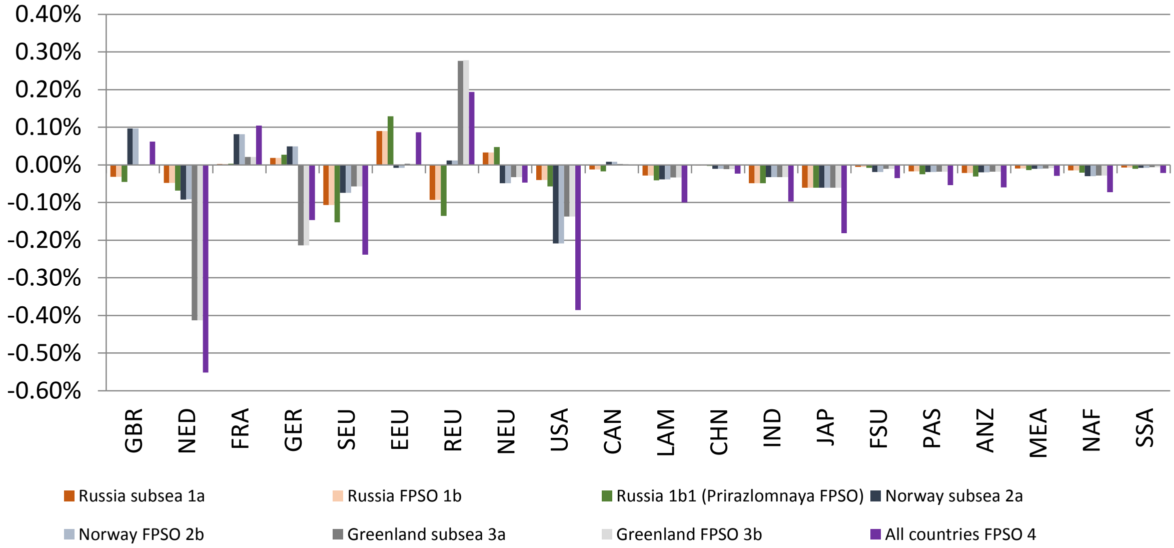


Figure 139: Change in the value of oil exports in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

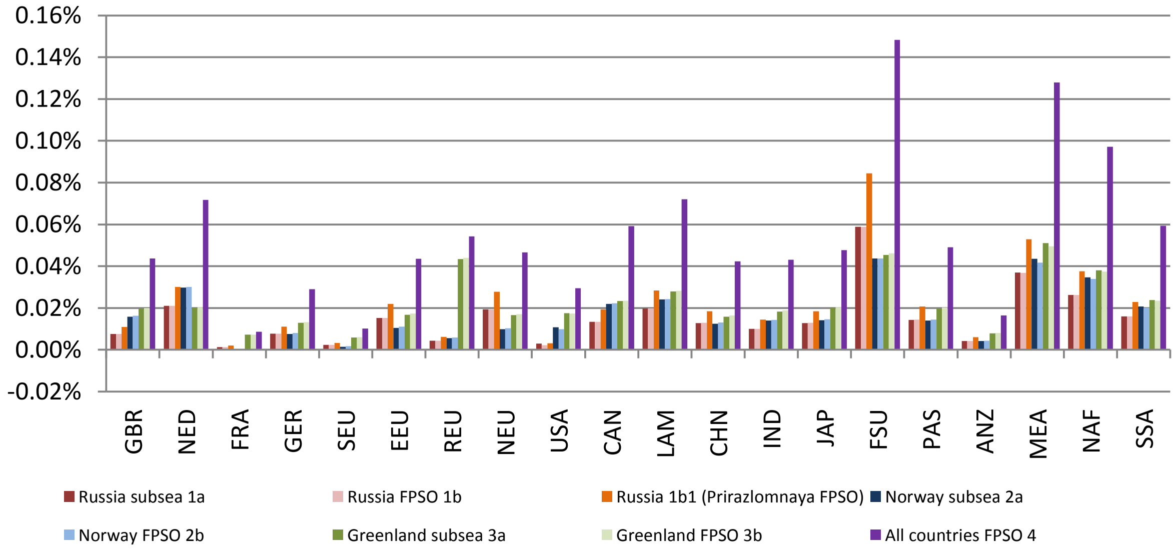
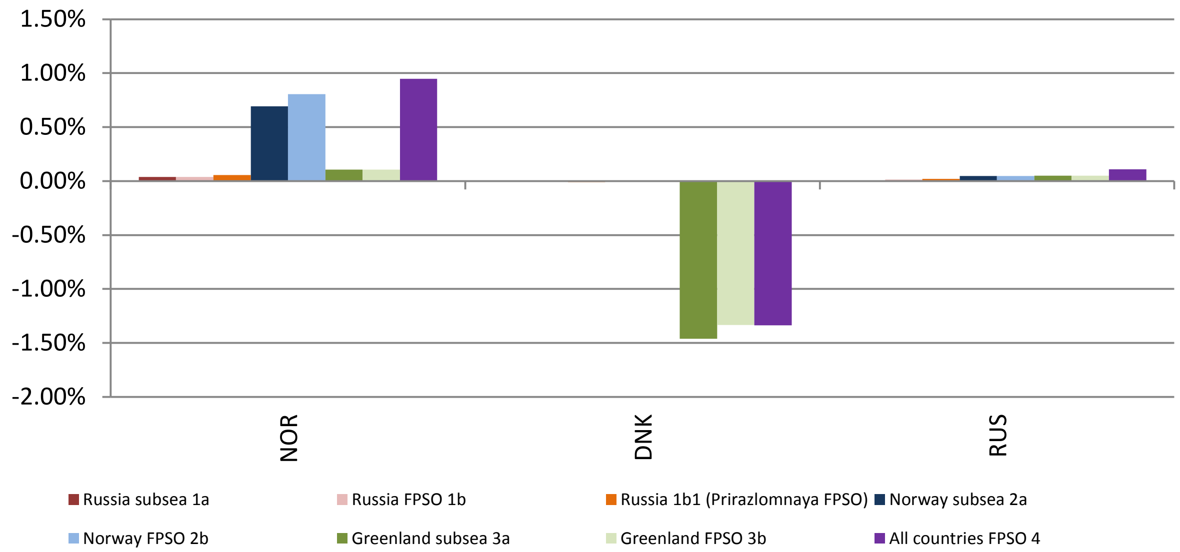


Figure 140: Change in the value of non-oil exports in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Panel a:



Panel b:

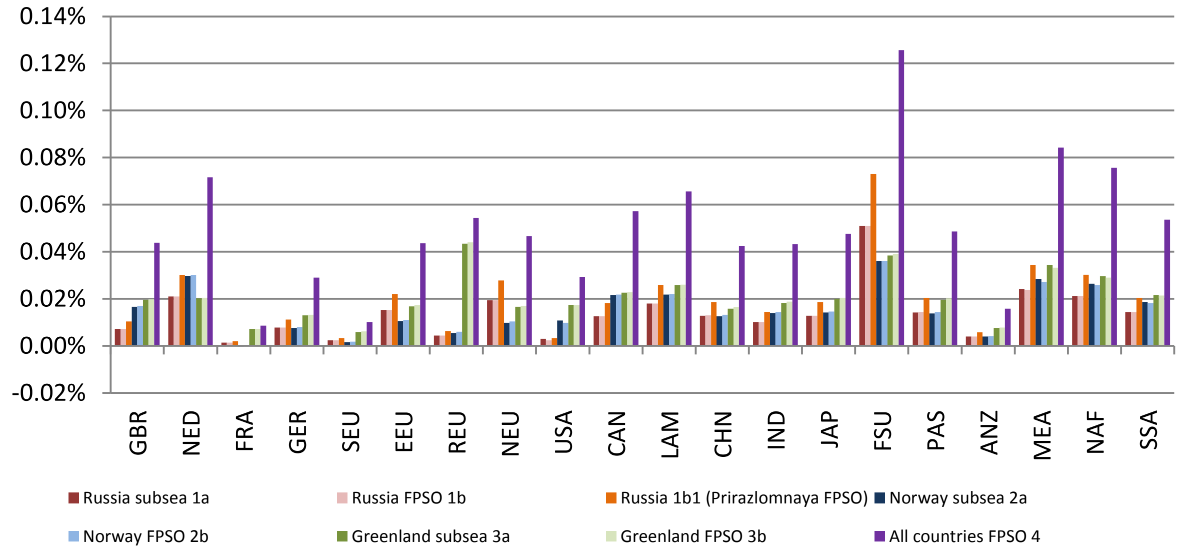


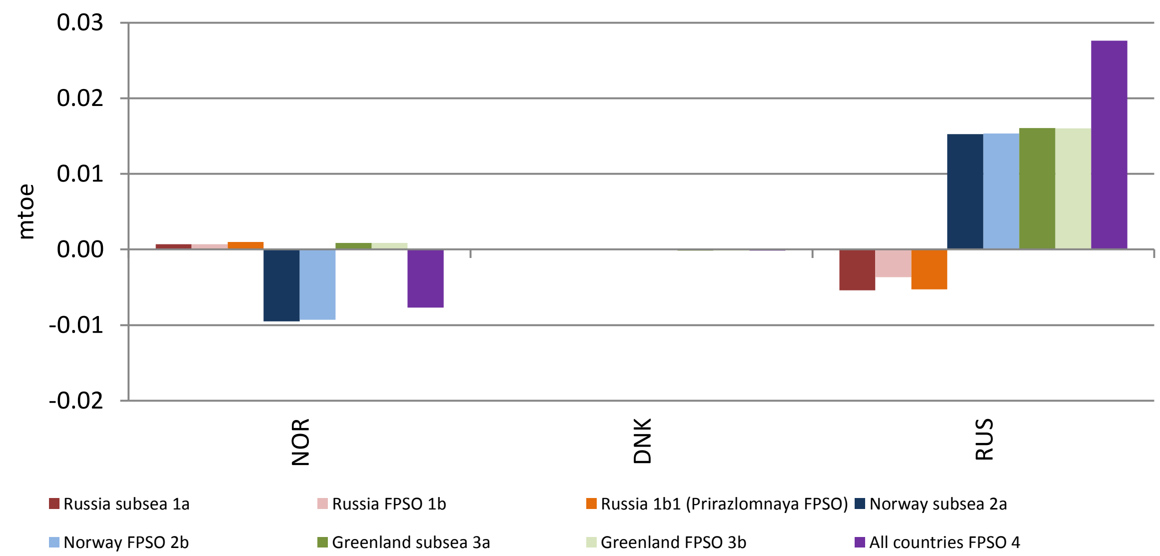
Figure 141: Change in total export values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

12.5. Impact on the production of other fuels

Additional offshore production of Arctic crude oil has an effect on the production of (1) other fuels than oil, (2) oil from other sources and (3) oil products. If the cross-relation between a fuel and oil is substitutional, we expect a negative response to additional gas production in the first round, while first-round effects should be positive in the case of complementary goods. Additionally, some fuels, first and foremost petroleum products, but also e.g. electricity, will use crude oil as an input factor of production. To study the economy-wide general equilibria effects, we focus on the interrelation between Arctic oil production and production of other fuels namely coal (Figure 142), non-Arctic crude oil (Figure 143), natural gas (Figure 144), electricity (Figure 145), and petroleum products, including a number of processed energy fuels other than electricity, e.g. coke (Figure 146).

If crude oil production substitutes for coal production, the effect on coal production would be negative. Contrary to the case of natural gas, this is not the case for oil, except for the producing country itself. However, even for the producing countries, the effect is negligible, as Norwegian as well as Russian coal production decrease by less than 0.01 mtoe compared to the Reference Scenario (Figure 142). The indirect effects from the stimulus of lower oil prices is, however, much larger. Coal production in Germany (GER) and China (CPA) expands most significantly, with increases of up to 0.04 mtoe if one of the Arctic country produces Arctic oil. Also, the indirect effects on Latin America (LAM), the Pacific Region (PAS and ANZ), the USA and Russia are large and positive.

Panel a:



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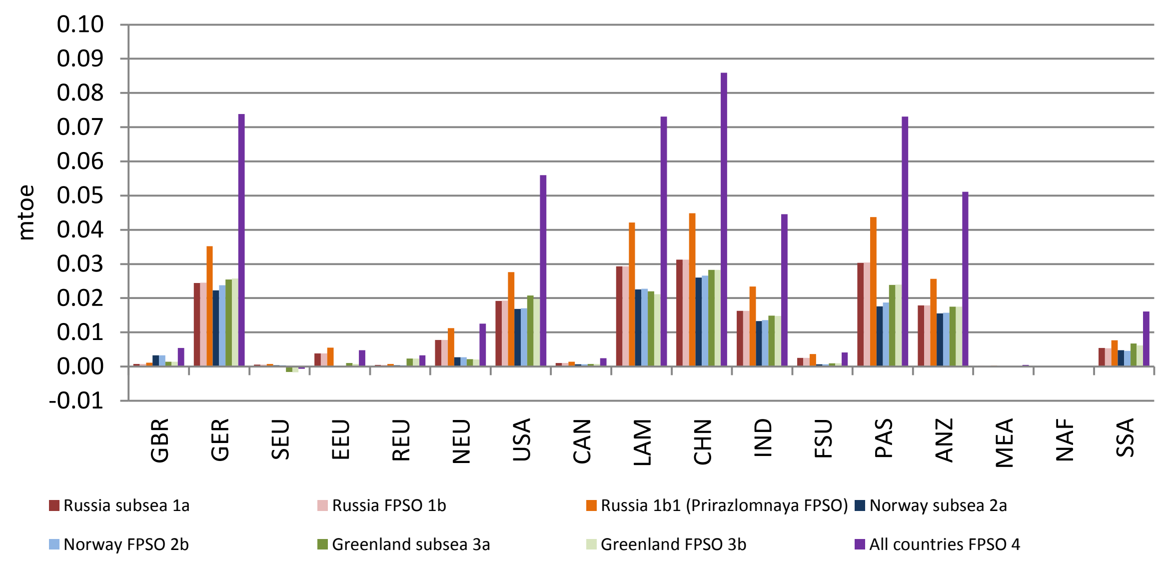
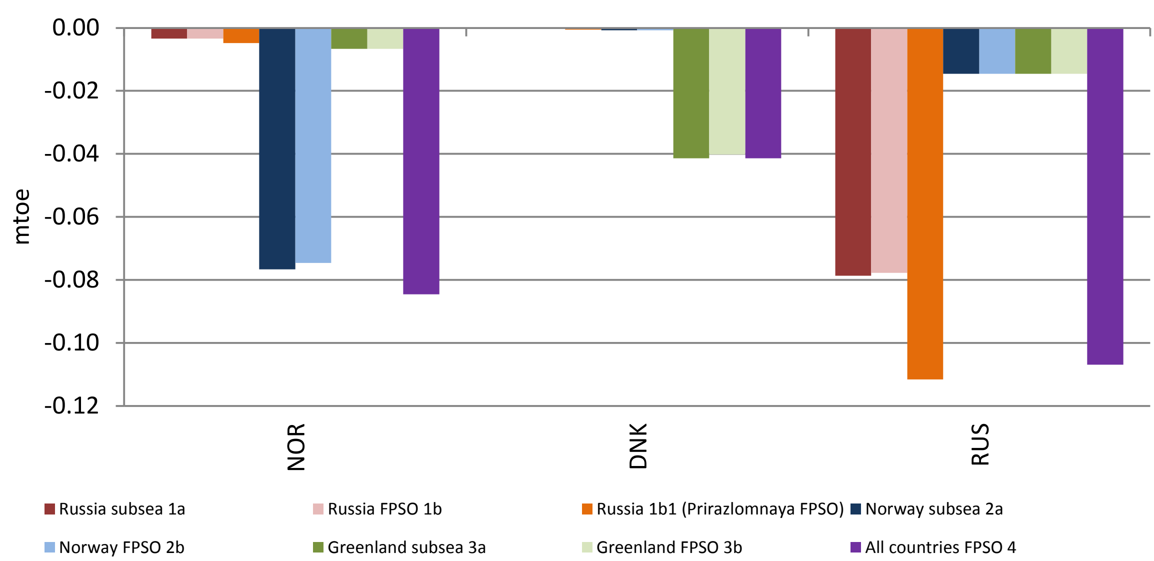


Figure 142: Change in coal production in 2040, absolute difference to Reference Scenario (mtoe)
Source: Own presentation based on DART model results.

Unsurprisingly, the production of crude oil from other sources is affected as well, and exclusively negative. Crowding-out lowers demand for non-Arctic crude oil both in the country that produces Arctic oil and abroad (Figure 143). Surprisingly, it is not even the producing countries that are affected most, but production of other prominent oil exporters. While production of non-Arctic oil in the producing country drops by about 0.8 mtoe in Norway and Russia (subsea or small FPSO) , production in Latin America (LAM) or the Middle East (MEA) may drop even more.

Panel a:



Panel b:

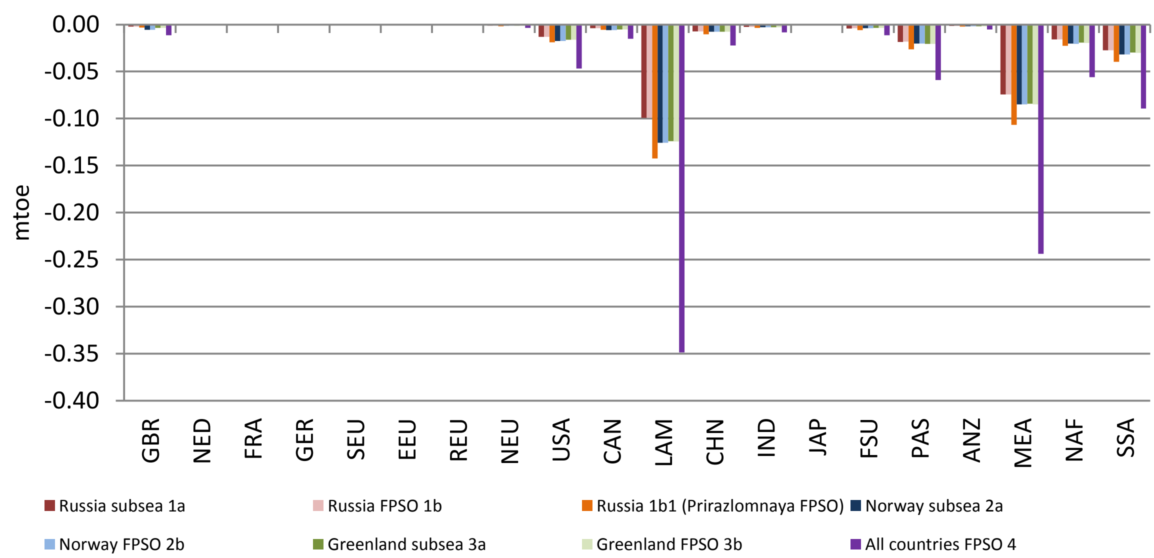
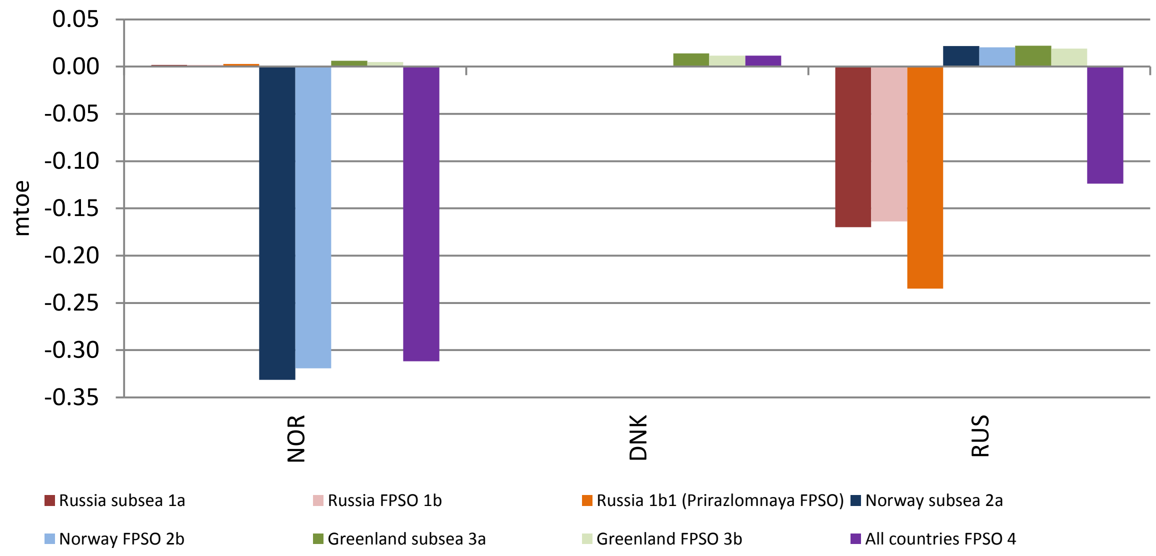


Figure 143: Change in non-Arctic crude oil production in 2040, absolute difference to Reference Scenario (mtoe)
Source: Own presentation based on DART model results.

Since natural gas is a classical substitute fuel for crude oil, we would expect negative effects of additional oil production on gas production. We find this effect for the oil producing countries Norway and Russia (Figure 144). The drop in gas production of up to 0.33 mtoe in the Norway relative to the Reference Scenario is particularly pronounced. However, just as in the case of coal, the indirect stimulus effect leads to a positive response of gas production in some countries. Gas producers in China (CPA), Latin America (LAM), and the Middle East (ME) expand production slightly.

Panel a:



Panel b:

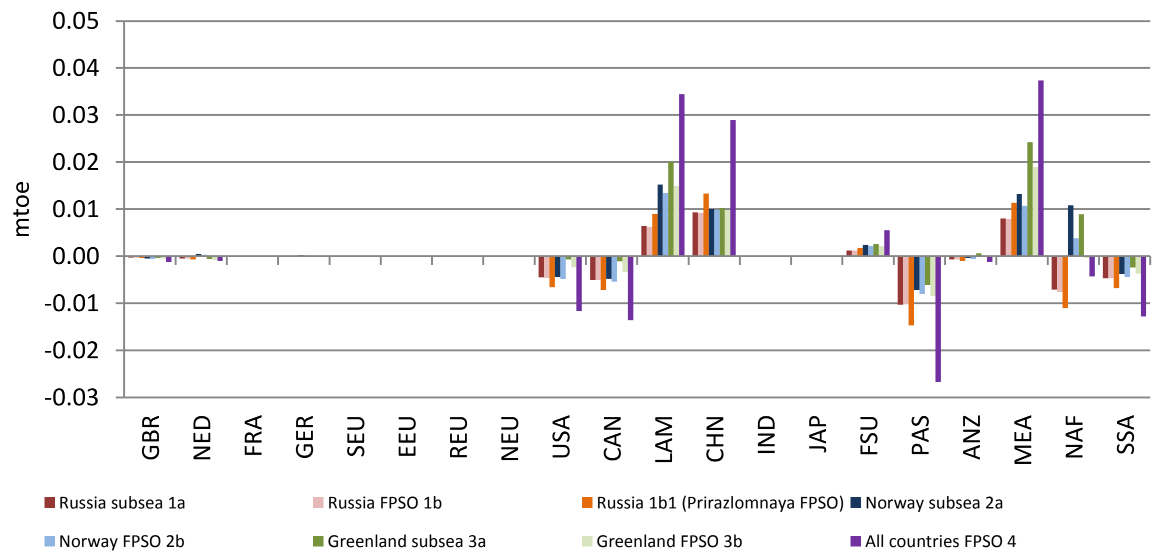
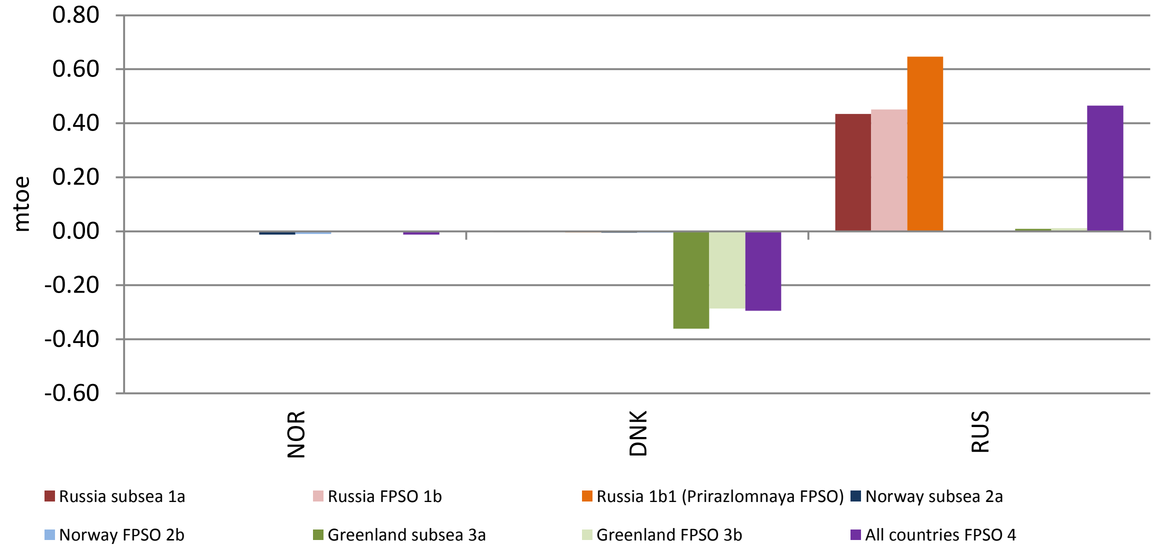


Figure 144: Change in natural gas production in 2040, absolute difference to Reference Scenario (mtoe)
Source: Own presentation based on DART model results.

As electricity demand is sensitive to the business cycle and partly uses oil as an input, we expect mostly positive production effects on electricity production. Indeed, the largest changes in production are positive with an increase of up to 0.45 mtoe for Russia and China (CPA) for a small FPSO scenario relative to the Reference Scenario (Figure 145). A notable exception is Denmark/Greenland, where electricity production drops by around 0.3 mtoe. Substitution effects or competition about input factors are potential explanations.[13]

Panel a:



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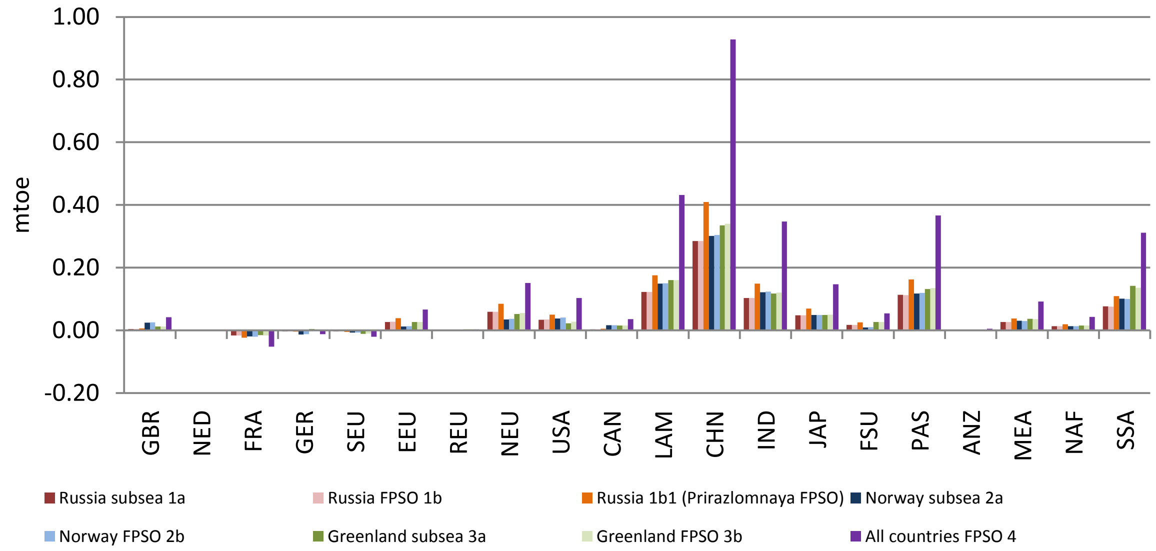


Figure 145: Change in electricity production in 2040, absolute difference to Reference Scenario (mtoe)
Source: Own presentation based on DART model results.

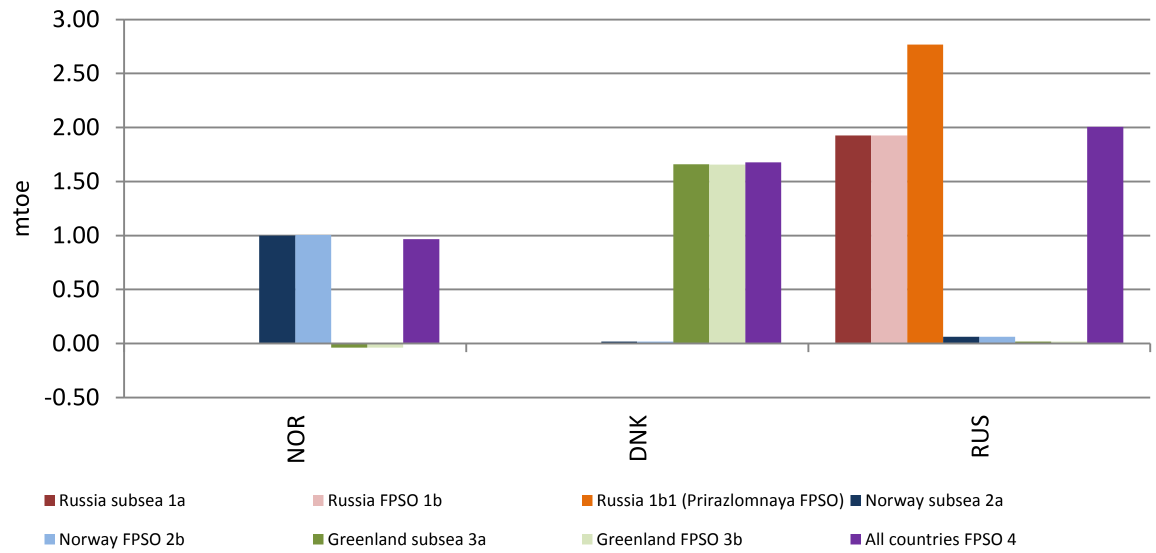
The final category we are studying is processed fuels. Due to the strong link between crude oil and refined oil products, which use crude oil as an input, the effect is significant and positive. We observe the largest effect in Russia, where the production of petroleum products increases by about 2 mtoe relative to Reference Scenario (Figure 146). The effect of the

[13] Electricity, as any other form of energy, can be measured in tonnes of oil equivalent, since a tonne of oil equivalent is a general energy unit, standardized using the energy content of crude oil. A tonne of oil equivalent is equivalent to approximately 42 GJ.

Prirazlomnaya-like scenario is slightly larger. Also the Norwegian and Danish oil products industry increases production after additional supply of domestic oil. Responses in indirectly affected countries are also almost exclusively positive, especially the Chinese (CPA) production of oil products increases.

Overall the effect of extended Arctic offshore production increases production oil products and crude oil production outside the Arctic, but effects on other fuels are relatively small.

Panel a:



Panel b:

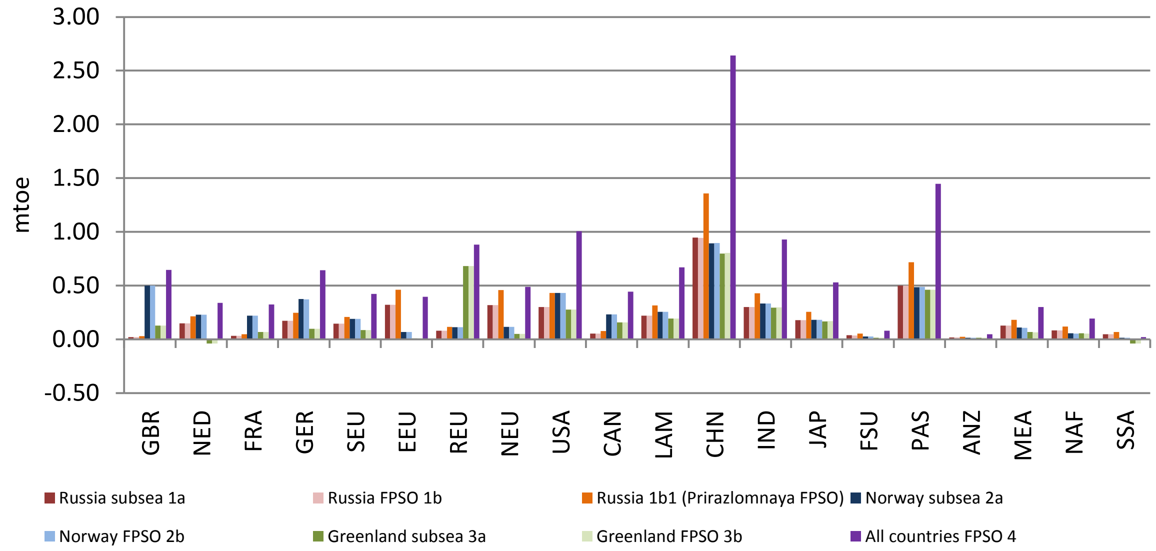


Figure 146: Change in production of oil and coal products in 2040, absolute difference to Reference Scenario (mtoe)
Source: Own presentation based on DART model results.

12.6. Impact on other sectors

Other sectors will be affected if they compete with the crude oil sector about inputs, such as labour and capital, or as (partial) substitutes on output markets. Along the input market channel, we expect negative effects of additional oil production, especially in, but not limited to, the country in which additional production takes place. As qualified labour is an important and, compared to capital and intermediate goods, a less mobile factor of production, we devote a separate section to the analysis of the effect of additional oil production on the labour market (see Section 12.7 below). Apart from competition about inputs, additional Arctic crude oil production may also have impacts on downstream sectors that use it as an input and on other energy sectors that compete with Arctic oil on downstream markets. In the case of downstream sectors, the additional energy inputs may offset effects from competition about other factor inputs. This is especially important here, since additional oil production has an impact on the oil price and the oil price is known to be an important determinant of the business cycle in some countries and sectors. Overall, an expansion of production might be observed after the intial expansion of oil production. In the case of other energy sectors, the increased competition on output markets will add to the negative effects from competition on factor markets. However, the final effect of increased economic activity is not predetermined. In the following, we will first analyse the effects on other sectors in Norway (Figure 147), Denmark (Figure 148), and Russia (Figure 149) and then do a sector-by-sector analysis for the non-Arctic countries (Figure 150 to Figure 156).

As expected, and related to the results for energy production (see Section 12.7), the most affected sector in Norway is the production of oil and coal products (Figure 148). Additional crude oil production in Norway leads to an increase in the value of output of around 6 % relative to the Reference Scenario. All other sectors are negatively affected. Production is lower especially in the manufacturing sectors; the chemicals, energy intensive industry, heavy industry and light industry sectors loose up to around 2 % of output values. Contrary to initial intuition, the natural gas sector is only mildly affected. The impact of additional production of Arctic crude oil in Greenland or Russia has almost no effect on sectoral production in Norway.

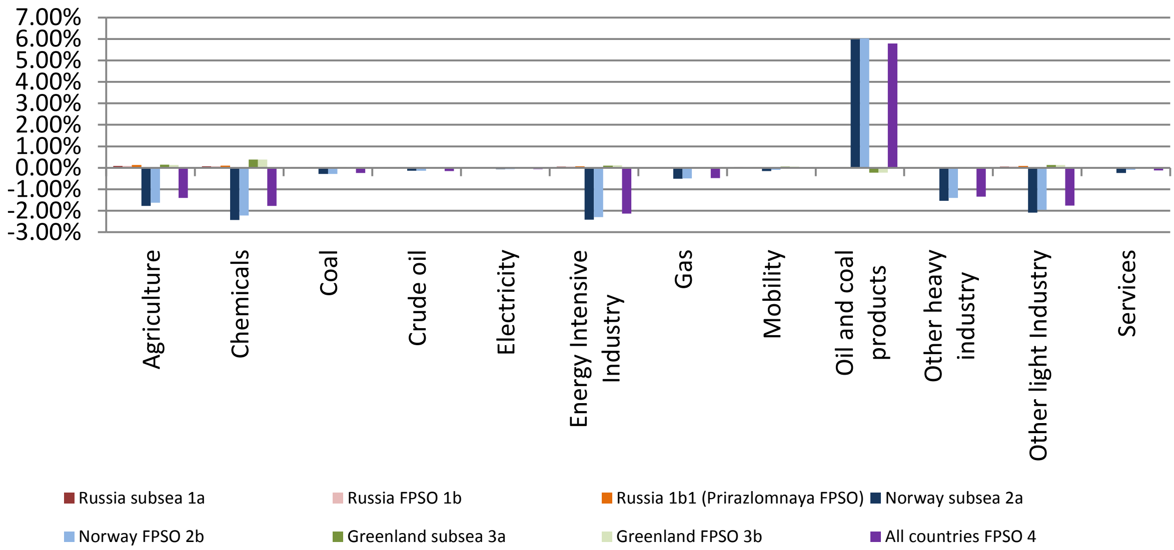


Figure 147: Change in Norwegian output values by sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

For Denmark the development is similar to that of Norway. Again, production of oil and coal production skyrockets, with an increase in output value of 37 % relative to the Reference Scenario (Figure 148). Contrary to Norway, the mobility services sector gains as well, as important inputs get cheaper. Again, the manufacturing sectors are negatively affected, with decreases in output value of around 4 % in the chemicals industry. Effects in other sectors are even smaller. Again, oil production elsewhere in the Arctic has no significant effect on sectoral activity in Denmark.

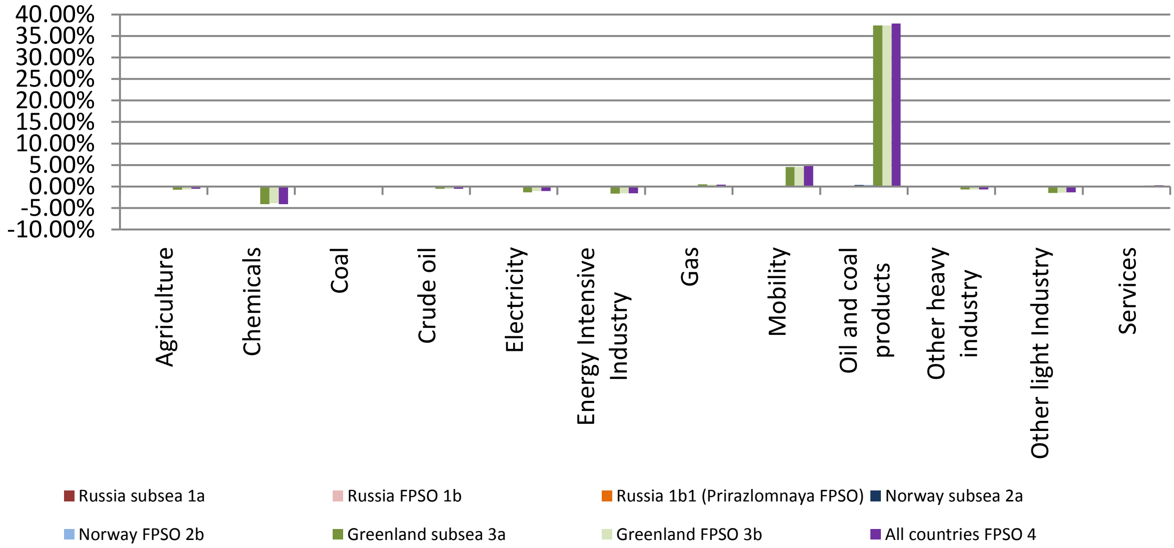


Figure 148: Change in Danish output by sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Compared to the nordic countries just studied, the situation in Russia is quite different . Here, output values in the oil and coal products sector, the mobility sector, the chemical industry and a number of other sectors increase (Figure 149). Gains are largest in the oil and coal product sector, with a plus of 0.8 % in the case of subsea or small FPSO technology relative to the Reference Scenario (1.2 % in for the Prirazlomnaya-like scenario). Output values of the manufacturing sectors, apart from the chemicals sector, are lower, however, especially in energy intensive industry sectors. Overall, the relative effects in Russia are smaller compared to Norway or Denmark, as the overall size of the economy is larger.

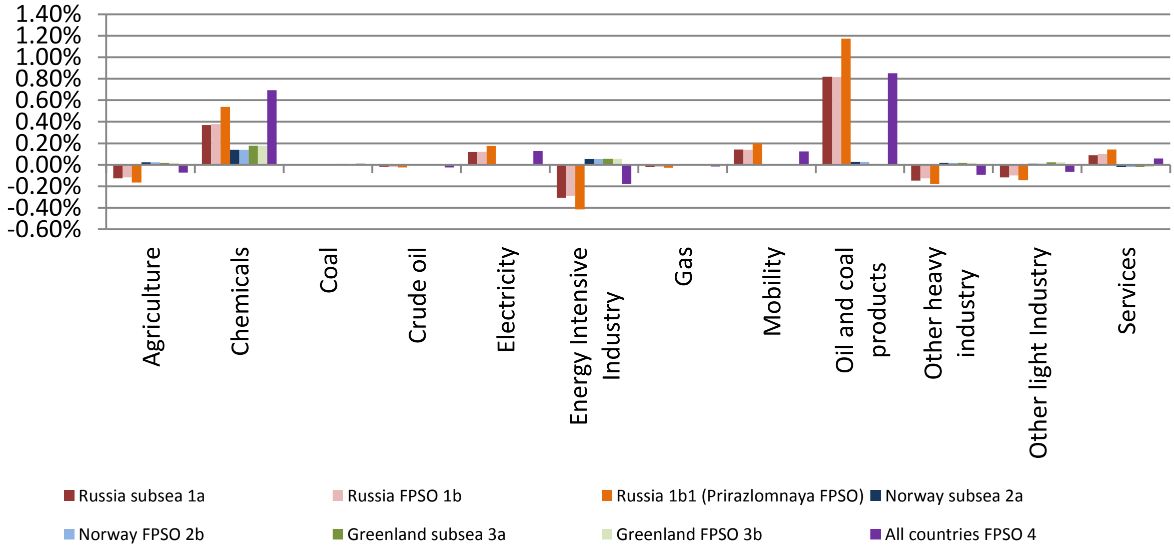


Figure 149: Change in Russian output values by sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

In the following, we present output changes in non-Arctic countries on a sectorial base, covering agriculture (Figure 150), chemicals (Figure 151), energy intensive industries (Figure 152), mobility (Figure 153), other heavy industries (Figure 154), light industries (Figure 155), and services (Figure 156).

In general, and similar to the case of natural gas presented above, the effects of additional Arctic offshore oil production on individual sectors are small. Only in the "all countries" scenario the effects are somewhat sizeable. Due to the importance of oil as a direct input in the chemicals and transport sector, there the effects are especially large; in particular for the Netherlands (NED) and the UK (GBR)

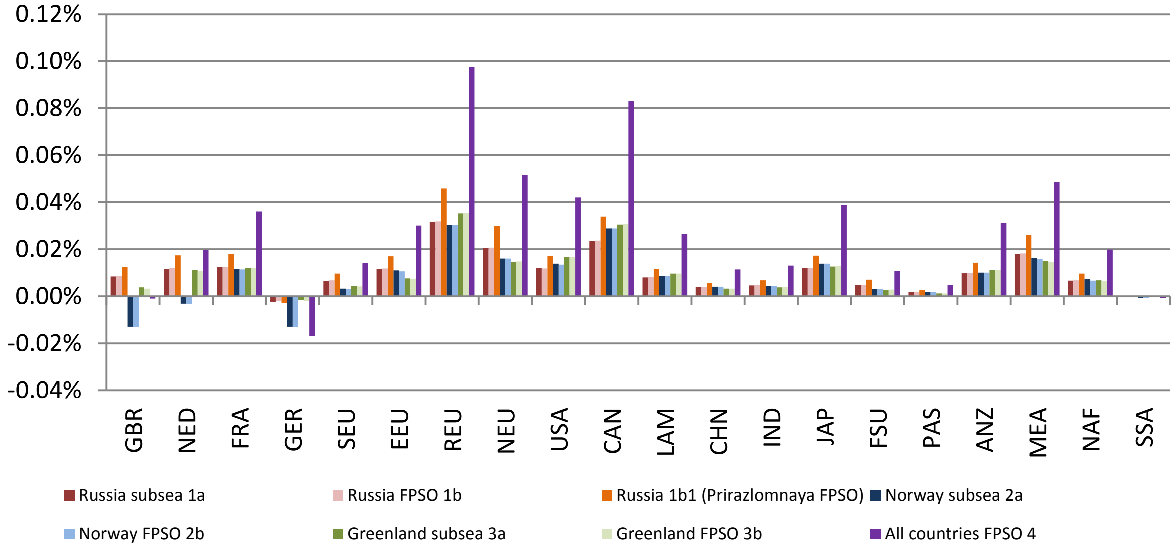


Figure 150: Change in agricultural output values in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

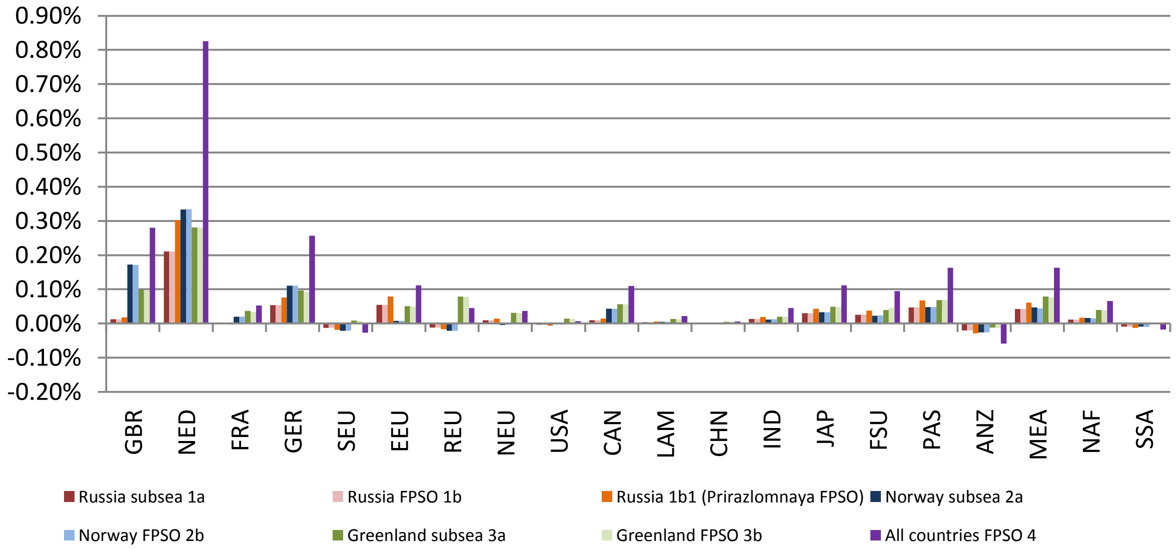


Figure 151: Change in output values of chemical industry in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

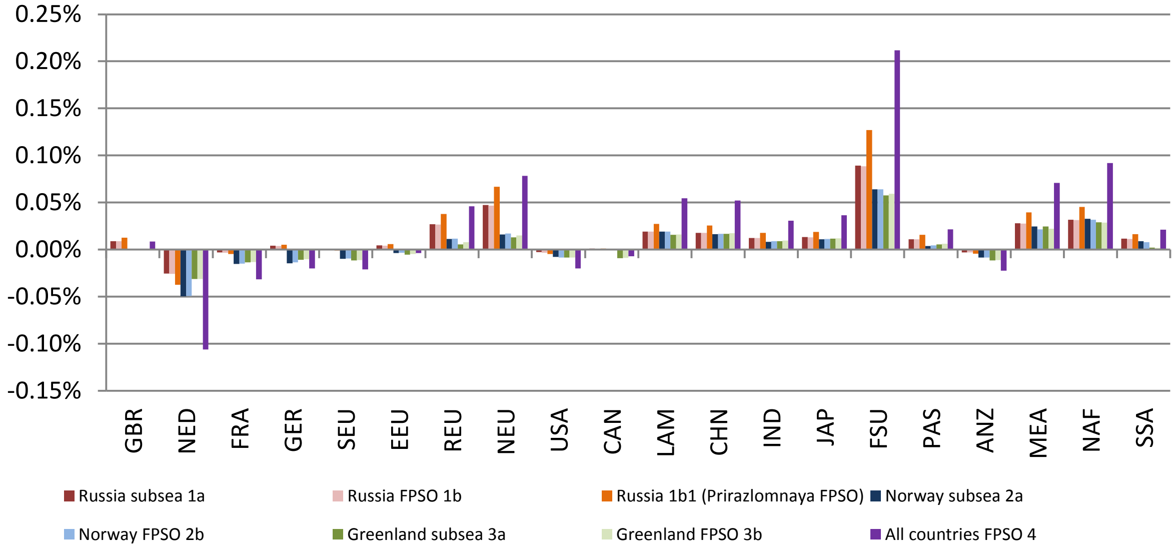


Figure 152: Change in output value of energy intensive industry in 2040, difference relative to Reference Scenario (%) Source: Own presentation based on DART model results.

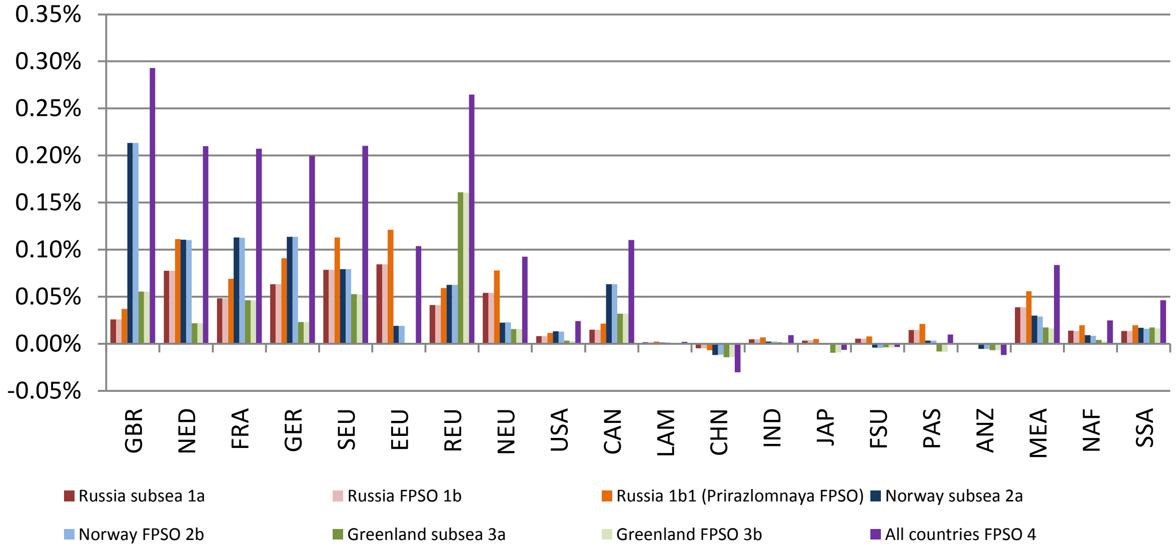


Figure 153: Change in output value in the transport sector in 2040, difference relative to Reference Scenario (%) Source: Own presentation based on DART model results.

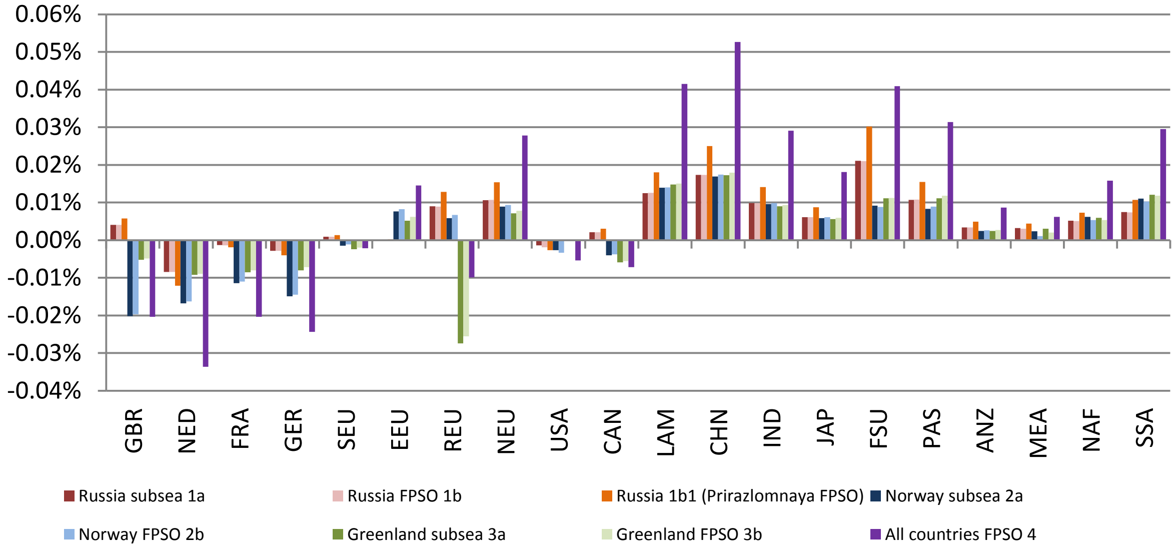


Figure 154: Change in output value of other heavy industry in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

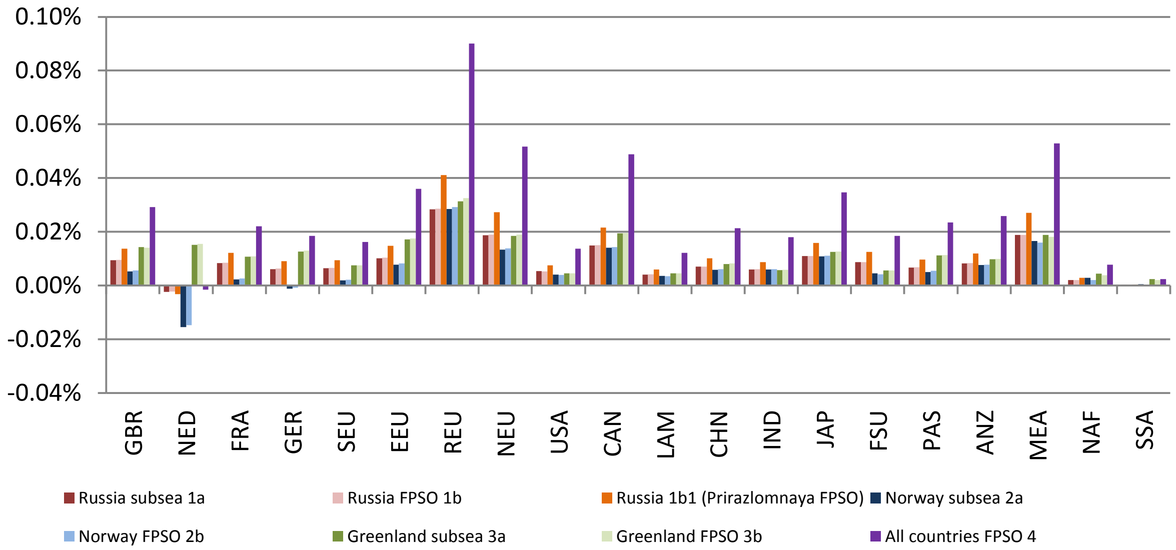


Figure 155: Change in output value of other light industry in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

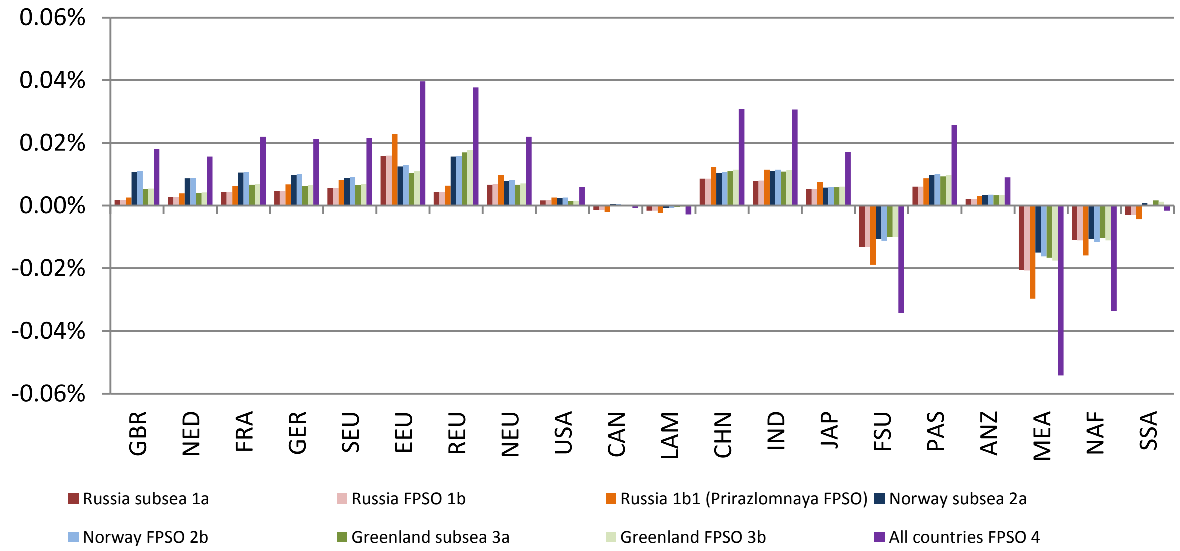


Figure 156: Change in output value of the service sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

12.7. Impact on the labour market

As depicted in Section 12.6, competition of crude oil production with other sectors about factor inputs for production is one of the channels that drive sectorial and economy-wide activities. Qualified labour is of particular importance in that respect, because it is relatively immobile across countries (compared to capital) and supply is price-elastic only in the very long run. Especially companies engaging in offshore hydrocarbons production have been facing shortage of highly specialized and qualified labour in the past. This may not only pose a restriction for the expansion of production in the energy sectors, but the resulting high wages may also lead to labour flows from other sectors, especially in manufacturing, with negative effects on these industries. At the same time, potential positive effects on sectorial output in the other sectors, as described in Section 12.6, may lead to corresponding positive effects on employment.

The CGE framework employed here is restrictive in the way that an increase of labour in one sector will always be compensated by a corresponding decrease in labour use by another sector. While this will underestimate the supply of unqualified, low-wage labour in some economies, it is relatively suitable for qualified, high-wage labour, which makes up a crucial part of employment in the production of offshore hydrocarbons. For this reason, we concentrate less on the overall development of employment, but more on inter-sector shifts of labour input. We first show those shifts for the three Arctic countries Norway (Figure 157), Denmark (Figure 158), and Russia (Figure 159), which are supposedly affected most. After that we present a sector-by-sector presentation of the non-Arctic economies (Figure 160 to Figure 170).

The additional labour input in the Norwegian production of crude oil of 23 % to 28 % in the Norwegian production scenarios relative to the Reference Scenario, depending on the production technology, peters through to the oil and coal products industry, where labour input increases of almost 7 %. The additional labour input in those two sectors is satisfied especially by reduction of labour input in the manufacturing sectors, but also agriculture. Input losses are largest in the chemicals industry, with about 3 %, followed by energy intensive industry sectors. Offshore oil production in Arctic Russia or Greenland has almost no effect on Norwegian labour input, not even in the oil and gas industries.

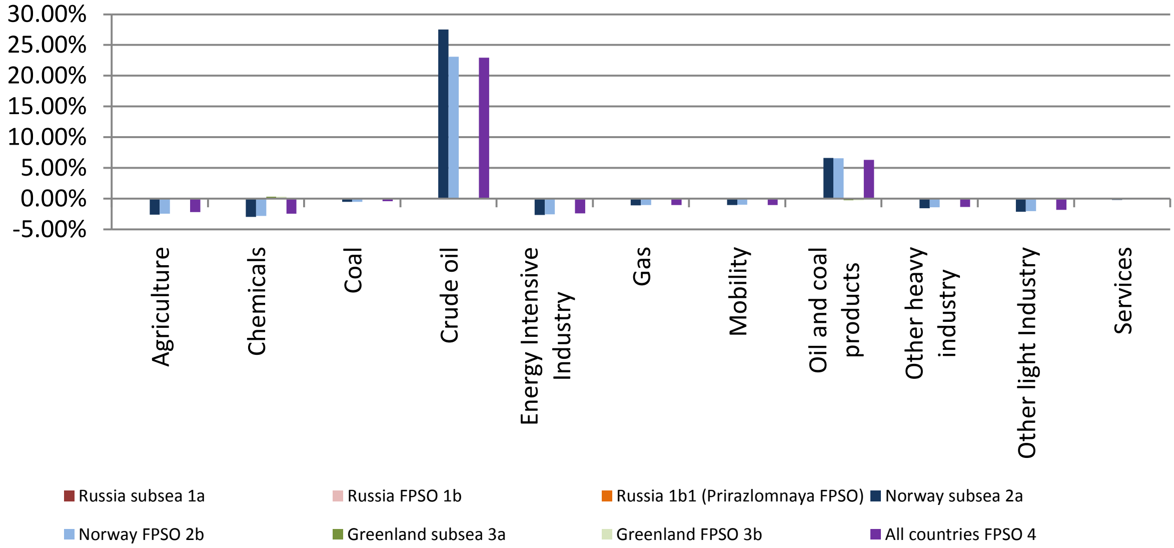


Figure 157: Change in labour input values by sector (Norway) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Denmark's labour market is characterised by an extreme increase in labour input both in the crude oil industry (up to 194% in the case of subsea technology) and in the oil products industry (39 %) for the Greenland production scenarios relative to the Reference Scenario. Also, the gas industry and transport sector increase employment by up to 1.7 % due to reduced factor costs and the general (global) economic stimulation. This is, again, comes at the expense of reduced labour input mainly in the manufacturing and agricultural sectors. The chemical industry reduces employment most, by 3.8 %. As in the case of Norway, the Danish labour market is not significantly affected by Arctic production in other countries.

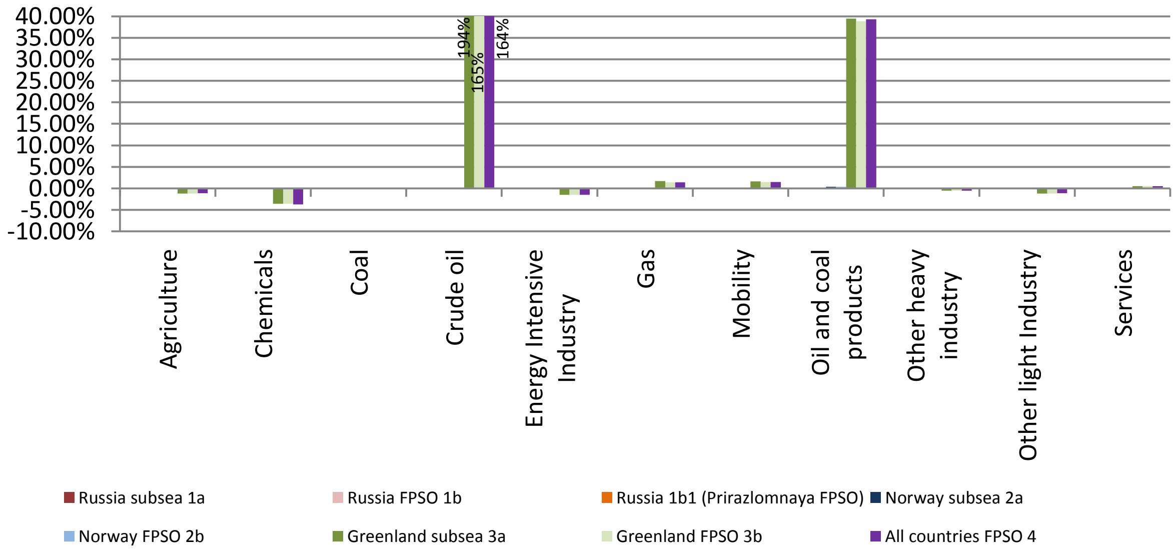


Figure 158: Change in labour input values by sector (Denmark) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

Also in Russia, the increases in labour input stretches beyond the crude oil sector to the oil and coal products sector for an increased production in Russia. The crude oil sector increases employment by 2.7 % in the subsea scenario and 2.2 % in the FPSO scenarios, relative to the Reference Scenario. The oil and coal products industry increases employment by 0.7 %, still a respectable figure, given the size of the Russian economy. Unlike Norway and Denmark, the chemicals industry in Russia does not reduce labour input. The limited international mobility of labour plays out here. Nevertheless, also in Russia the manufacturing and especially the energy intensive industry sector reduces employment to provide labour for the petroleum industry. Employment is reduced by 0.4 %. Arctic oil production in Norway and Greenland has a mild effect on employment in chemicals, where employment increases by 0.2 %, otherwise the Russian labour market is not affected.

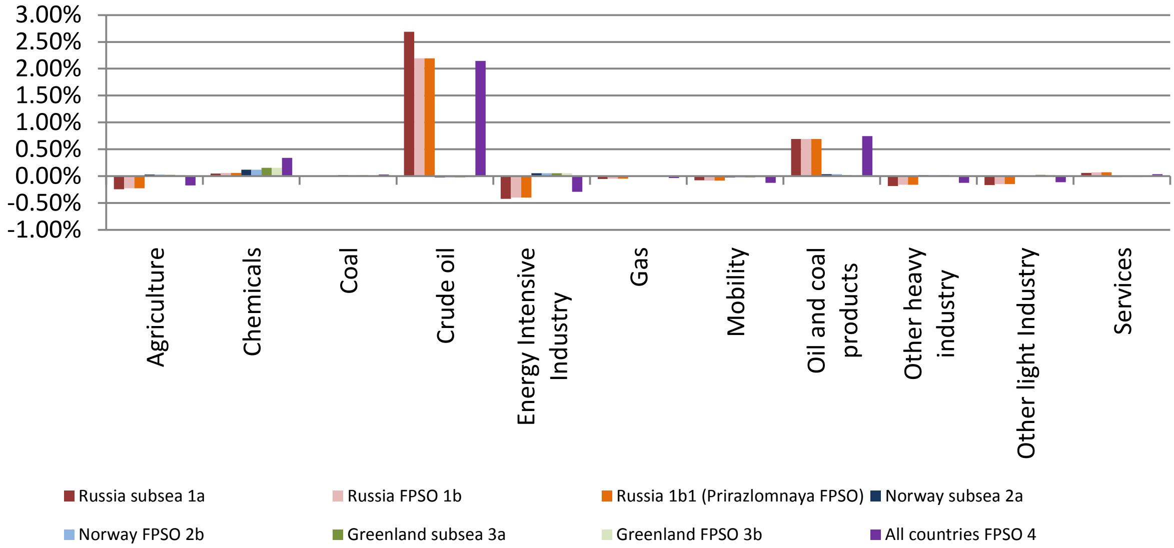


Figure 159: Change in labour input values by sector (Russia) in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

As the international integration of labour markets is low, we find largely small effects on sectoral labour input in non-Arctic economies. In the following we presentlabour input changes in non-Arctic countries sector-by-sector, studying agriculture (Figure 160), chemicals (Figure 161), coal production (Figure 161), crude oil production (Figure 163), energy intensive industries (Figure 164), the natural gas sector (Figure 165), mobility (Figure 166), heavy industries (Figure 167), light industries (Figure 168), petroleum and coal products (Figure 169), and services (Figure 170).

Surprisingly, and contrary to the case of additional production of Arctic natural gas, the largest changes in labour input do not take place in the crude oil industries of other countries (at most a reduction of 0.1 % for GBR in the Greenland scenarios relative to the Reference Scenario, Figure 163). Largest employment shifts are detected for the oil and coal products sector (Figure 169), where labour input increases throughout the world (highest in GBR by 1 % in the Greenland scenarios). The effect on labour input in the chemical industry is more mixed, with, for example, the Netherlands (NED) being especially positively affected irrespective of the producing country (up to 0.25 % in the Greenland scenarios).

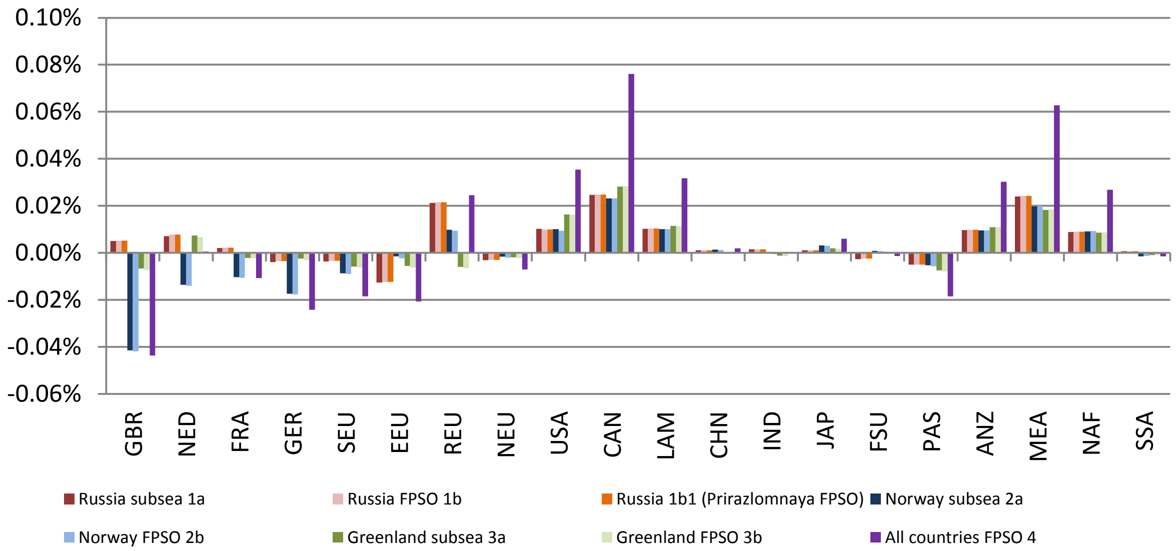


Figure 160: Change in labour input values in agriculture in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

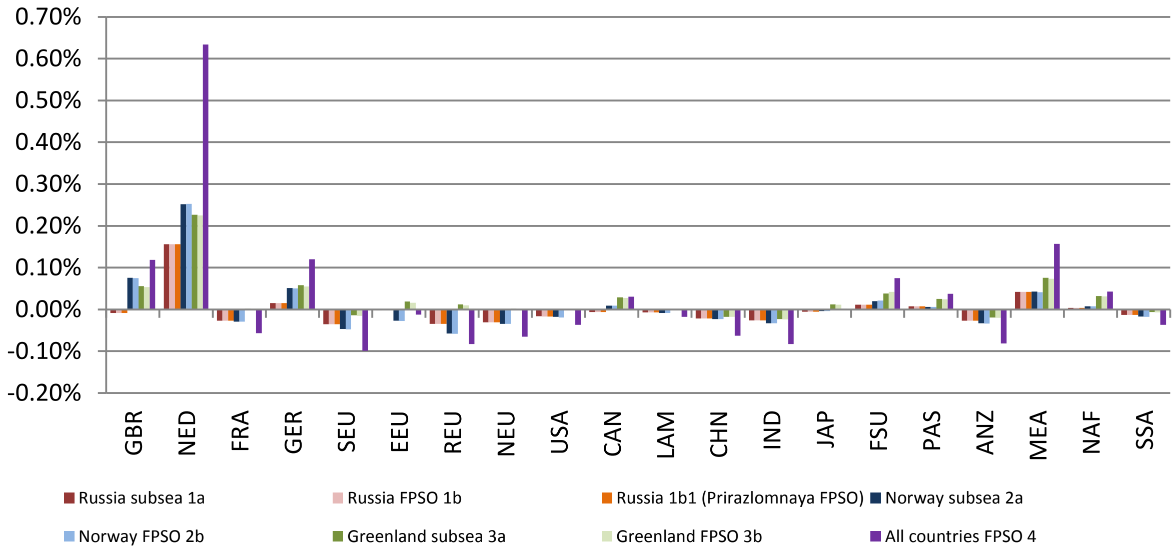


Figure 161: Change in labour input values in the chemical industry in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

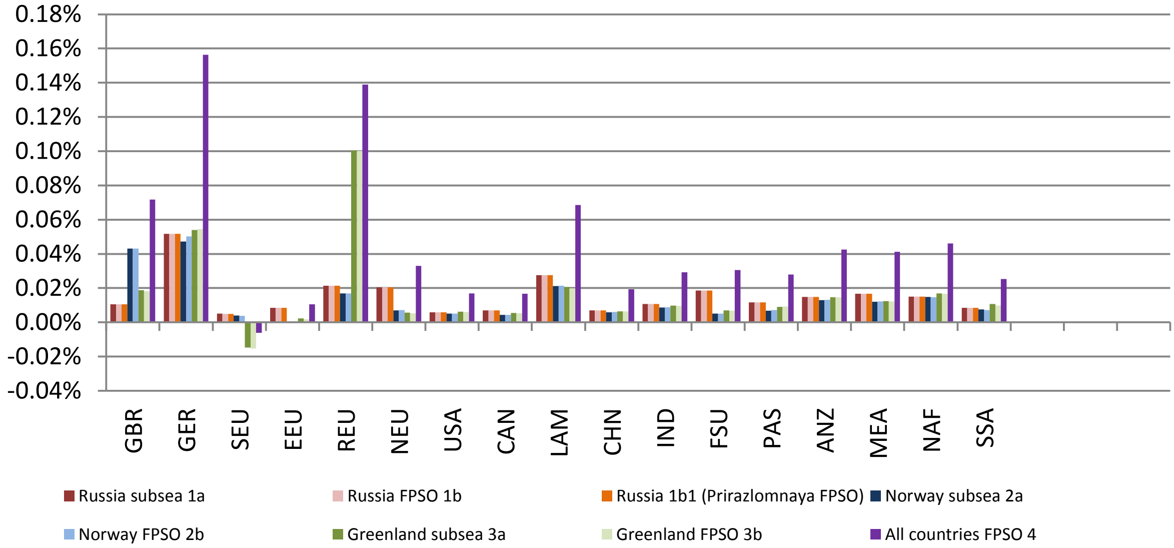


Figure 162: Change in labour input values in the coal sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

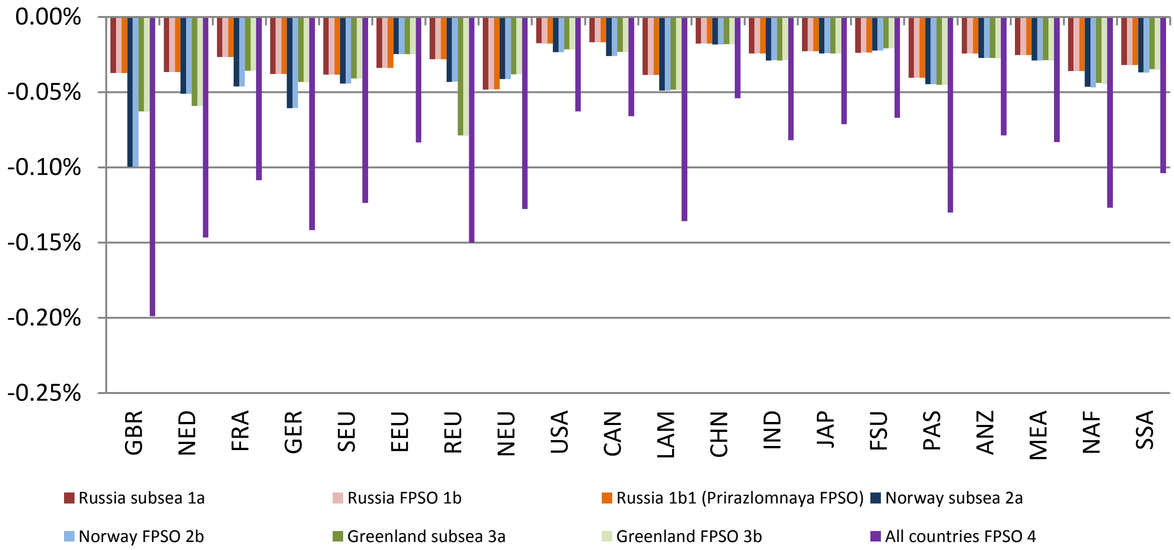


Figure 163: Change in labour input values in the (non-Arctic) crude oil sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

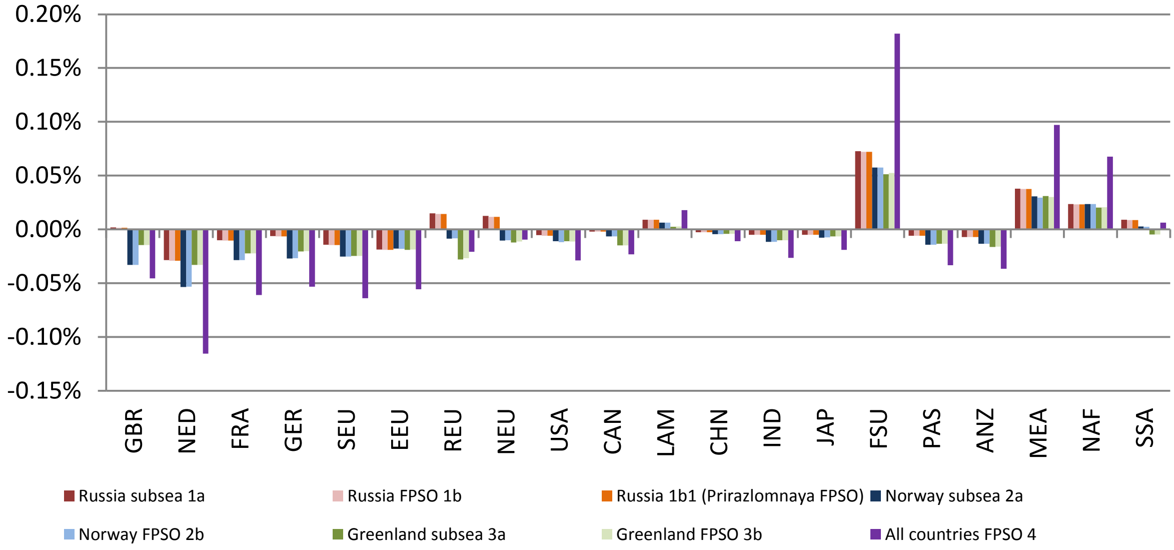


Figure 164: Change in labour input values in the energy-intensive industry sector in 2040, difference relative Reference Scenario (%)
Source: Own presentation based on DART model results.

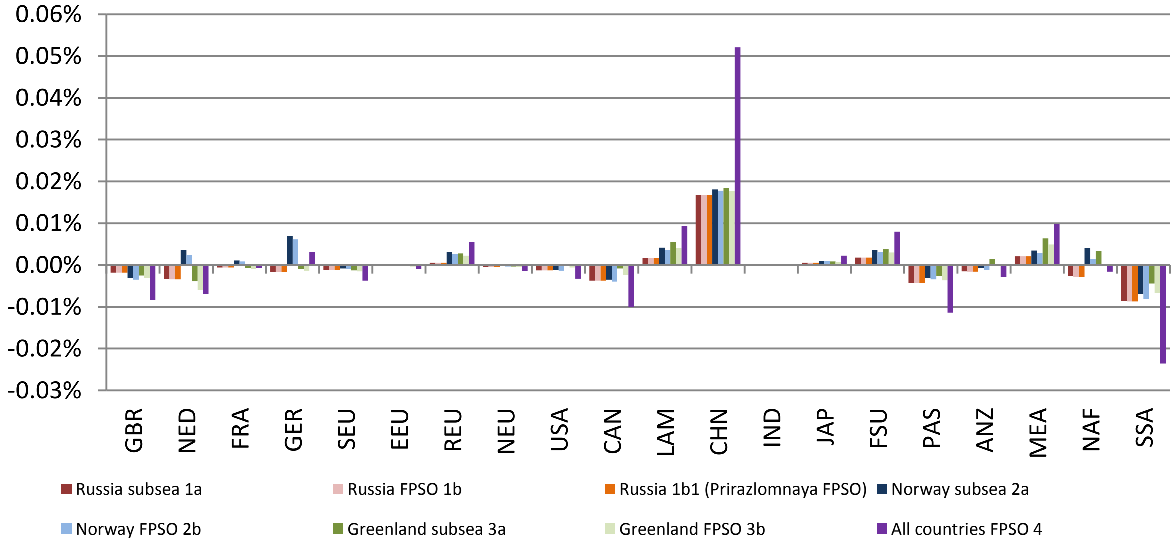


Figure 165: Change in labour input values in the natural gas sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

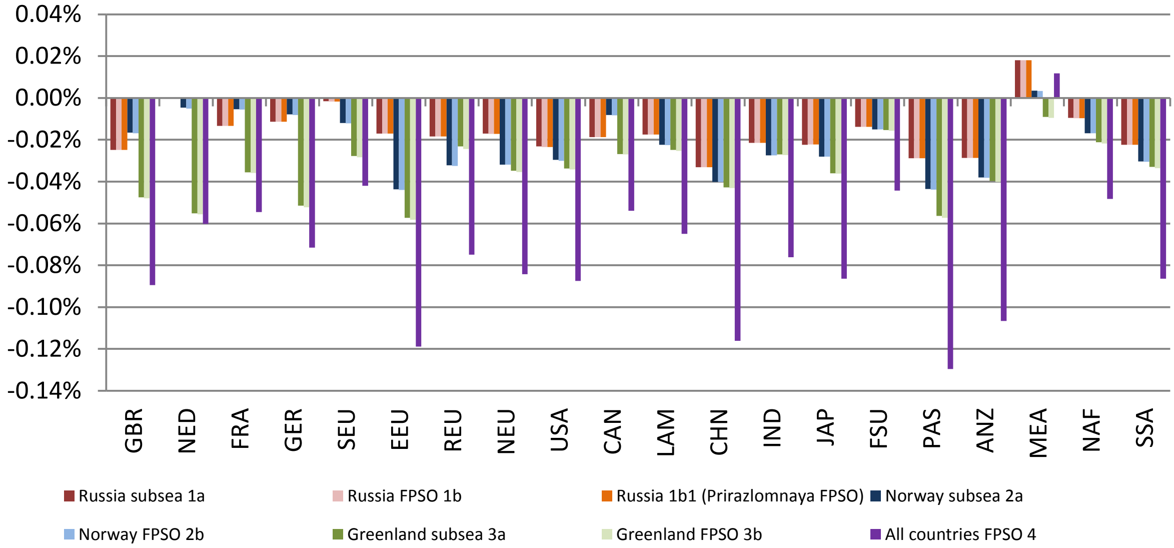


Figure 166: Change in labour input values in the mobility services sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

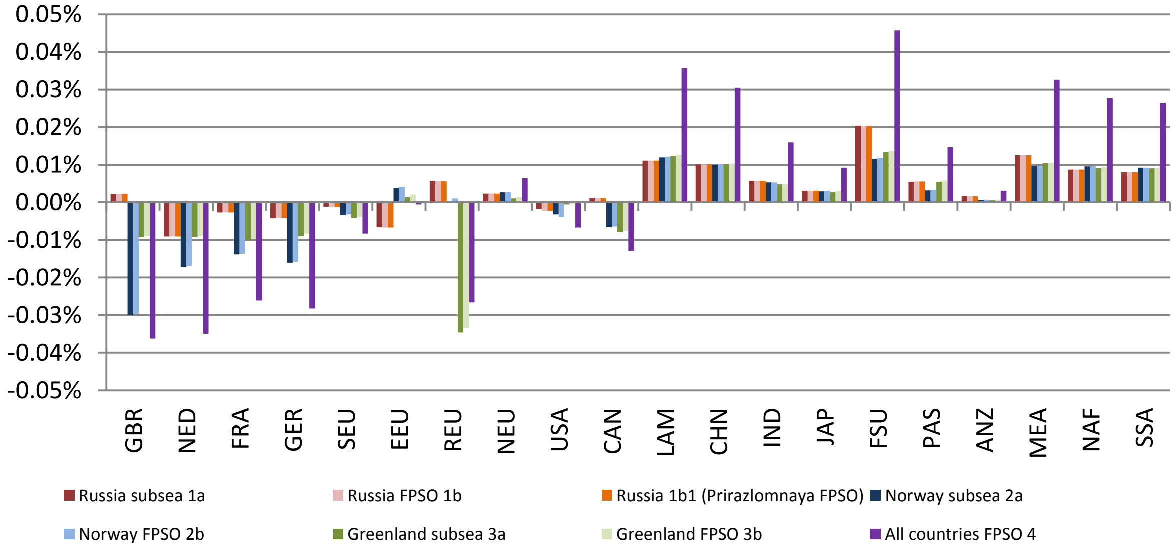


Figure 167: Change in labour input values in the other heavy industry sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

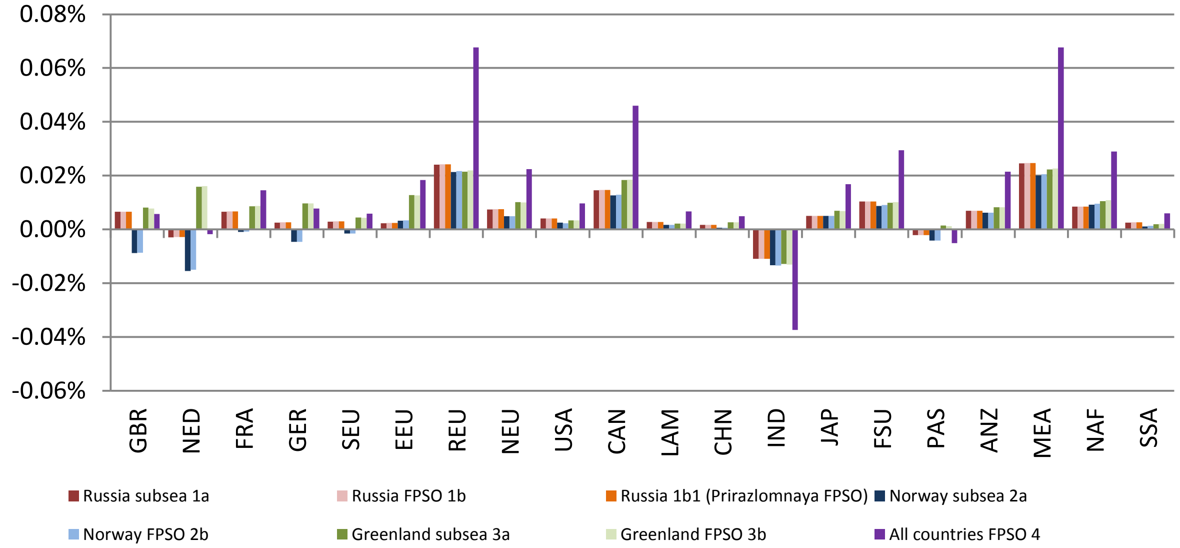


Figure 168: Change in labour input values in the other light industry sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

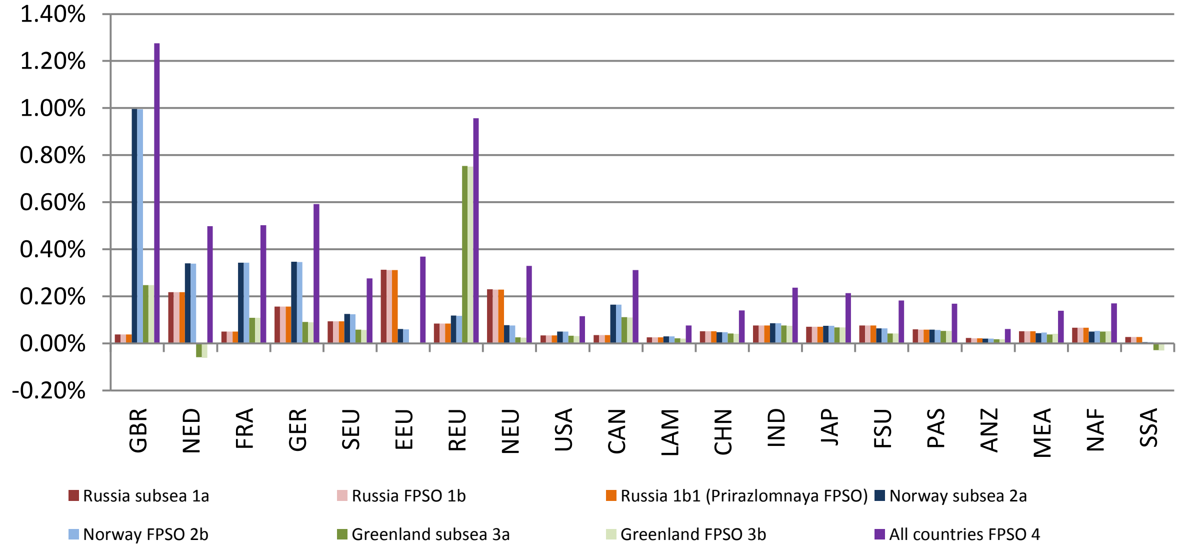


Figure 169: Change in labour input values in the oil and coal products sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

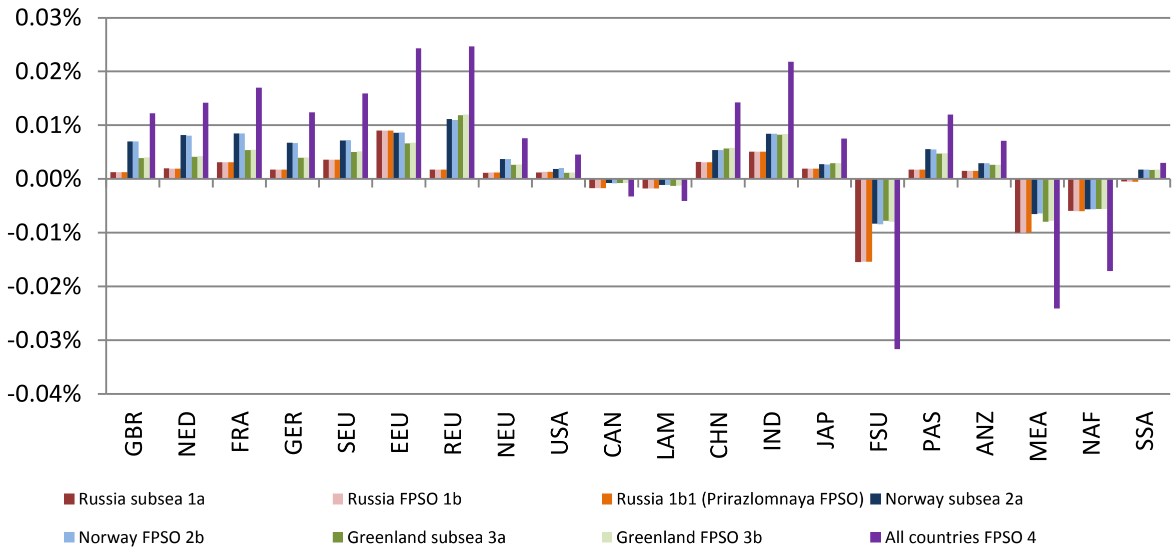


Figure 170: Change in labour input values in the service sector in 2040, difference relative to Reference Scenario (%)
Source: Own presentation based on DART model results.

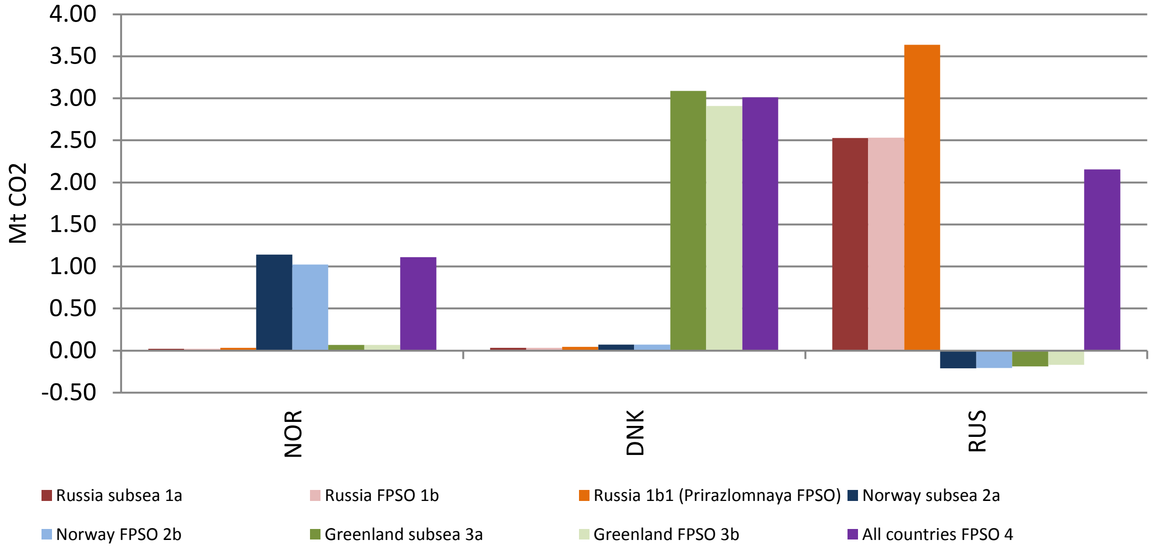
12.8. Impact on decarbonisation efforts

The decarbonisation of economic activity is one of the major policy goals globally. Europe, for example, aims at a 40 % reduction of CO_2-emissions relative to 1990 in 2030. Obviously, the composition of a countries' energy mix is a key determinant of CO_2-emissions in Europe and globally, and so is the production of oil. Additional oil production leads not only to shifts in the energy mix (see Section 12.5), but it also is an economic stimulus in many countries via reduced oil prices (see Sections 12.2 and 12.3). As oil is, furthermore, one of the most carbon intensive fuels in the energy mix, we will expect an increase in CO_2-emissions in the producing countries and beyond. And indeed, CO_2-emissions increase following increased production of natural oil in practically every country and for every scenario.

Global CO_2-emissions from burning coal, gas and oil increase by 10 mt (0.02 %) in the Russia subsea and small FPSO scenarios, by 11 mt (0.02 %) in the Norway scenarios and by 13 mt (0.03 %) in the Greenland scenarios. In case of larger production units, such as the Russian Prirazlomnaya unit, global emissions incease by 13 mt (0.03 %). If all three countries operate a small FPSO field, global CO_2-emissions increase by 34 mt (0.07 %). Given the small size of the intervention relative to global energy production, this is a sizeable increase.

Figure 169 demonstrates that CO_2-emissions increase in almost all countries and regions irrespective of the scenario. An exception, although small in magnitude, is Russia in the Greenland or Norway scenarios. The highest single increase in emissions is visible for Denmark in the Greenland scenarios (3 mt), but also emissions in Russia increase significantly following domestic expansion. Other regions are largely affected in relation to their energy consumption, with large increases in the USA, Japan (JPA), China (CPA), and Latin America (LAM). As expected, additional offshore oil production in the Arctic makes European and global climate protection efforts more difficult.

Panel a:



Panel b:

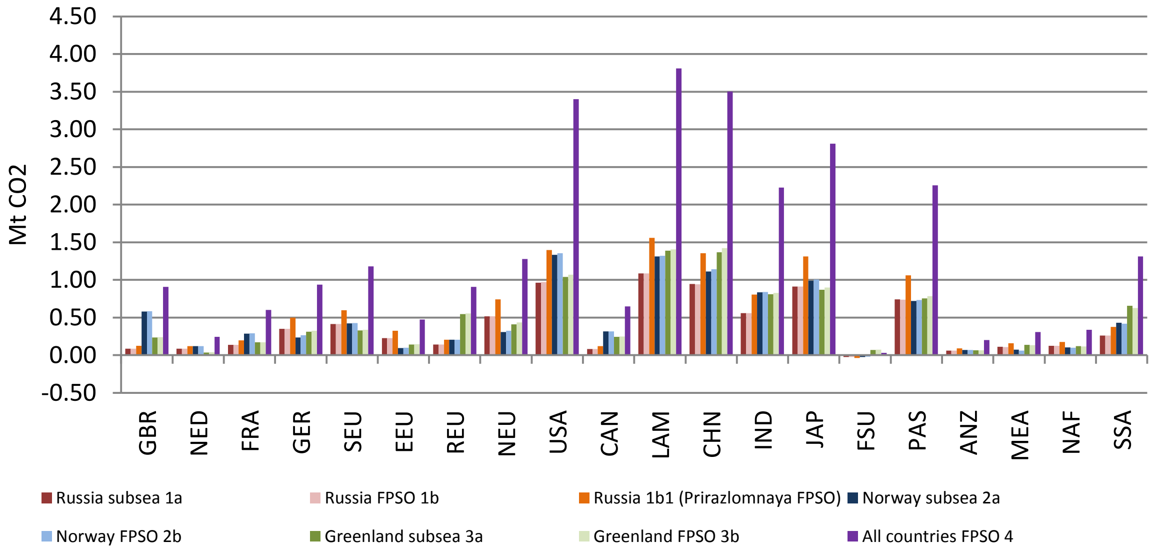


Figure 171: Change in CO2-emissions in 2040, absolute difference to Reference Scenario (%)
Source: Own presentation based on DART model results.

13. Concluding remarks on the impact of Arctic crude oil

This analysis has been on the effects of offshore oil production in the European Arctic, based on scenarios about potential offshore production sites in the Arctic. We cover potential sites in Norway, Greenland, and Russia. We find that Arctic oil has a number of significant consequences for European economies, not all of which are in line with European policy goals. We are, however, not able to take into account potential detrimental environmental effects of Arctic oil production in our economic models. The most significant effect of Arctic oil – and presumably any additional oil production for that matter – would be a decrease in oil price of significant order of magnitude, both in producing and importing countries. As oil is one of the, if not the single most important input factor for any economy, the price reduction acts as a stimulus program. GDP increases significantly in producing countries, especially in Norway and Greenland/Denmark (up to 1.7 % GDP).However, economic activity expands in other countries as well, most notably European countries. Only competing oil exporters are negatively affected, such as the Middle East countries, North and Sub-Saharan Africa and the states of the Former Soviet Union.

The price changes and the economic expansion in many parts of the world have important implications for world trade. The terms-of-trade decrease substantially for producers of offshore Arctic oil, individual non-producing region is not much affected. Consequently, exports especially in manufacturing decrease in the producing countries. The value of Danish exports, for example, decreases after oil production in Greenland while the value of exports remains constant for Russia. In both countries significant inter-sector shifts across exporting sectors are visible. Dutch Disease effects, i.e. the disadvantageous appreciation of the producing country's real exchange rate and increased competition on domestic input markets are likely reasons. Only Norway profits overall in terms of exporting activity. The rest of the world increases exporting activity as the overall economic expansion spurs global demand. Nevertheless, this economic expansion is not sufficient to generate larger changes in labour input outside of the producing countries. In thosecountries, however, we find significant labour market effects, including shifts from manufacturing sectors towards the oil and oil processing industry. While we do not find significant shifts on the markets for primary fuels, we do find a significant increase of CO_2-emissions as a consequence of additional oil production. Globally, CO_2-emissions increase by over 10 mt (0.02 %) for the smallest production unit studied here.

The conclusion we drew regarding the production of natural gas in the Arctic also applies as a general conclusion for European Arctic offshore oil: while having some modest regional effects, Arctic oil is certainly not a game changer for Europe. Even though oil production and the accompanying price decrease acts as a small stimulus program for European economies, this effect is not confined to Arctic oil.

Part IV: Overall summary and conclusions

Both oil and gas production from the Arctic Ocean are being discussed currently as a solution to diminishing fossil fuel supply and energy security worries in Europe. We conclude in our interim summaries in Sections 8 and 13 that neither European Arctic offshore natural gas, nor European Arctic offshore oil are a game changer for Europe. While production in the European Arctic might in the long term alleviate some effects of severe supply disruptions, as we illustrate with the hypothetical example of a Russian natural gas embargo (see excursus in Section 7.12), markets, especially in Asia, attract whatever production might we witnessed in Greenland, the Norwegian Barents Sea, or even the Russian Arctic.

Based on existing cost estimates we analyse the economy viability of increased offshore production of hydrocarbons in the European Arctic. Under certain conditions, oil and gas projects are viable in existing natural gas locations in Norway and Russia, in Greenland, and in the case of oil production, should the necessary discoveries be made. Nevertheless, most natural gas would be shipped to Asian markets. The economic unviability of new production sites with large step-out distances far offshore in Norway and Russia highlights the importance of existing infrastructure for economic development in the High North, which serves as a catalyst for future development.

Our analysis demonstrates that additional Arctic gas or oil production would have a positive effect on GDP in the producing countries, even larger in the case of oil compared to gas in

Norway and about the same for Greenland/Denmark and Russia, with some modest second-round effects for downstream sectors. The downstream sectors in Norway are mostly negatively affected, with declines in output especially in the chemicals and energy intensive industry sectors. These sectors suffer twice from additional production, (1) because of increased competition about qualified labour and (2) because of Dutch Disease effects. The Russian downstream sectors, especially the chemicals and electricity sectors, partly profit from lower prices for natural gas and realize production increases. Nevertheless, increased competition for qualified labour is more present in Denmark and Russia, and to a smaller effect also in other natural gas producing economies, including The Netherlands and countries in North Africa. For both fuels, the terms-of-trade decrease substantially for the Arctic producers, while other countries terms-of–trade are almost unaffected. Consequently, exports, especially in manufacturing, decrease in the producing countries. This effect is more pronounced in the case of oil compared to natural gas. Also most labour market effects are confined to the producing country and do not extend significantly across borders.

Regarding countries outside the Arctic, we find that the effects of oil production in the Arctic on other producing countries (NAF, MEA) are considerably larger than those of natural gas production. This reflects the higher international integration of the oil market as compared to the more regional gas markets. The same larger integration also leads to smaller price decreases in Russia and Denmark/Greenland for oil compared to natural gas.

Any hopes that additional natural gas production might lead to reductions in CO_2-emissions do not realize. We find an increase in CO_2 emissions for both fuels and all scenarios except for the hypothetical Russian gas embargo. In that case, a severe economic downturn in Eastern Europe leads to a decrease in emissions that more than compensate increases in other world regions.

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14. Appendix

14.1. Abbreviations

bbl	Barrel
bcm/a	billion cubic meters natural gas per year
CES	constant elasticity of substitution
CGE	Computable General Equilibrium
CMIP5	Climate Model Intercomparison Project, Phase 5
EUR	Euro
EWI	Cologne Institute for Energy Economics
FID	Final Investment Decision
FLNG	Floating liquefied natural gas
FPSO	Floating Production, Storage, and Offloading Facility
FTA	Free-Trade-Agreement
IEA	International Energy Agency
IfW	Kiel Institute for World Economics
IPCC	Intergovernmental Panel on Climate Change
kcm	thousand cubic meters natural gas
KLE	capital-labour-energy aggregate
MWh	megawatt hour
LNG	Liquefied Natural Gas
LTC	Long-term Contract
mt	million tons
MTGMR	Medium Term Gas Market Report
mtoe	million tons of oil equivalent
mtpa	million tons per year
NSR	Northern Sea Route
ppm	parts per million
RCP	Representative Concentration Pathway
USGS	United States Geological Survey
USGS-CARA	United States Geological Survey's Circum-Arctic Resource Appraisal
WEO	World Energy Outlook

14.2. Country abbreviations

NOR	Norway
DEK	Denmark and Greenland
RUS	Russia
GBR	United Kingdom
NED	Netherlands
FRA	France
GER	Germany
SEU	Southern Europe (Italy, Spain, Portugal, Greece, Malta, Cyprus)
EEU	Eastern Europe (Lithuania, Estonia, Latvia, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria)
REU	Rest of EU (Belgium, Luxemburg, Finland, Sweden, Austria, Ireland)
NEU	Non-EU Europe (Belarus, Ukraine, Moldova, former Yugoslav countries, Turkey, Switzerland)
CAN	Canada
USA	USA
ANZ	Australia and New Zealand
JAP	Japan
FSU	Rest of Former Soviet Union
CHN	China and Hongkong
IND	India
LAM	Latin America
PAS	Pacific Asia
MEA	Middle East
NAF	Northern Africa
SSA	Subsaharan Africa