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# Plausible futures for the Norwegian Offshore Energy Sector: Business as Usual, Harvest or Rebuild?

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# Plausible futures for the Norwegian Offshore Energy Sector: Business as Usual, Harvest or Rebuild?

**Abstract:**

The global energy transition from fossil to low-carbon energy challenges the future of the Norwegian petroleum sector, a major factor in the country's economy, now facing financial climate risk and long-term declining demand, particularly for gas to the EU. What energy policies can assist the transition into a low-carbon society? We explore three investment scenarios for the Norwegian offshore energy sector from 2020 to 2070: 1) Business as usual, 2) Increasing cash-flow by harvesting existing petroleum fields and cutting investments (Harvest-and-Exit), or 3) Rebuilding with green offshore energy investments. In a new economic model, we compare impacts on key macro- and sector-economic variables. We find that investing moderately in green offshore energy production can reverse the extra job decline that a quicker phase-out of petroleum investments would incur. The impacts on the Norwegian sovereign wealth fund - Government Pension Fund Global - and on gross domestic product (GDP) per capita are insignificant to 2050 and positive by 2070. The simulated investments and economic results can be compared with observations to constitute forward-looking indicators of Norway's energy transitioning.

**Keywords:** Green transition, Energy, Petroleum, Offshore wind

**JEL classification:** Q43, Q54

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## Sammendrag

Endringen i energibruk globalt, fra fossil til lav-karbon energi, reiser spørsmålet om den videre utviklingen for petroleumssektoren i Norge som gjennom de siste førti årene har bidratt avgjørende til landets økonomi og velstand. Petroleumssektoren står nå overfor finansiell klimarisiko og langsiktig avtakende etterspørsel, spesielt for gasseksport til EU. Hvilken type energipolitikk er best egnet til å støtte opp om transformasjonen av Norge til et lavutslippssamfunn? Hvordan kan norsk produksjon av olje og gass ev. fases raskere ut samtidig som man unngår ekstra fall i sysselsettingen for de ansatte i offshore-næringen medregnet leverandørindustrien og sikrer at kompetansen i næringen kan benyttes til ny industriutvikling?

Vi undersøker tre scenarier for investeringer i norske offshore energinæringer fra 2020 til 2070: 1) «Business as usual»: Petroleumssektoren videreføres iht gjeldende trender, 2) Høsting: Kontantstrømmen fra petroleumssektoren økes på kort sikt ved å høste (tømme) alle felt i produksjon men med raskt synkende investeringer og 3) Gjenoppbygging: Høstingen kombineres med investeringer for å utvikle nye offshore lavkarbon-energiprodukter. I en nyutviklet økonomisk modell sammenlikner vi virkningen av de tre politikk-scenariene på eksport av energiprodukter, sysselsetting i offshore energinæringer, bruttonasjonalprodukt (BNP) per innbygger, offshore klimautslipp målt i $CO_2$-ekvivalenter, og Statens pensjonsfond utland (SPU).

De tre scenariene innebærer ulike forutsetninger om politikk for investeringer i nye energiprodukter. Strategien for scenariet Gjenoppbygging er at myndighetene sikrer at ny produksjonskapasitet på 1,5 GW havvind ferdigstilles hvert år fra 2028. Dette innebærer private- og offentlige investeringer på om lag 30 milliarder kroner per år. For å oppnå en videre kostnadseffektiv utbygging av havvind er det avgjørende at auksjonssystemer designes for å styrke innovasjon og drive kostnader ned, samtidig som produksjonskapasiteten i en tidlig fase ikke blir så stor at det blir overskuddstilbud og fall i spot-priser i Nordsjø-området. Nye lavutslipps-energiprodukter kan over tid utvikles til å inkludere energilagring, som grønt hydrogen og grønn ammoniakk. Analysen forutsetter at staten i en overgangsperiode sikrer privatøkonomisk lønnsomhet for lavutslipps-energiprodukter inntil samfunnsøkonomisk lønnsomhet oppnås, for eksempel ved en policy-mix av skatte-incentiver og statlig prisgaranti for omsetning. Et hovedresultat av analysen er at kun moderate investeringer i scenariet Gjenoppbygging kan gi grunnlag for en politikk som motvirker nedgangen i sysselsetting i offshore-næringen, mens virkingene på SPU og BNP per innbygger kun er ubetydelig negative fram til 2050 og positive i 2070.

Modellberegningene for utvikling av investeringer og makroøkonomiske variable, kan tolkes som et indikatorsett med framoverskuende, modellbaserte indikatorer, der vedtatte investeringer og gjeldende trender i makroøkonomiske variabler tolkes som uttrykk for hvorvidt utviklingen de neste tiårene peker i retning mot et lavkarbon-samfunn. Indikatorer for klima-omstilling bør forankres i det internasjonale rammeverket for bærekraftsindikatorer, *Sustainable Development Goals (SDG)*, som nå er under utvikling i Norge. Bærekraftsindikatorer skal i prinsippet belyse avveininger mellom miljø, økonomi og sosiale forhold. Erfaring fra tidligere forskning tilsier at indikatorer for komplekse avveininger mellom samfunnsmål ikke kan hentes direkte fra statistikk, men må være basert på forskning om sammenhenger mellom ulike sider ved bærekraftig utvikling. Det er derfor relevant å utvikle modellbaserte fremoverskuende indikatorer. Det modellbaserte indikatorsettet kan brukes til å evaluere effekten av politikk på utviklingen av norsk energiproduksjon og vurdere bærekraft i form av lavkarbon-energi, sysselsetting, og økonomisk lønnsomhet. Indokatorsettet kan dermed tidlig peke på behov for justering av kursen.

# 1. Introduction

Norway has handled its fortunes from vast petroleum reserves well, in terms of avoiding the Dutch disease and the resource curse (Bjørnland et al., 2019; Mehlum et al., 2006; Torvik, 2001). In the process it has built the world's largest sovereign wealth fund, the *Government Pension Fund Global,* referred to as the oil fund, while also building a solid welfare state providing high levels of human development and life satisfaction to its citizens (Helliwell et al., 2019; Moses, 2021; UNDP, 2019).

Progressing into the 2020s, the declining costs of renewable energy and storage combined with rising climate risks and costs of carbon taxes and regulations are ushering in peak oil demand (DNV GL, 2020b; Mirzoev et al., 2020; Randall & Warren, 2020) and the age of electricity (Helm, 2017; Helm & Hepburn, 2019; Ram et al., 2019). The key question for the transition to a more sustainable, low-carbon Norway is how the fossil offshore-sector will undergo the major structural change necessary in coming decades. The offshore petroleum sector is the largest emitting sector with more than 28% of domestic emissions (Norwegian Environment Agency, 2021). Reducing Norway's exports of fossil fuels would also contribute to supply-side climate measures (Asheim et al., 2019; Fæhn et al., 2017), reducing greenhouse gas emissions of 530 $MtCO_2$-eq/yr from Norwegian exports, more than ten times domestic emissions.

The issues at stake for Norwegian policy makers and voters in the 2020s are: What are the consequences for the economy if the government starts an organized decline of the petroleum sector from a peak in the 2020s to near zero in 2050? How can one seek in the process to transfer and employ the relevant competence of the ~150.000 employees currently in the offshore energy sector (Brasch et al 2019, Hungnes et al 2020), directly and indirectly including industries delivering to the petroleum sector, into low-carbon products and services? New jobs could be made in the building up of new innovative low-emission energy industries like offshore wind power, conversion of power and/or gas to hydrogen using CCS  even *before* these outputs become profitable through market prices alone.

Our research question is: *In a long-term perspective, what are the smart pathways that Norwegian policymakers can choose in the 2020s, to ensure and monitor investments in the successful transition of the country's offshore energy sector to a low-carbon economy before 2050?*

Norway may choose to continue with business-as-usual petroleum policies: keeping the current regulations and incentives designed to stimulate maximum exploration and construction of oil and gas fields. This has worked well for 40 years for the Norwegian economy and represents the business-as-usual alternative. But the risk landscape has changed (Bang & Lahn, 2020; Caldecott et al., 2016; Van de Graaf, 2018). With 'Business-as-usual' we mean that the petroleum sector continues to expand as it has in the past until stopped by lower oil demand, reserves or prices (Scenario 1). Could there be less financial climate risk by cancelling new investments and thereby maximising short-term cash flow (Scenario 2)? Or combine this latter with increasing investments in green offshore products such as offshore wind (Scenario 3)? We explore these generic scenarios by manipulating near-term investment patterns in order to estimate their long-term effects on key energy and macroeconomic variables. To provide plausible macroeconomic estimates, we have adapted the Earth3 model (Randers et al 2019) to the Norwegian macroeconomy, expanded it with petroleum and renewable offshore energy sectors, and renamed it to the "Green Transition Model" (GTM). The outputs are consistent estimates that can provide data-based input and forward-looking indicators to the public debate and Norwegian policymaking during coming years.

## 2. Three policy scenarios for the Norwegian offshore sector: Transitioning to a low-carbon society?

During the last decade an average of 186 constant billion NOK[1] was invested annually in Norwegian offshore capacity (Figure 1). This capacity generated large volumes of oil and gas, on average 185 Mtoe/yr. Figure 2 shows how the Norwegian petroleum sector has since 2000 transitioned from oil toward gas, with gas becoming increasingly important for exports. These petroleum exports have funded the growth of the oil fund from 0 in 1998 to above 10 000 billion NOK in 2020, after the annual deduction of a significant contribution to the state budget (of some 250 billion NOK/yr in later years). The sector has directly and indirectly employed an average of 150 000 persons per year since 2010, around 7 % of total Norwegian employment. The offshore sector emits some 15 $GtCO_2$-eq/yr mainly from offshore gas turbines and increasing energy demand during later stages of oilfield production.

The key policy issues and concerns of politicians mindful of near-term re-election in Norway (Bang & Lahn, 2020) is the threat of losses in jobs, exports, GDP and the oil fund. These potential losses are domestically widely perceived as a threat to Norway's current status as a well-functioning welfare state, hence the attitudes are generally supportive among citizens for continued petroleum exploration (NTB, 2017; Oskarsen, 2019).

[1] In the following, GNOK means giga, billion or $10^9$, Norwegian kroner in constant 2018-NOK currency.

As the global transition toward a post peak oil-demand, low-carbon and renewable energy system is accelerating (DNV GL, 2020b; Van de Graaf, 2018), the choice confronting Norway's policy makers and oil industry decisionmakers is in this analysis assumed to be captured by three broad alternatives for the offshore energy sector: 1) continue with *Business as Usual, "BAU"* – i.e. keep up high investments in exploration and construction of new fields on the Norwegian continental shelf as long as reserves last. Or 2) start a managed decline by following a "*Harvest*" and exit strategy where maximum near-term profits are extracted from existing offshore petroleum with rapidly declining investments in new capacity. Or 3) follow the Harvest strategy while at the same time "*Rebuilding*" the offshore sector with investments in renewables and zero-emission energy products.

The Norwegian continental shelf (NCS) is a mature basin with reserves in a long-term decline. New large finds have been increasingly rare the last decades, with the giant Sverdrup discovery in 2010 being the one exception (Figure 3). The Sverdrup field, which is Western Europe's biggest oil producing field and started producing in 2019, is by itself capable of producing a second "camel hump" in Norway's oil production toward 2030 (Figure 4).

**Figure 1. Annual oil and gas investments in constant prices, 1980-2020 split across exploration, greenfield construction, brownfield developments, onshore activity and shutdown & removal costs. Sum annual investments (dotted line) is shown on the right axis. Data source: Statistics Norway (2020a)**

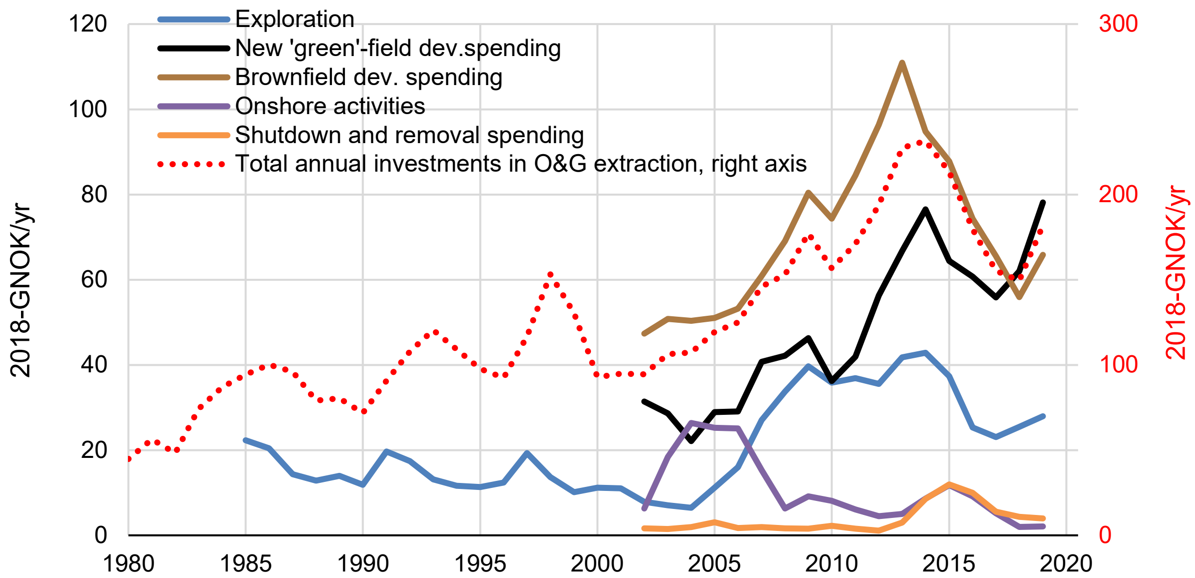


**Figure 2. Norwegian a) oil exports in Mtoe/yr (left axis) and b) gas exports in volume GSm$^3$/yr (left axis) and export value (both right axes, billion 2018-NOK/yr). Sources: Statistics Norway (2020a), Table 08800, Norwegian Petroleum (2021).**

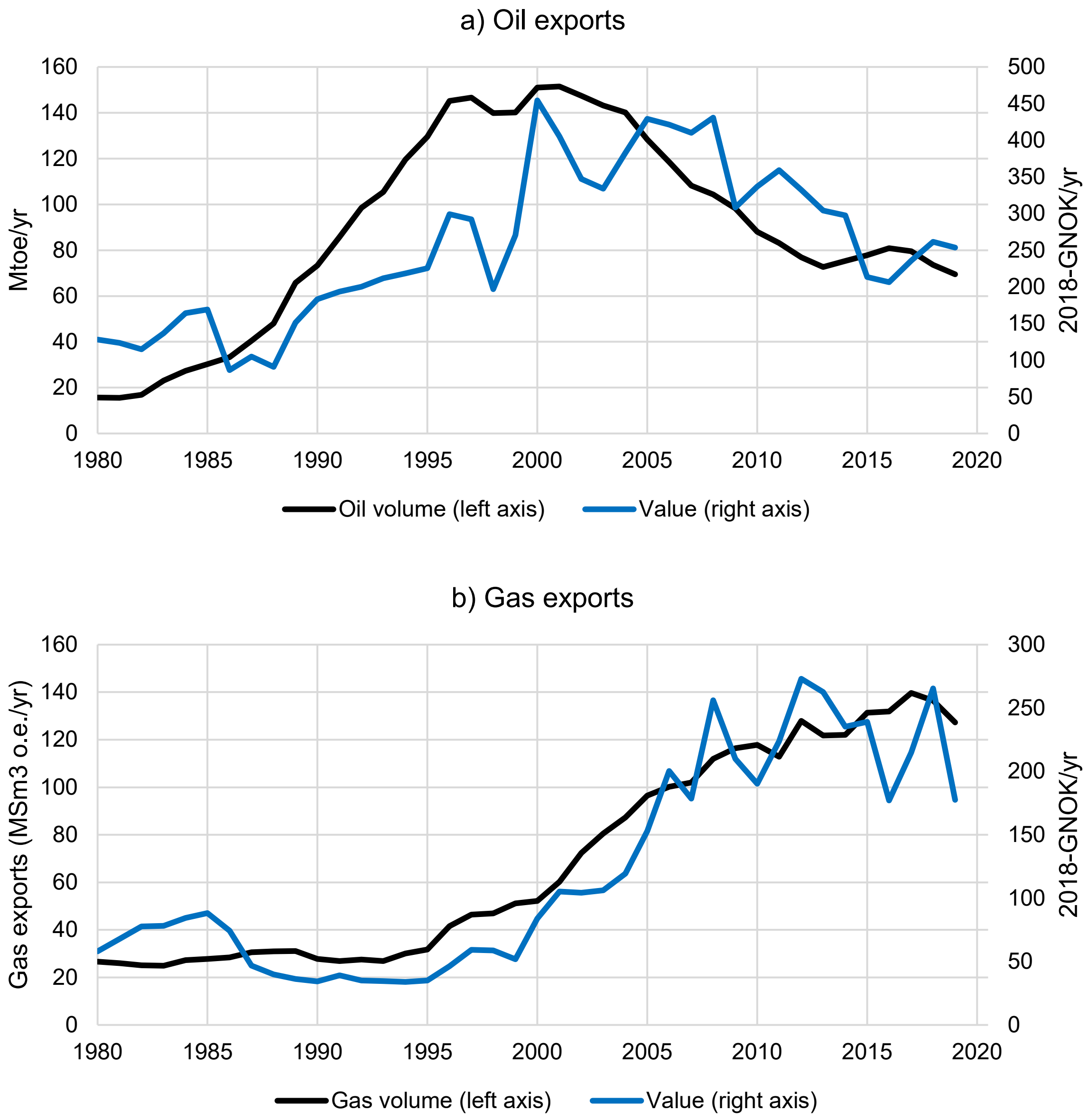
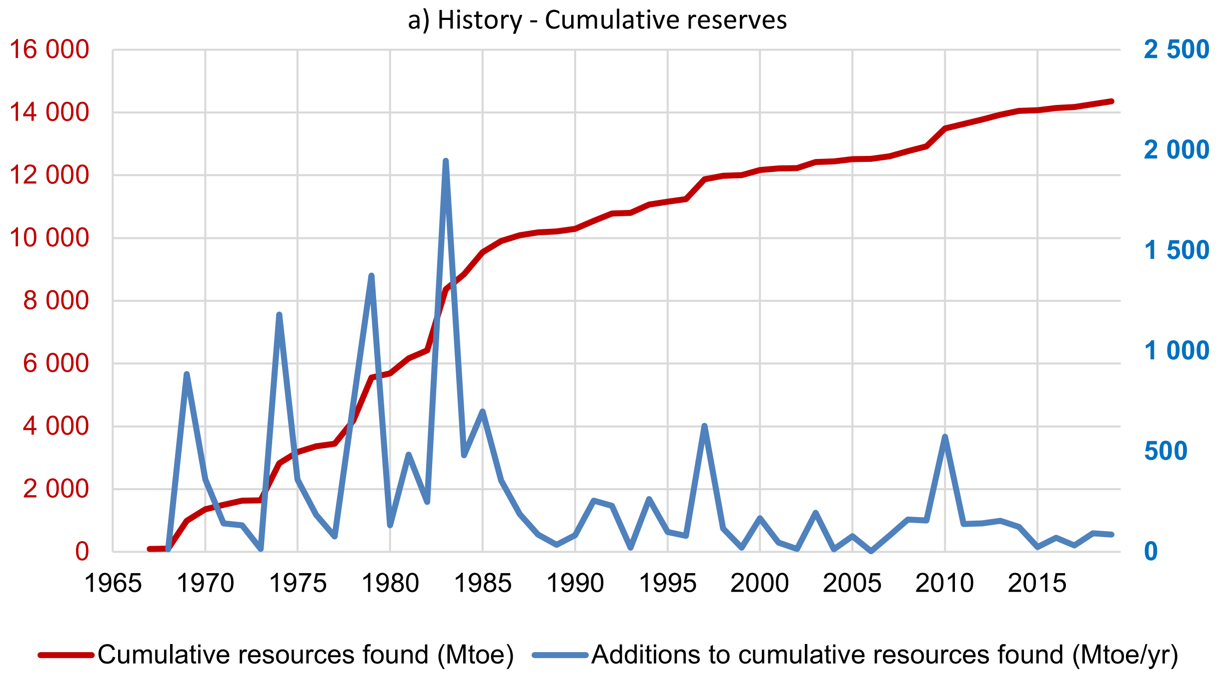


**Figure 3. Annual additions and cumulative reserves on Norwegian continental shelf (NCS) 1965-2020. The peak around 2010 is the discovery of the Sverdrup field. The cumulative sales and how remaining reserves have declined since 2000 in b). Contingent resources are proven oil and gas reserves for which a production decision has not yet been made. Data source: Norwegian Petroleum Directorate (2020)**



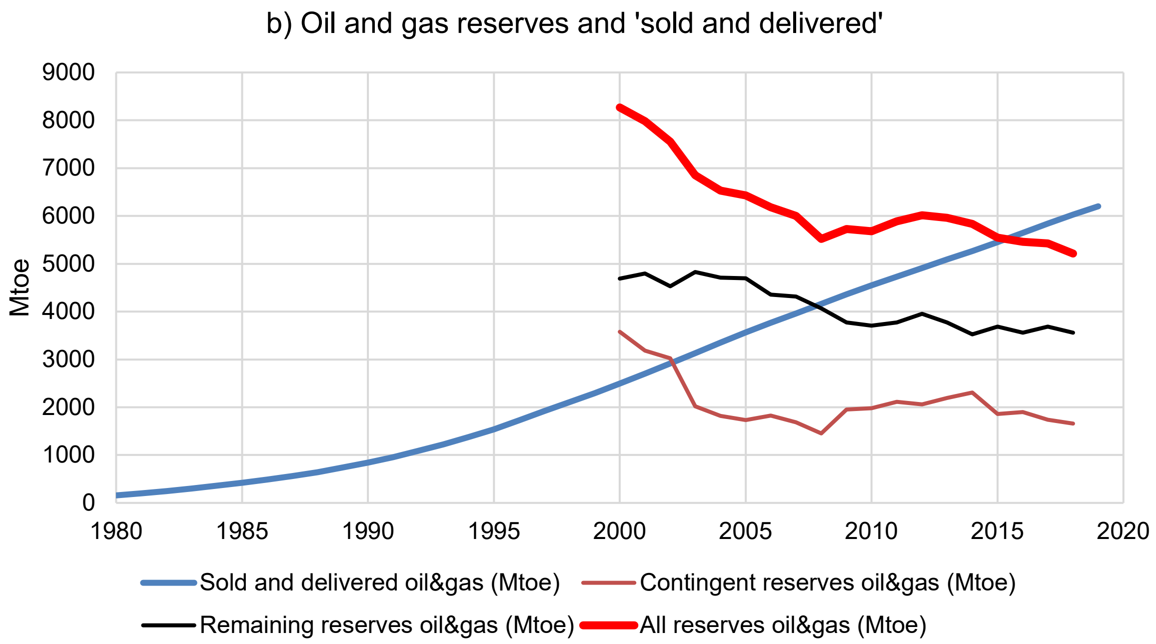
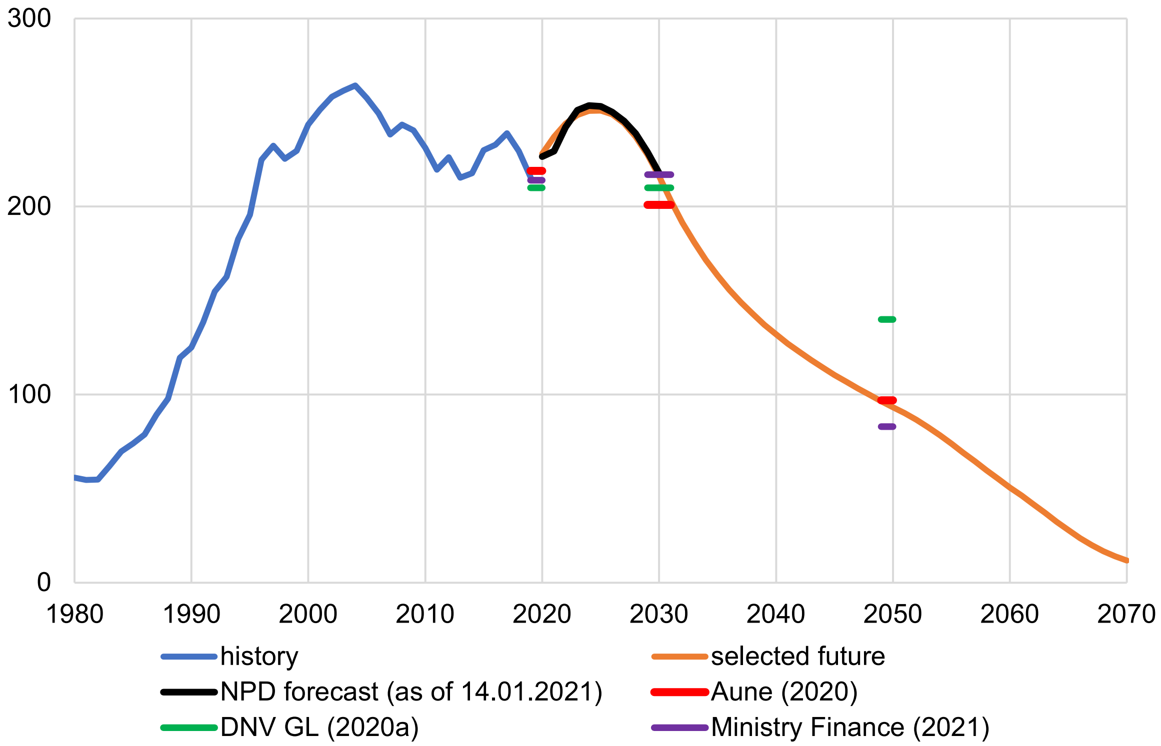



**Figure 4. Historic and expected oil and gas production from NCS with business-as-usual to 2030, 2050 and 2070 in million standard cubic meters of oil equivalents per year. The black line is the official prognosis from Norwegian Petroleum Directorate to 2030. The orange line is our 1) Business As Usual scenario. Green dots show DNV GL (2020a) baseline and red dots show baseline Statistics Norway (Aune et al., 2020) prognoses to 2050. Purple dots are the baseline scenario from the Long-term outlook by Norwegian Ministry of Finance (2021)**




Based on historic trends and the current policy situation, we investigate how Norwegian policymakers could reduce the expected decline in welfare, following from expected decline in jobs and exports in the petroleum sector. This could be initiated by public procurement of advanced green products – shifting investments to first fixed and then floating offshore wind power, conversion of power and/or gas to hydrogen using CCS, and electric vessels – using similar subsidies and tax regimes (such as high rates of depreciation and loss carry-forward) as the oil and gas offshore sector already enjoys, but tailored for the offshore green sector. While providing investment incentives, the petroleum tax regime is designed to secure the benefit of the petroleum resources for the nation of Norway, by capturing resource rent (Lund 2014), and it is here assumed that the same logic applies to capture the resource rent of wind power. The details of such regulatory and tax frameworks are outside the scope of this study. We illustrate consequences of shifting annual investments into different types of offshore investments and assess the long-term consequences for the offshore sector and the total Norwegian economy for the three investment scenarios.

## 2.1 Business as usual, "BAU"

*BAU* is the base-line scenario. It portrays the continuation of the broad trends of macroeconomic development in mainland Norway and its petroleum sector since 1980 over the next coming decades, as expected by most public authorities and analysts. BAU means that Norway will stick to its stable, pre-corona policies of recent decades while the external world evolves in line with what is generally seen as the most likely future, IEA's "Stated Policies scenario" (IEA, 2020). The result is a long, gradual decline in offshore investment and production, toward zero in 2070, as new petroleum projects gradually become ever less profitable (because of rising costs from exploration, dwindling reserves, smaller new fields and tail-production). Our BAU scenario follows closely the baseline scenarios from Statistics Norway (Aune et al., 2020), Norwegian Ministry of Finance (2021) and DNV GL (2020a) to 2050 (Figure 4). Accordingly, the $CO_2$ emissions from the sector decline only gradually. The standard BAU scenario sees little or no stranded offshore petroleum assets as the oil price is assumed to be a stable 50 $/brl all the way to 2070, when all petroleum production has ended in all scenarios.

The oil price assumption in BAU does not take into account the potential of financial climate risk in the coming decades if declining oil demand drives prices down by policies to deliver on the Paris agreement (Caldecott et al., 2016; Fæhn & Stoknes, 2018; Leaton, 2013; van der Ploeg & Rezai, 2020). We model this financial climate risk by calculating the sensitivity of BAU outcomes to a price falling 40% to an average of 30$/brl (section 5).

## 2.2 Harvest and exit, "Harvest"

In *Harvest*, we assume that Norwegian policy makers stop the allocation of new exploration licenses from 2025 and at the same time reduce some of the tax incentives the petroleum sector currently enjoys on investments (including exploration refund scheme, favorable depreciation rates, and uplift deductions). The near-term effect is rapidly declining investments into exploration and new greenfield development. With the Norwegian petroleum taxation model that taxes profits, such reductions in investment costs give an *increase* in the net tax revenues from the oil-producing companies into the oil fund during the late 2020s and early 2030s as oil and gas fields are producing at low cost until their reserves are drained, hence the scenario name *Harvest* (Helm & Hepburn, 2019). The longer-term effect is a more rapid decline in oil and gas production than in BAU, with a more rapid fall in employment (of some -10% per year from 2025 to 2040) and a loss of offshore competence. But Harvest does, in addition to generating more near-term tax revenue, also lead to significant decline in $CO_2$ emissions, both domestically and exported. Harvest represents supply-side climate policy, as described by (Asheim et al., 2019; Fæhn et al., 2017). By maximising near-term cash-flow and reducing long-term investments, this scenario illustrates a pathway that is less exposed to financial climate risk, as modelled in the sensitivity analysis in section 5 as a 40% fall in petroleum prices.

## 2.3 Rebuilding with renewables, "Rebuilding"

Scenario 3) *Rebuilding*, is similar to 2) *Harvest* but policymakers add incentives to build a new, moderately expanding, green offshore sector, starting with investments of 30 billion NOK per year. We assume that the Norwegian government in 2021-2022 auctions out suitable offshore wind licenses with tax regulations tailored to ocean wind power, in line with the petroleum tax regime, to get the first 1.5 GW operational in 2028 (as it takes at least 6 years from auction to operational offshore windfarms). In line with the logic of petroleum taxation in Norway, the suggested tax regime for offshore low-emission energy products is assumed to have two phases in order to secure continued build-up of the oil fund, an early phase with favorable tax rules to secure sufficient investments, and a second phase with higher tax revenues on corporate profits.

To give a steady pipeline of new, ever more cost-efficient offshore windfarms, it is important to design auction conditions tailored to continuously drive innovation and costs down, while not building too large volumes too early that would give oversupply and crash spot prices in the North Sea area (Vieira et al., 2019). These auctions for contracts on new emissions-free outputs can eventually go beyond wind power production to possibly include energy storage such as green hydrogen and ammonia. We assume auctions provide a mix of tax incentives and publicly guaranteed prices using contracts-for-difference (Chiappinelli & Neuhoff, 2020; Sartor & Bataille, 2019) for offshore green products until innovation and cost-reducing learning curves enable new wind power farms to return profits from unsubsidised sales. By including offshore wind-power in the taxation regime of the petroleum sector, some of the extra taxes from profits by harvesting the existing oilfields into the 2030s, are assumed to be reinvested into rebuilding the offshore sector with new, sustainable and renewable energy products, mainly for export. We view the costs of these state investments in offshore green products as the opportunity cost relative to keeping them in the oil fund at 3% expected real rate of return. We also assume that all new offshore wind-power projects is thoroughly assessed in terms of sustainability impacts on fisheries, marine ecosystems, seabirds and bird migration, and further, that all necessary measures to reduce such impacts are taken by positioning and construction according to best practice and scientific knowledge (de Jong et al., 2020; Degraer et al., 2020).

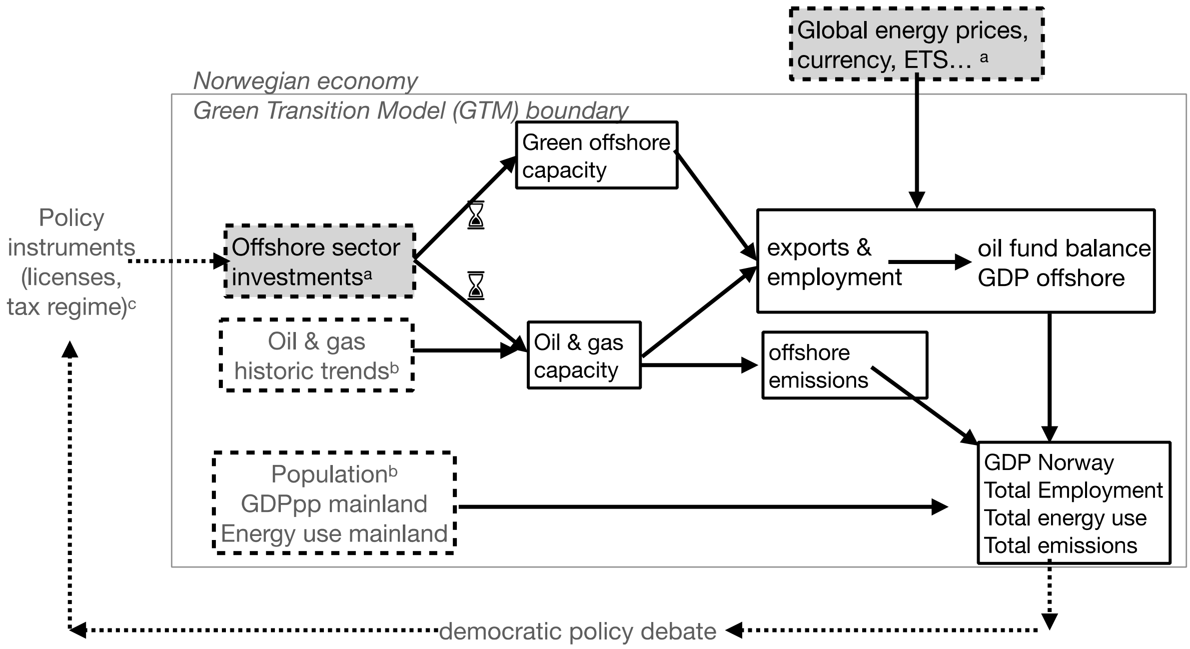
# 3. Approach, methods and data

Our approach has been to find historical trends for all key variables since 1980 by researching the different consistent datasets available, conduct interviews with leading industry players, develop the novel GTM model, assess variables and parameters for each scenario, chosen to fit history closely and then run 3 main scenarios from 2020 to 2070 including sensitivity analysis.

## 3.1 Description of the Green Transition Model (GTM)

GTM is a flexible macroeconomic model with three sectors (offshore petroleum, offshore green, and simplified mainland sector) designed to study the consequences that a wide range of possible energy policies could have on the Norwegian economy. The GTM model is based on the system dynamics theory (Forrester, 1993; Sterman 2002, 2010). It draws on the global system dynamics Earth3 model (Randers et al., 2019) but tailored to the case of Norway. GTM calculates the annual impacts for each year to 2070 of various sets of national policy alternatives implemented from the mid- 2020s and onwards. Policy options must be translated by the model user into future offshore investment patterns as the sum of state and private funding, and the model will – like a "what-if"-calculator – assess the long-term consequences. See Figure 5 for overview of model boundaries and main submodules (and Appendix 1 for details).

**Figure 5. High-level conceptual depiction of the GTM model, the main submodules (endogenous outputs in solid rectangles) and its outer boundaries. [a]) main input levers (exogenous, dotted grey rectangles), [b]) inputs generated from historic trends (exogenous, dotted rectangles), [c]) outside of model. "GDPpp" = GDP per person. "ETS" = EU Emission Trading System.**



We simulate the three main scenarios in the GTM model by varying the investments in order to estimate time series for the following key output variables for each year to 2070:

a) the offshore oil and gas sector: capacity, petroleum reserves, production, export, employment, profits and petroleum offshore GDP
b) the offshore renewable and green energy sector: capacity, production, export, maintenance, employment, profits, and green offshore GDP.
c) the mainland economy (simplified as one sector): mainland GDP per person (GDPpp), employment, consumption, Norway GDP, energy use, total emissions.
d) the balance of the oil fund and its cash flows: real returns on investements, exchange rates and net government cash flow from offshore activities, the structural non-oil fiscal deficit.

GTM mainly investigates the impacts on the Norwegian two offshore energy sectors and mainland macroeconomic variables. It is not an economic equilibrium model. We assume the industry actors will continue with the same (type of limited rationality) economic behaviors that are revealed by the historical trend dynamics. Many variables are determined from exogenous drivers, where the historical path is known from the data sources described in section 3.3. The model conducts a partial analysis of the consequences of various exogenously determined investments on the two offshore energy sectors. GTM tracks developments dynamically over time and projects the annual values for key variables. Furthermore, it calculates plausible impacts on mainland Norway's macroeconomic development over the 50-year period from 2020 to 2070 based on historical trend dynamics from 1980 to 2020. GTM can complement macroeconomic models in use (in Norway the models applied by the Ministry of Finance are called KVARTS and SNOW, as well as the models used to forecast offshore energy production such as FRISBEE, see Aune et al., 2020; Boug & Dyvi, 2008; Rosnes et al., 2019; Saxegaard, 2017).

GTM is programmed in Excel, in order to be transparent and publicly available, runs on any ordinary laptop computer and the simulation from 2020 to 2070 takes only seconds. The GTM model sectors are described further with both diagrams and specifications of most inputs and output variables in appendix 1. The whole Excel model itself is available for download in supplemental material.

Most variables are by default assessed from best-fit extrapolation from historical data time series from 1980-2020. Ideally, the *BAU* baseline scenario could have been a simple extrapolation of historical trends. But with *BAU* we rather mean how the official future is reflected in recent government and key public agency outlook documents, and variables are assessed accordingly. Simply calling it *BAU* does not imply that it is the most likely scenario.

## 3.2 Assessement of variables of the three main scenarios

In making the main policy scenarios we manipulate only *decisive* exogenous inputs to generate the three scenarios, while keeping other variables unchanged. These key inputs are: The mix and size of offshore energy investments and the rate of change in mainland GDPpp (Table 1).

**Table 1. Scenario overview of assumptions for the main exogenous variables. All currencies in constant, 2018-prices**

| ***Scenario Parameter overview*** | | ***Scenarios 2020 – 2070*** | | |
|---|---|---|---|---|
| *Inputs* | *Descr/ unit* | 1) *BAU* | 2) *Harvest* | 3)*Rebuilding* |
| Mainland GDPpp growth rate | percent per yr | *1.3%* | *1.2%* | *1.3%* |
| Petroleum investments | GNOK in 2030 | *103* | *41* | *41* |
| (150 2018-GNOK in 2019) | GNOK in 2040 | *81* | *15* | *15* |
| | GNOK in 2050 | *58* | *9* | *9* |
| Green energy investments | GNOK in 2030 | - | - | *31* |
| (0 in 2019) | GNOK in 2040 | - | - | *35* |
| | GNOK in 2050 | - | - | *38* |
| *Common for all scenarios:* | | | | |
| Population alternative | hi / main / low | main | main | main |
| Oil price | USD/brl | 50 | 50 | 50 |
| Gas price | NOK/$Sm^3$ | 1.75 | 1.75 | 1.75 |
| Export power price (PPA) | average NOK/kWh | 0.5 | 0.5 | 0.5 |
| EU ETS Carbon allowances | EUR/t$CO_2$,growing +2%/yr | 50 | 50 | 50 |
| Norwegian $CO_2$ tax | NOK/t$CO_2$ from 2030 | 2000 | 2000 | 2000 |
| Oil fund return on assets | average annual real return | 3% | 3% | 3% |

GDP per person mainland Norway growth rate 2020-2050 is set to ~1.3 % per year, but 1.2% in *Harvest* to reflect that deeper cuts in offshore investments give somewhat lower stimulus to mainland economy (Aune et al., 2020; Norwegian Ministry of Finance, 2017 Table 6.5). As shown in Table 1, for all the three main scenarios analysed, we keep all the following exogenous assumptions steady from 2020 to 2070:

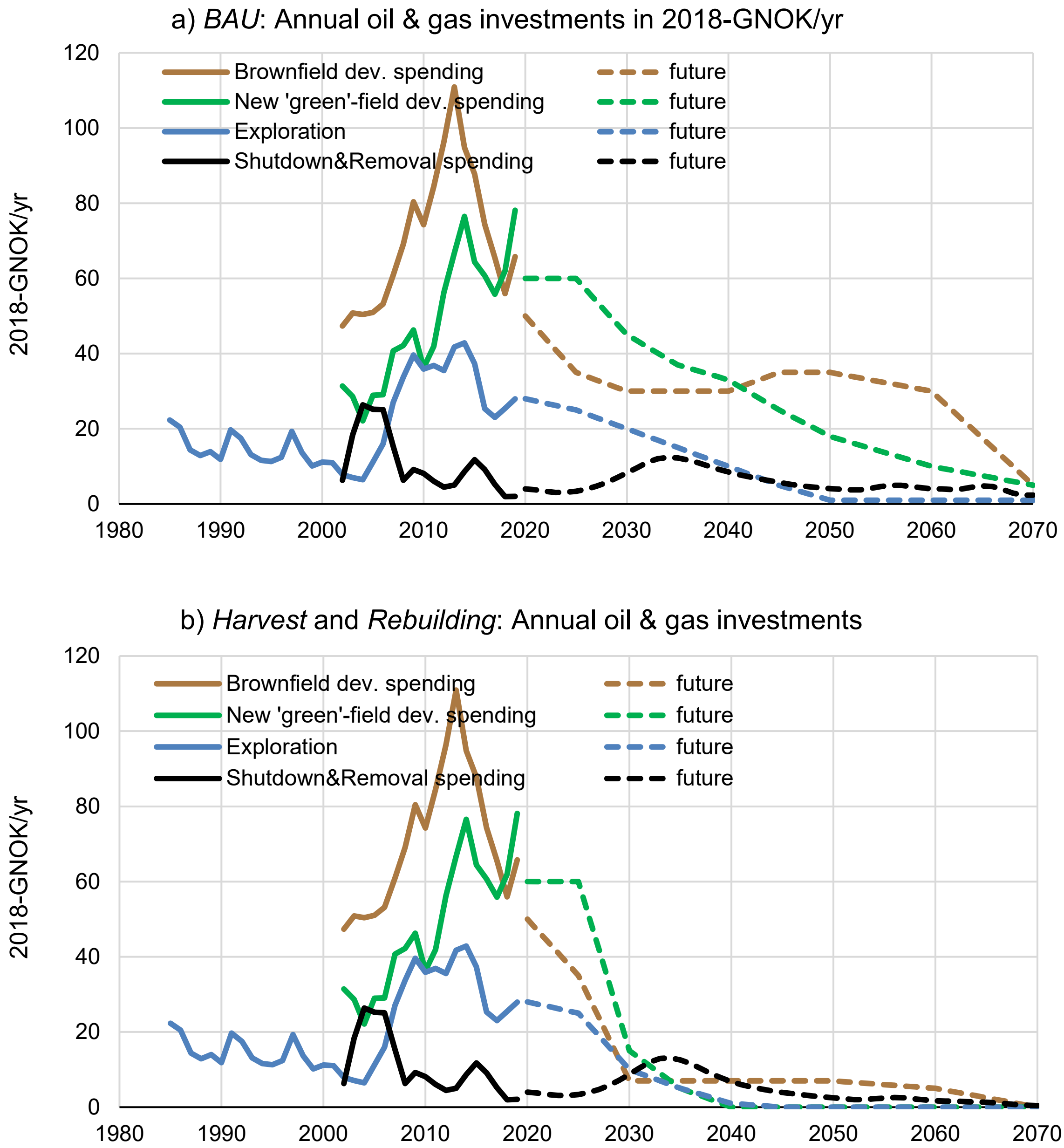
- Population growth follows the “main alternative” (Statistics Norway 2020b)
- Oil price: 50 USD/bbl (similar to Norwegian Ministry of Finance 2021 p. 91, and Aune et al., 2020, p. 74)

- Average gas price: 1.75 NOK/Sm3, equal to 1470 NOK/toe from 2025 (Ministry of Finance, 2021, p. 91, which is equal to 5.5 USD/Mbtu)
- Power price to EU / UK: 0.50 NOK/kWh, (equivalent to 38 2012-GBP/MWh, the average price for UK wind farm Power Purchasing Agreements (PPAs) since 2013).
- Carbon offset price EU ETS allowances at 50 EUR/t$CO_2$ from 2021, growing at 2% per year,
- Norwegian $CO_2$ tax = rising to 2000 NOK/t$CO_2$-eq from 2030, then stable to 2070.
- The oil fund gets 3% annual real returns on the fund's global assets. The Norwegian government draws more than 3% of the oil fund value in the first years after the Covid pandemic but returns to below 3% per year from 2023.
- Currency exchange rates of NOK/ USD = 9, and NOK/EUR = 11.
- Inflation 2% per year (in Norway and among trade partners).
- Rate of change of labour intensity in petroleum production is -1% in employees per Mtoe/yr produced (persons/(Mtoe/yr)), reflecting a steady improvement over historic learning curves from 1980 to 2019, (see the GTM model, tab SC-1 lines 457-486 for graphs showing labour intensities extrapolations)
- Offshore petroleum production emission intensity: Future annual change -0.5 %/yr (in Mt$CO_2$-eq/Mtoe); we consider this to be ambitious enough given that many oilfields are entering tail-production stage.

In modeling the scenarios, we assume that external demand for energy products (from the European and/or global economy) will not be affected by the shifts in Norwegian offshore sector investments across scenarios, however, we perform sensitivity analyses of the energy prices of -/+40% on each scenario in section 5.

For **scenario 1) *BAU***, we exogenously set the profile of petroleum investments based on historic trends since 2000, but modified to match the expected production volumes forecasted by Norwegian Petroleum Directorate (2021), DNV GL (2020a), Statistics Norway (Aune et al 2020) and Norwegian Ministry of Finance (2021). It is mainly the brownfield investments that stay high, but there are also some greenfield investments of assumed new reserves discoveries to be made during the 2030s and 2040s (Figure 6).

**Figure 6. Historic (solid) and future (dotted lines) petroleum investments in scenario 1- BAU (a) broken down into exploration, new green fields, brownfield investment and shutdown. The rapid decline of future O&G investments in scenarios 2) *Harvest* and 3) *Rebuilding* are shown in b). Source historic data: Statistics Norway (2020a)**

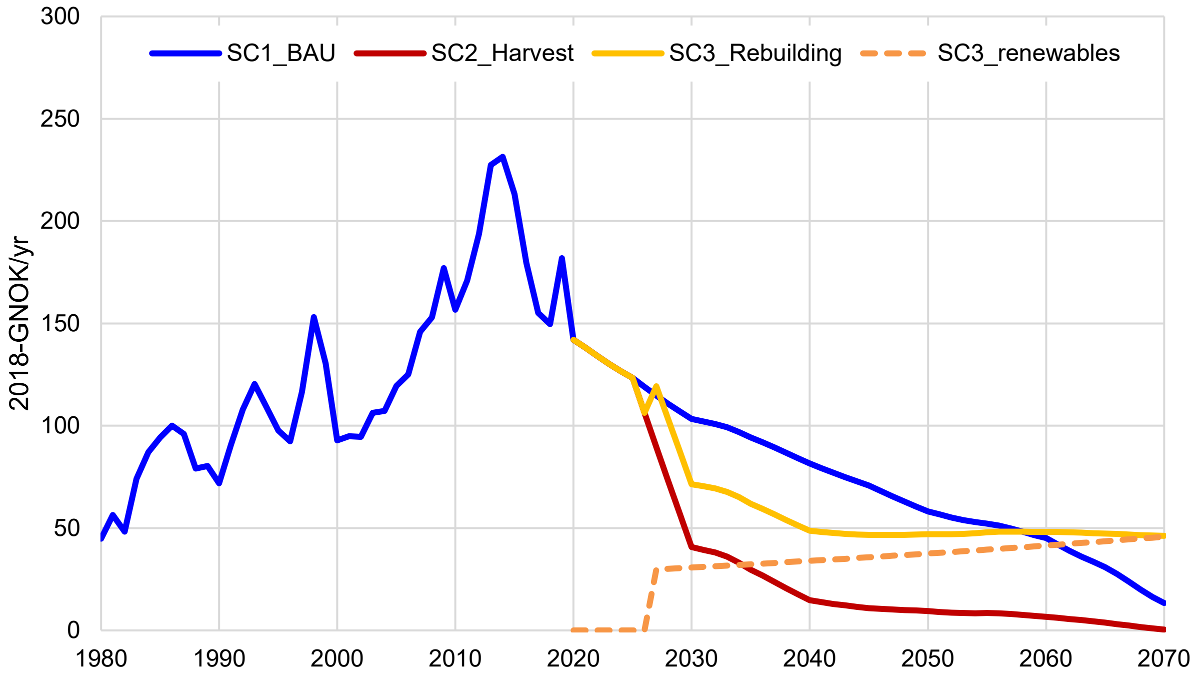



**Scenario 2) *Harvest*** differs from 1) *BAU* in assuming much lower petroleum investments (Figure 6b). Both brownfield and greenfield investments decline rapidly after 2025, while the investments in shutdown and removal are kept. Investments in brown- and green-fields decline at a rate of 14% per year after 2025 to 2040, compared to 3% in *BAU*. This starts out similarly and gives corresponding production volumes to 2050 as in the reduced activity-scenario “Physical-economic alternative”

modelled by Aune et al. (2020). In this way we can validate our GTM model by comparing our results with the results of the macroeconomic KVARTS model and the production estimates from the FRISBEE petroleum model, both used by Aune et al. (2020).

**Scenario 3) *Rebuilding*** is similar to "*Harvest*", but here we introduce a growing volume of investments in green offshore, starting with 30 billion NOKs for 1.5 GW in 2028[2] on top of the same (declining) oil investment trajectories as in *Harvest*. Green offshore investments subsequently increase with +1% per year, while the learning curve reduces costs in billion NOK/GW with 3% per year. This results in the investment patterns for 1980-2070 as shown in Figure 7.

**Figure 7. Historical offshore annual energy investments 1980-2020, and then showing future investment for 2020-2070 in constant billion 2018-NOK for all three scenarios. The investments in green offshore products starts with 30 billion NOK in 2027, and then grows with 1% annually (dotted line). The line for 3) Rebuilding shows the sum of offshore investments (Harvest plus the green energy investments)**




[2] The new Danish offshore windfarm «Thor» with 1 GW capacity has total investment costs of 15.5 GDKK (approx. 22 GNOK/GW in 2021). Thor contracts are signed in 2021, with completion during 2026. According to our interviews with NORWEA (2021, pers.comm) the earliest possible completion of Norwegian large offshore windfarms will be 2028, as licensing, impact assessments, planning and construction phase will take at least 6-7 years.

In the *Rebuilding* scenario, the government uses public procurement and auctions for new emissions-free outputs (for green products made by the offshore sector).[3] As investment increases with 1% and the learning curve gives 3% reduction of costs in billion NOK/GW, the green offshore sector installs +4% more new capacity every year to 2070. We assume that 50% of all investments in green offshore are imported components and services, and that 50% of capital expenses go to Norwegian suppliers, roughly similar to today's split in the petroleum sector (Hungnes & Strøm, 2020).

By 2050, 3.3 GW new capacity is added annually, by investing 38 billion NOK, which takes the cumulative installed capacity to 49 GW. A study by WindEurope (2020) presents scenarios reflecting up to 450 GW of offshore wind capacity by 2050 in areas near Europe, whereof at least 30 GW in Norwegian ocean areas, enabling up to 90% decline of EU fossil gas demand. Based on industry sources and DNV GL (2020), we assume that the capacity utilisation for large offshore wind turbines to be 55%, which means that the 49 GW produces a total of 236 TWh/yr. We further assume that approximately 20% of offshore power is sold to mainland while the export fraction of the offshore power is 80% export, a fraction that is increasing over time. Hence, in 2050, Norwegian mainland sector will use ~50 TWh/yr offshore electricity to power a decarbonised mainland economy, while ~190 TWh/yr are exported. Some power from floating wind turbines is also (in the beginning of the period) used to electrify the offshore petroleum platforms. This improves the annual reduction in offshore emission intensity (Mt$CO_2$-eq/Mtoe) from 0.5 %/yr in *BAU* and *Harvest*, to 2%/yr in *Rebuilding*.

A study by the academic partnership Energiomstilling-VEST concluded that "to install 30 GW one will require only around 1% of Norwegian ocean areas (Norwegian economic zone). Hence it should be possible to find areas where there is a low level of conflict with regards to other industries and ecosystems" (University of Bergen, 2020). In our *Rebuilding* modeling, the sum total installed capacity increases steadily until it finally reaches 140 GW in 2070, which produces around 650 TWh/yr on 3-5% of ocean economic zone areas.

We assume an average price of 0.5 NOK/kWh for power export to EU/UK, a price that remains stable in real terms all the way to 2070. The key reasons why the price stays relatively high and stable

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[3] The Norwegian consultancy Menon (Winje et al 2020) delivered a report which provides an overview over the main types of policy that can enable effective offshore wind investments. Another report from Menon (Winje et al 2019), recommends some strategies that illustrate the scenario *Rebuilding* well: "a) A proactive domestic market that is designed for a full, operative value chain, b) Take a leading role early enough as offshore windmill technology improve its competitiveness, c) a clear vision from government that provides predictable frameworks for Norwegian actors, d) Tailored instruments for maximising cost curves as offshore wind is scaled up and make it possible for Norwegian players to compete in the global market."

despite growing exports, is that the entire EU area will be decarbonizing its economies over the coming decades. Accordingly, one expects an increasing EU ETS price, and hence there will be a growing demand for clean power and derived products (such as green hydrogen, synfuels or ammonia). We therefore assume that a lot of the power is converted into derived products and sold at the average same price. The effect of this is that large volumes of electricity can be stored and sold, stabilizing prices, despite production being very variable over days and seasons.

From the volume of investments in green offshore wind and derived products, we have calculated the number of employees building on the entire value chain analysis of IRENA (IRENA, 2018), from planning and environmental impact analysis to construction and maintenance. For the future employment levels, we have assumed annual improvements in labour intensity (employees / GW) based on IRENA's estimates to 2030 and beyond. Also, we find that the number of new jobs created is roughly the same in offshore wind as in petroleum investments, at 1 employee per 2.5 MNOK invested.

## 3.3 Main historic data sources

For the 1980-2020 period the GTM draws on the extensive databases of Statistics Norway (SSB), Norwegian Petroleum Directorate (NPD), BP Statistical Review (BP) and others converted to a consistent set of units and variables.

Our main sources for the time series are:

- Population from 1980 to 2070, following the main alternative from the projections (Statistics Norway, 2020b).
- Historical production of oil and gas from 1980 to 2020 from Norwegian Petroleum (2021).
- Contingent reserves ($MSm^3oe$) from Norwegian Petroleum Directorate, Resource Report 2019, Discoveries and Fields, including production projections to 2030.
- Oil exports (billion NOK/yr) from Statistics Norway's Table 08800: External trade in goods, main figures (NOK million), by year, trade flow and contents
- Gas production ($GSm^3$/yr) from BP Statistical Review of World Energy June 2020.
- Oil price Brent (USD/brl) and gas prices (USD/MBtu) from BP Statistical Review (BP, 2020)
- Exchange rate (NOK/USD), from currency database fxtop.com (FXTop, 2020)
- Norwegian petroleum investments, split in exploration, investment in new oil-fields ("green-fields"), investments in more capacity in existing fields ("brown-fields"), onshore activities, shutdown and removal spending, are all from Statistics Norway (2020a).

- Oil & Gas employment, both direct and indirect, comes from Statistics Norway Table 04526 and 07458: “Employment and unemployment”, as well as drawing on Hungnes & Strøm (2020).
- Offshore wind employment labour intensities, both direct and indirect, are based on IRENA (2018).
- Petroleum production costs intensities, are based on extrapolations from Norwegian Petroleum Directorates Resource report (2020, Table 2.21)

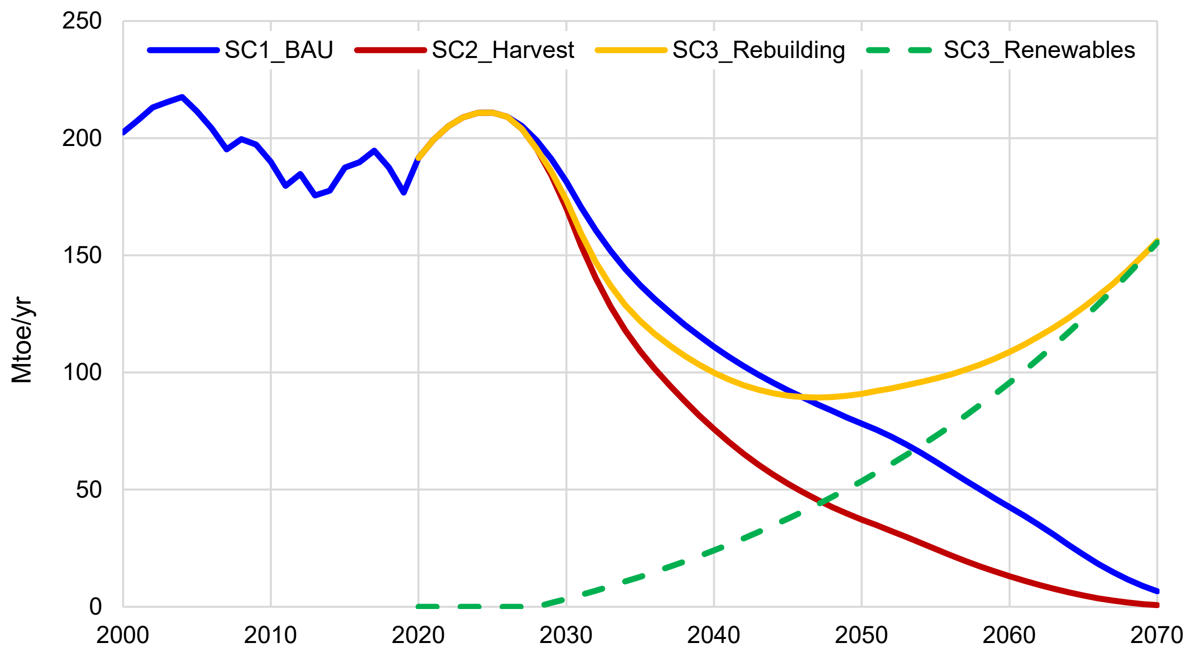
The GTM model contains a number of additional trend datasets in its “history” tab sheet, where each time series is given with source, in supplemental material.

# 4. Results

Based on the above historic data and trends, and the main assumptions outlined in Table 1, we ran the GTM model with the three different energy investment pathways (Figures 6-7), to estimate the long-term effects of each scenario.

## 4.1 Energy production and exports

**Figure 8. Energy production in Mtoe per year for 1) *BAU*, 2) *Harvest* and 3) *Rebuilding*. Historical data to 2020, and scenario results 2020-2070. Scenario 3 *Rebuilding* curve shows petroleum production + power production where 1 Mtoe = 4.4 TWh. Dotted line shows only the renewables production in Scenario 3**

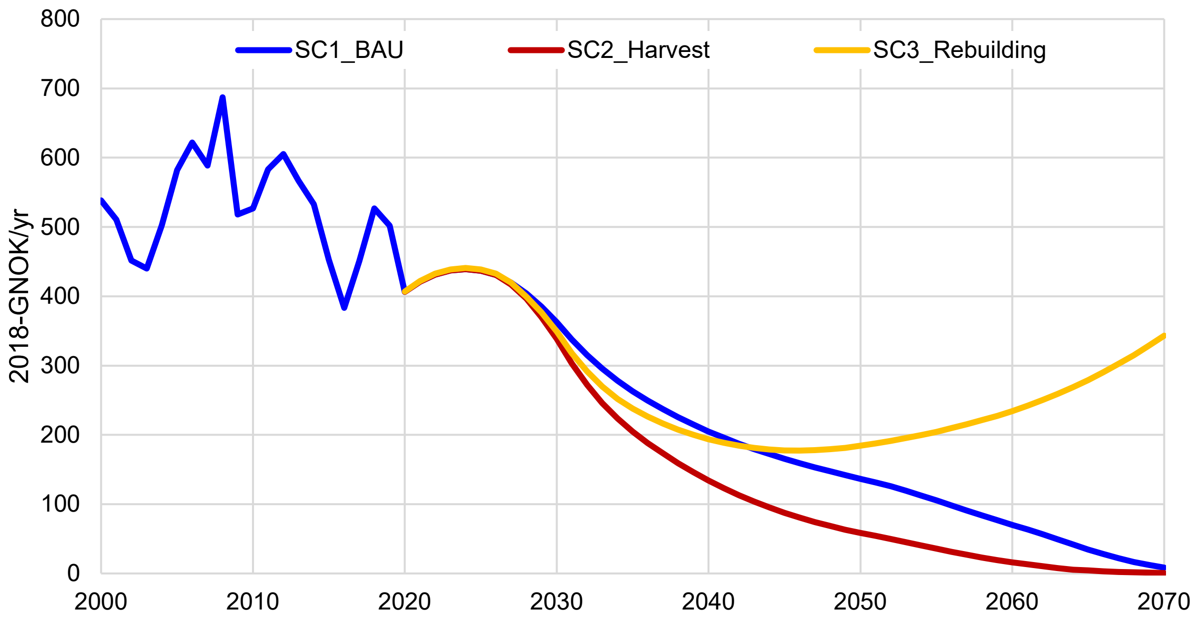


All recent publications from Norwegian public agencies and analysts (Aune, 2020; DNV GL, 2020; Norwegian Petroleum Directorate, 2021; Norwegian Ministry of Finance, 2021) expect a large decline in annual petroleum production from 2020 to 2050 in the -50% to -65% range. When we use the *BAU* investment patterns from the *BAU*-curve in Figure 6a as exogenous inputs and run the GTM, we get a middle-of-the-road decline of 59% in petroleum production from 192 Mtoe in 2020 to 78 Mtoe in 2050, see Figure 8.

In the *Harvest* scenario, to model the effects of stopping licenses from 2025 along with a cut in incentives for new fields, we assume that investments will decline as shown in Figure 6. This results in the much larger production decline of 81% (from 192 in 2020 to 37 Mtoe by 2050) as shown by the SC2_Harvest line in Figure 8.

Scenario 3, *Rebuilding* has higher energy production than *Harvest*, and the difference comes from offshore wind power on top of the same petroleum energy as in *Harvest*. In the chart, we convert TWh to Mtoe according to the conversion factor 4.4 TWh per Mtoe (BP Statistical Review, 2020). The offshore power produced (dotted line) is 15 TWh from 3.1 GW in 2030 and 236 TWh from 49 GW in 2050. The latter is 60% more than the current power production of mainland Norway (~150 TWh/yr in 2020).

**Figure 9. Offshore energy exports in billion NOK per year for 1) BAU, 2) Harvest and 3) Rebuilding. Historical data to 2020, and scenario results 2020-2070. Scenario 1) and 2) have only petroleum exports, while the 3) Rebuilding curve shows the sum of petroleum + power offshore exports**

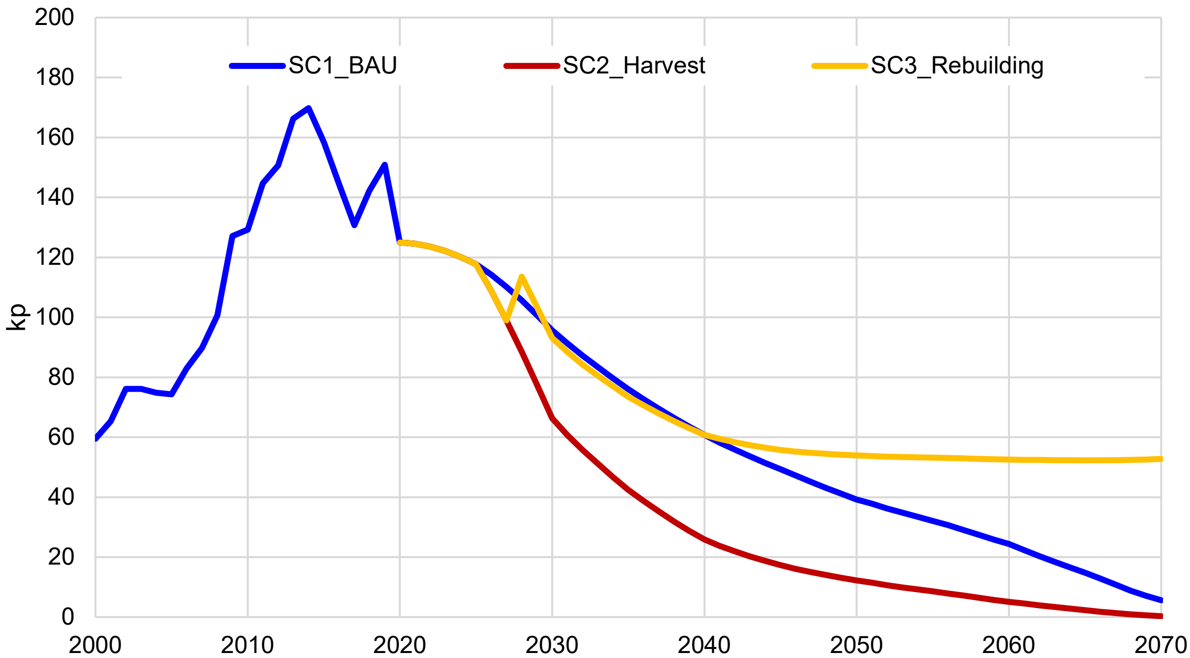


The three above energy production trajectories result in long-term offshore exports as shown in Figure 9: *BAU* gives a slow and steady decline in export revenues. The petroleum exports are roughly halved from an average of 510 billion NOK/yr in the 2010s to average 290 billion NOK/yr in the 2030s.

In *Harvest*, exports decline yet more quickly in the 2025-2040 period. The curve for exports earnings in the *Rebuilding* scenario illustrates that it takes many decades of steadily rebuilding the offshore energy sector with green products before revenues get near to the extraordinary revenue levels from petroleum exports in the 2010s.

## 4.2 Employment and emissions

**Figure 10. Offshore energy sector employment, showing the sum of direct + indirect (onshore supplier) jobs in all scenarios, in kp=1000 persons. The difference between 2) *Harvest* and 3) *Rebuilding* from 2027 to 2070 are the new jobs generated in offshore green products**

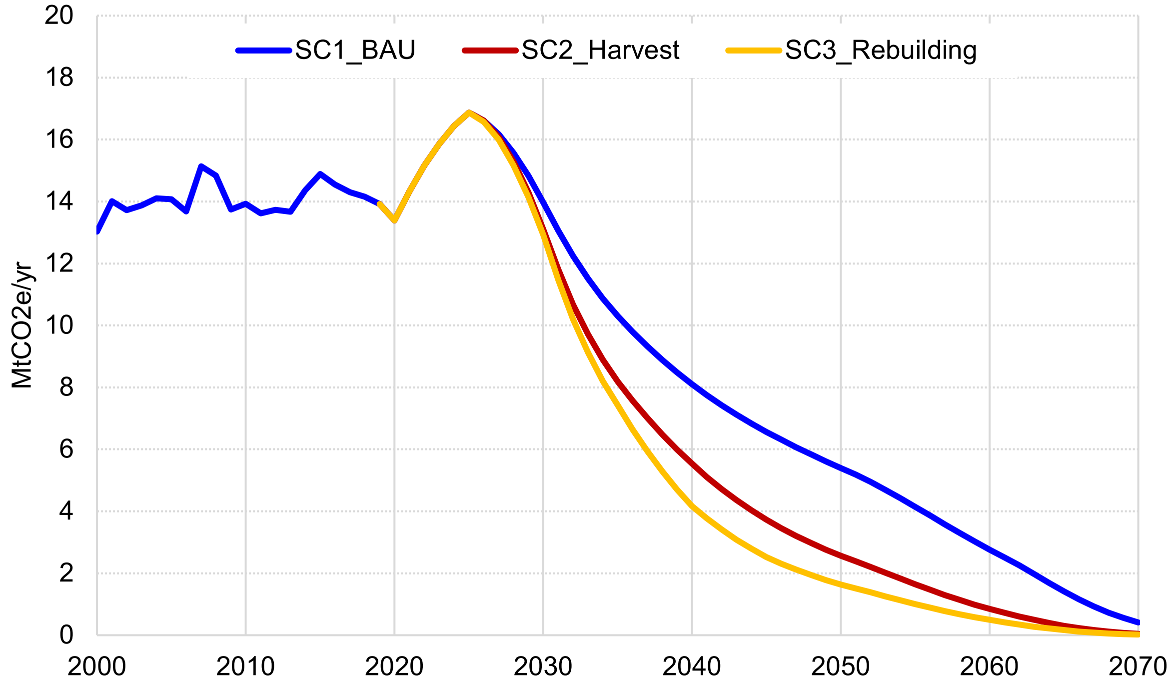



The employment in the Norwegian petroleum sector, both direct and indirect, has already been in steady decline since the peak in 2014 (Brasch et al., 2019; Hungnes et al., 2016; Hungnes & Strøm, 2020). This is to a large extent the result of steadily improving labour intensities due to cost control measures, digitalisation, production technology and learning. In *BAU* it falls further from 151 000 jobs in 2019 to 96 000 jobs in 2030 and to 39 000 in 2050 (Figure 10). This is an annual decline rate of 4% in the 2019-2030 period. This rate means that the sector is shedding around 5000 employees per year in direct and indirect petroleum related jobs. In the GTM model it is assumed that the mainland sector absorbs this annual transfer of workers (representing 0.16% of total workforce) without significant impacts on key macroeconomic trends that exceed those already seen in historic trends. The largest share of these indirect jobs is in private services subcontracting to the petroleum companies with little or no highly specialised petroleum competence and some are foreign workers. Offshore employment was in total 6% of all Norwegian jobs in 2019, projected to be 3% in 2030 and only 1% in 2050. This decline happens despite business-as-usual policies, where strong tax-incentives for investments are kept up and ample new exploration areas are licenced.

In *Harvest* the decline in petroleum employment is even more rapid, sinking to 66 000 jobs in 2030, an annual decline rate of 7% (~8000 jobs/yr) during the 2019-2030 period.

In *Rebuilding*, however, while there is the same rate of decline in petroleum employment as in *Harvest*, there is a significant growth of new jobs in production of offshore wind and other green products. The size of this new employment, in both direct (windfarm construction, operations and maintenance) and indirect jobs (in suppliers of engineering services and products including wind power foundations, blades, towers, ships, cranes, chains, electrolysers), will to a large degree depend on how early, ambitiously and predictably the Norwegian government moves ahead with auctions at competitive conditions and incentives. In *Rebuilding*, we assume that a significant activity in Norwegian offshore supply industry and construction can be achieved, at sufficient scale and innovative capacity to keep up both jobs growth and an international competitiveness. Given the level of investments in the *Rebuilding* scenario, there will be no extra loss of jobs relative to BAU during the 2030s, and by 2050 there will be more employees in the wind and green offshore sector than the number of petroleum employees in a BAU-scenario, despite rapid automation (3% annual labour productivity increase) in the offshore wind industry. Beyond 2050, these jobs on the Norwegian continental shelf may continue growing into the second half of the century, exporting green energy products to a low-carbon EU and other countries around the North Sea.

**Figure 11. Historic $CO_2$-eq emissions from 2000 to 2019 and future projections. The BAU decline from 2020 to 2050 is -65%, while the decline in *Harvest* is -83% to 2.6 $MtCO_2$-eq, and -86% in *Rebuilding* to 1.8 $MtCO_2$-eq.**



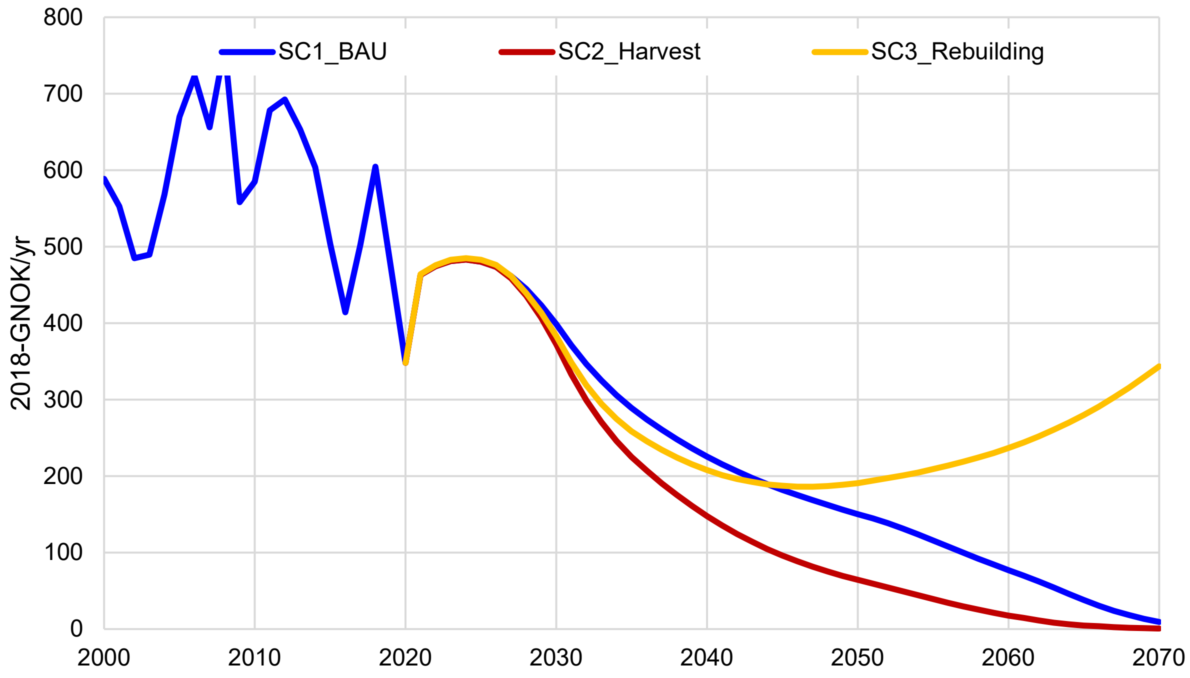

From 2000 to 2019 the offshore sectors' carbon emissions intensity ($tCO_2$-eq/toe produced) was worsening, at a rate of +1.1% per year. Due to already ongoing energy-efficiency and electrification initiatives for some offshore fields (such as Sverdrup, Gjøa, Tampen), we assume that the carbon emissions intensity will start improving also in BAU in the 2020s. We estimate this shift to be from +1.1% per year in the previous decades to -0.5% per year in the coming decades. But as these electrification initiatives are implemented with power from the mainland, it is assumed thar further large-scale electrification is halted due to extensive public opposition to increases in costs and power price hikes this extra demand on power from the mainland incurs on Norwegian households. This stalls any quicker improvement in carbon intensity than -0.5% per year.

The *Harvest*-and-exit scenario leads to rapidly falling offshore carbon emissions. Hence, to halt new exploration licenses and to remove subsidies for exploration and construction from 2025, is - as this scenario shows - an effective supply-side policy tool for reducing Norway's domestic emissions.

The *Rebuilding* scenario is equal to *Harvest* with regard to petroleum investments. But this scenario includes early build-out of offshore wind-power. Some of these wind turbines will be close to offshore petroleum platforms, which make partly or full electrification of these possible. The effect of increased offshore wind to electrify the platforms is a more rapid decline in carbon intensity offshore in *Rebuilding* (-2 %/yr) than in *BAU* and *Harvest* (-0.5%/yr). The resulting emissions fall to 1.8 $MtCO_2$-eq by 2050 in *Rebuilding*, compared to 2.6 $MtCO_2$-eq in *Harvest*, see Figure 11

## 4.3 Economic outcomes: Offshore GDP, Norway GDP and oil fund value

**Figure 12. Offshore sector GDP, showing historic numbers 2000-2020, and the three main scenarios to 2070**

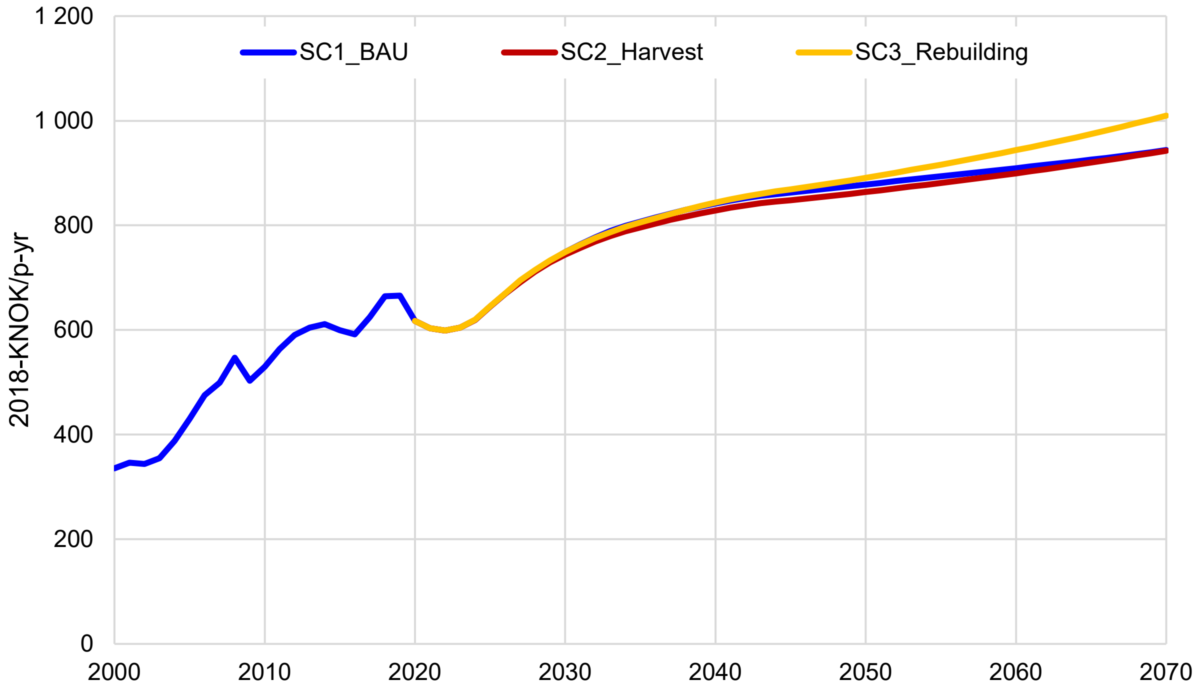



Due to declining petroleum reserves, production and exports, the *BAU* scenario shows a gradual decrease in offshore GDP . The decline from an expected peak in 2025 (due to the Sverdrup "camel hump") to 2050 is 66%, an average rate of -4% per year. This is similar to Aune et al. (2020), where offshore GDP is 3% of mainland GDP in the baseline scenario to 2050.

In scenario 2) *Harvest,* offshore GDP falls even quicker, an average rate of -7% per year. In 2050, offshore GDP is only 1% of mainland GDP.

The curve for 3) *Rebuilding* shows how the output from renewables starts to dominate over petroleum production during the 2040s, even surpassing the *BAU* before 2050. Beyond 2050, it totally dominates offshore output to 2070 (given the exogenously assumed allocation of power demand). As a share of the mainland GDP, offshore GDP sinks from 13% in 2019 to 4% by 2050 in *Rebuilding* compared to 3% of mainland GDP in 2050 in *BAU*.

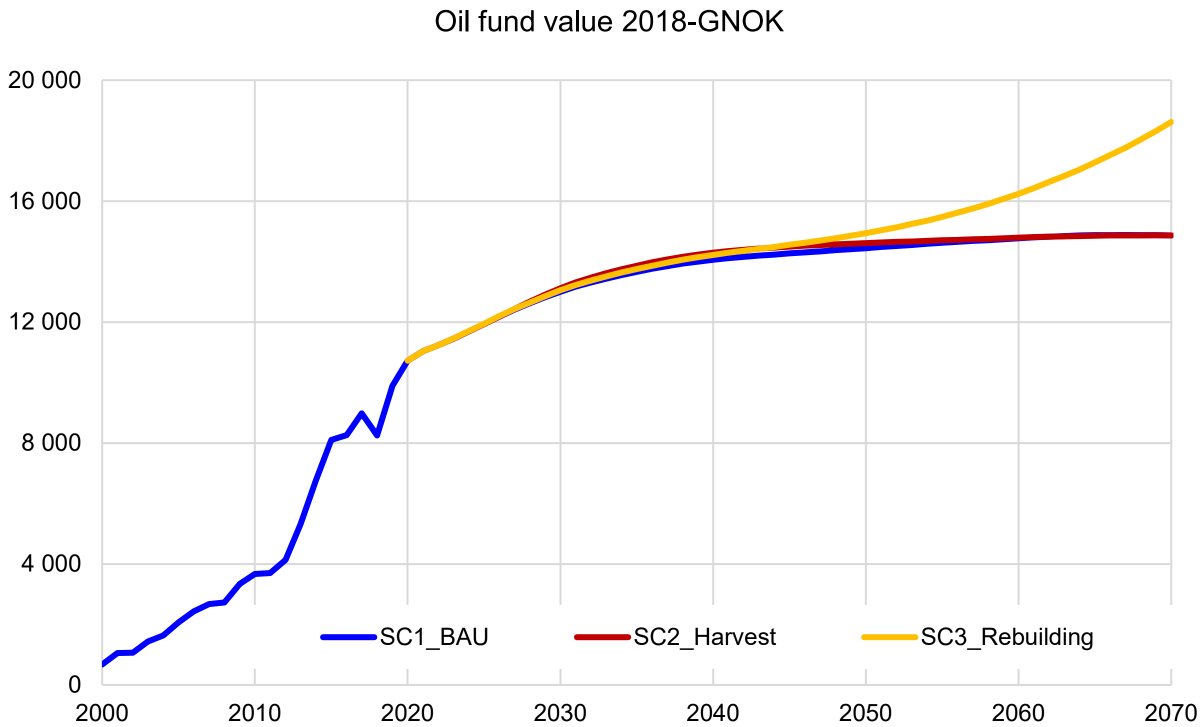
**Figure 13. Norway GDP per person, for all scenarios to 2070**




When comparing the GDP per person for Norway (GDPpp) across scenarios, very small differences appear. *Harvest* is only 1% lower than *BAU* by 2040, something which is close to results in Aune et al. (2020, p. 52). Both results go counter to a widely held notion among Norwegians that the oil sector has huge impact on the Norwegian economy, so that future welfare is dependent upon keeping up high level of licensing, exploration and new petroleum activities.

From Figure 13 it is clear that Norwegians do not suffer loss of welfare as measured by lower mean incomes (GDPpp) by changing offshore energy policy to a *Harvest* or *Rebuilding* strategy. Rather, in this simulation, choosing *Rebuilding* policies makes future GDPpp effectively the same in 2040 and 2050, but becomes even 6% higher than *BAU* in the long run, i.e. by 2070. This is due to offshore green installed capacity (assets) that keeps getting cheaper to install and maintain as total capacity accumulates over the years and continue to generate profits from the renewable and "free" wind resources.

**Figure 14. The value of the Norwegian Government Pension Fund Global, or the "oil fund" for short, in 2018-billion NOK**




By 2020, the Norwegian oil fund was the world's largest sovereign wealth fund, having grown steeply since 2010 (Figure 14) to roughly 350% of mainland GDP. Going forward, the oil fund in the *BAU* scenario represents 340% of mainland GDP in 2030, and 280% in 2050. These results from the GTM are very similar to the baseline results reported by Aune et al. (2020, p. 31) at 300% in 2030 and 250% in 2050 based on the KVARTS model. The main reasons why the projection for the oil fund does *not* continue the strong growth trend as was observed from 2010 to 2020, are due to assumptions regarding both the real rate of return and policy. First, the exogenous assumption, shared by GTM and KVARTS, is that after 2021, the oil fund will achieve no more than 3% annual real return on the fund's global assets. Secondly, it is assumed that the Norwegian government draws more than 3% on the oil fund reserves in the first years after the Covid pandemic. This extra draw lasts to 2023 after which the government is assumed to return to the normal fiscal rule of taking no more than 3% per year from the fund into the state's annual budget.

The *Harvest* policy scenario increases the oil fund value by 2% in 2040 relative to *BAU* (14 300 billion NOK vs 14 000 billion NOK). This is in main due to lower expenses in exploration, construction and operations of new fields than in *BAU*, but also results in much lower additions to new petroleum reserves by 2040. During the 2050s, the oil fund contracts compared with BAU and constitutes 280% of the mainland GDP, a number close to the "The Physical-Economic alternative" in Aune et al. (2020, p. 57), in which the oil fund was calculated to be 230% of mainland GDP in 2050.

In the intermediate run to 2040, the *Rebuilding* scenario does not yield as much as in *Harvest*. As the offshore petroleum tax regime in this scenario is expanded to include offshore wind and other non-fossil energy products, green construction capital expenses are refunded from the offshore taxes making the net cash-flow to the oil fund somewhat smaller (than in *Harvest*). But from mid 2040s and out, the extra exports of green products increase the oil fund by even more than the extra funds collected in *Harvest* and the state's net cash-flow from offshore energy keeps growing as more and cheaper capacity is added.

# 5. Policy discussion: sensitivities and forward-looking model-based indicators

What policies can be conducive to the transition from a petroleum-based exporter to a low-carbon society? Norway is an interesting case for a study of policy responses to energy transition and climate risk, since it is simultaneously and paradoxically seen as a leader in petroleum resource management (Al-Kasim, 2006) and a "front-runner" in international climate policy (Lahn & Rowe, 2015).

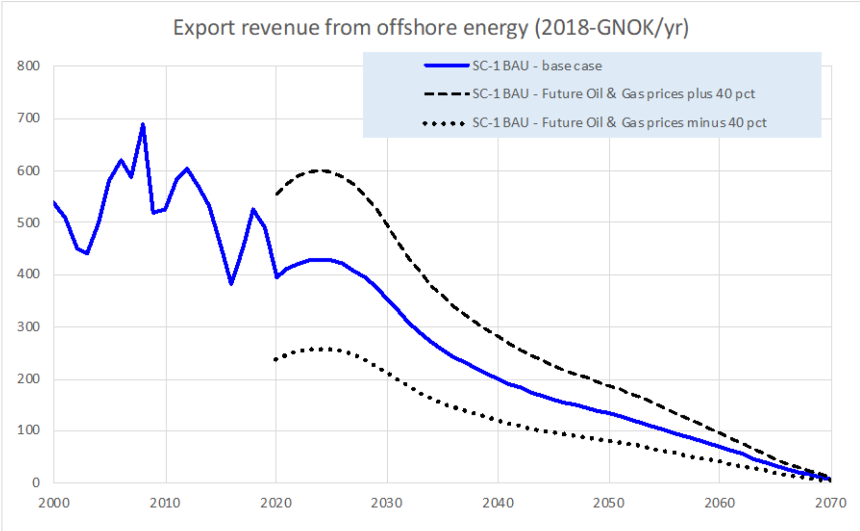
Our main policy finding is that by auctioning offshore wind-capacity that trigger investments of at least 30 billion NOK/yr in new green offshore wind from the late 2020s (*Rebuilding-policy*), increasing by 1% per year, the Norwegian government can stop the additional decline in petroleum sector jobs from cutting new licenses (*Harvest-policy*). This is a small amount compared to the 186 billion NOK/yr invested annually in oil and gas. We also find that Norway's GDPpp declines only insignificantly in *Harvest* relative to *BAU* by 2050, and that GDPpp in *Rebuilding* is higher than in *BAU*. Similarly, the oil fund value is marginally higher in *Harvest* than in *BAU* by 2050, and yet higher in *Rebuilding*.

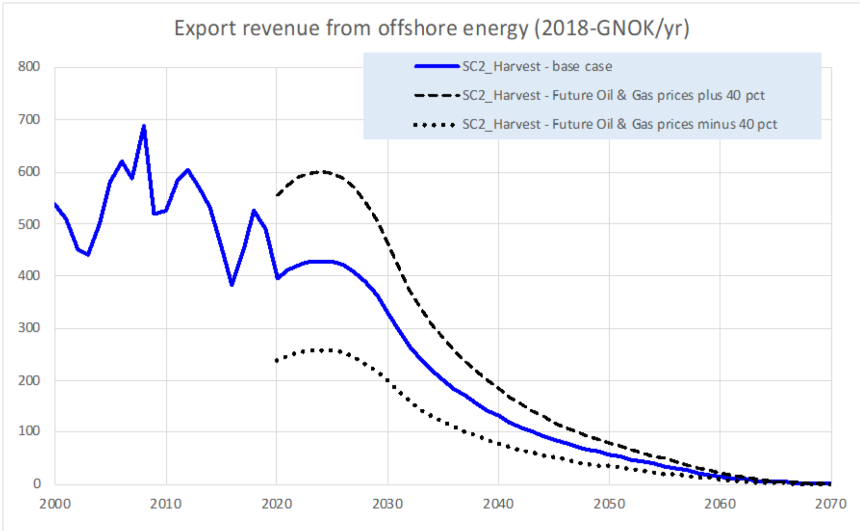
## 5.1 Sensitivity analysis

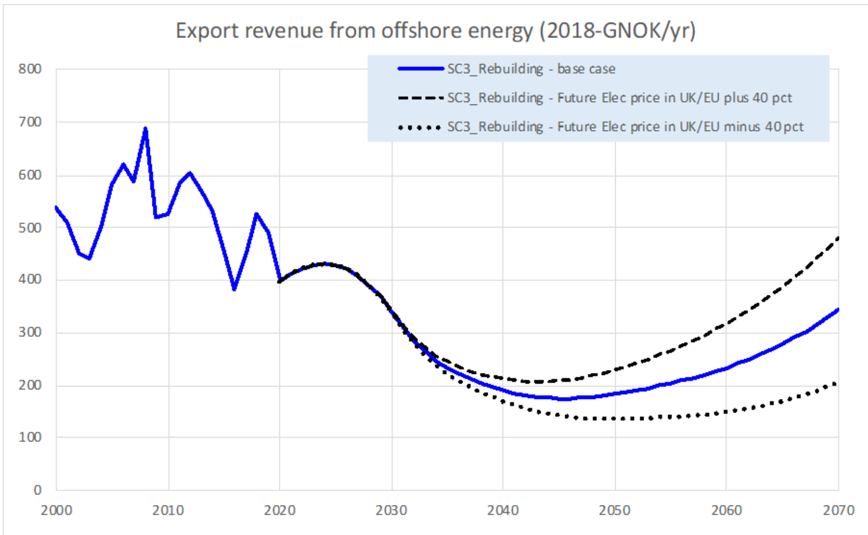
In order to test the robustness of these findings to key global factors, we conducted sensitivity analysis for oil and gas prices, electricity prices and the annual return on the oil fund (Figures 15-17). Specifically, we calculate the impact of oil and gas price increase and decrease with 40% (from 50 $/brl to 70 and 30 $/brl, and from 5.50 $/Mbtu for gas to 7.7 and 3.3 $/Mtbu) on exports and the balance of the oil fund, in the *BAU* and the *Harvest* scenarios. For *Rebuilding* we keep oil and gas prices stable and calculate the impacts from increase and decrease with 40% in electricity prices (from 0.5 NOK/kWh to 0.7 and 0.3 NOK/kWh).

We find that *Harvest*-policies contribute to a higher oil fund balance than *BAU*-policies in both high and low oil and gas price futures to 2040. In the long term, i.e. to 2050 and beyond, the *BAU* and *Harvest* policies are equal in terms of high oil price futures (in both cases the oil fund reaches 20 000 billion NOK in 2050). But in a low-price future, the *Harvest* policies create a somewhat higher balance in the oil fund than *BAU* policies do (9 300 billion NOK relative to 8 700 billion NOK in *BAU*). This shows that the downside financial risk of stranded assets is limited for the Norwegian petroleum sector given that long-term prices do not fall more than 40% in coming decades.

**Figures 15. Sensitivity analysis of +/- 40% in energy prices on exports in billion constant 2018 NOK, for Scenario 1, 2) and 3), where the third is done with +/-40% in electricity prices in Scenario 3, while keeping oil and gas prices unchanged**



**Figures 16. Sensitivity analysis of +/- 40% in oil & gas prices on oil fund value in billion constant NOK for Scenario 1) (top), Scenario 2) (mid) and +/-40% in el-prices in Scenario 3 (bottom)**

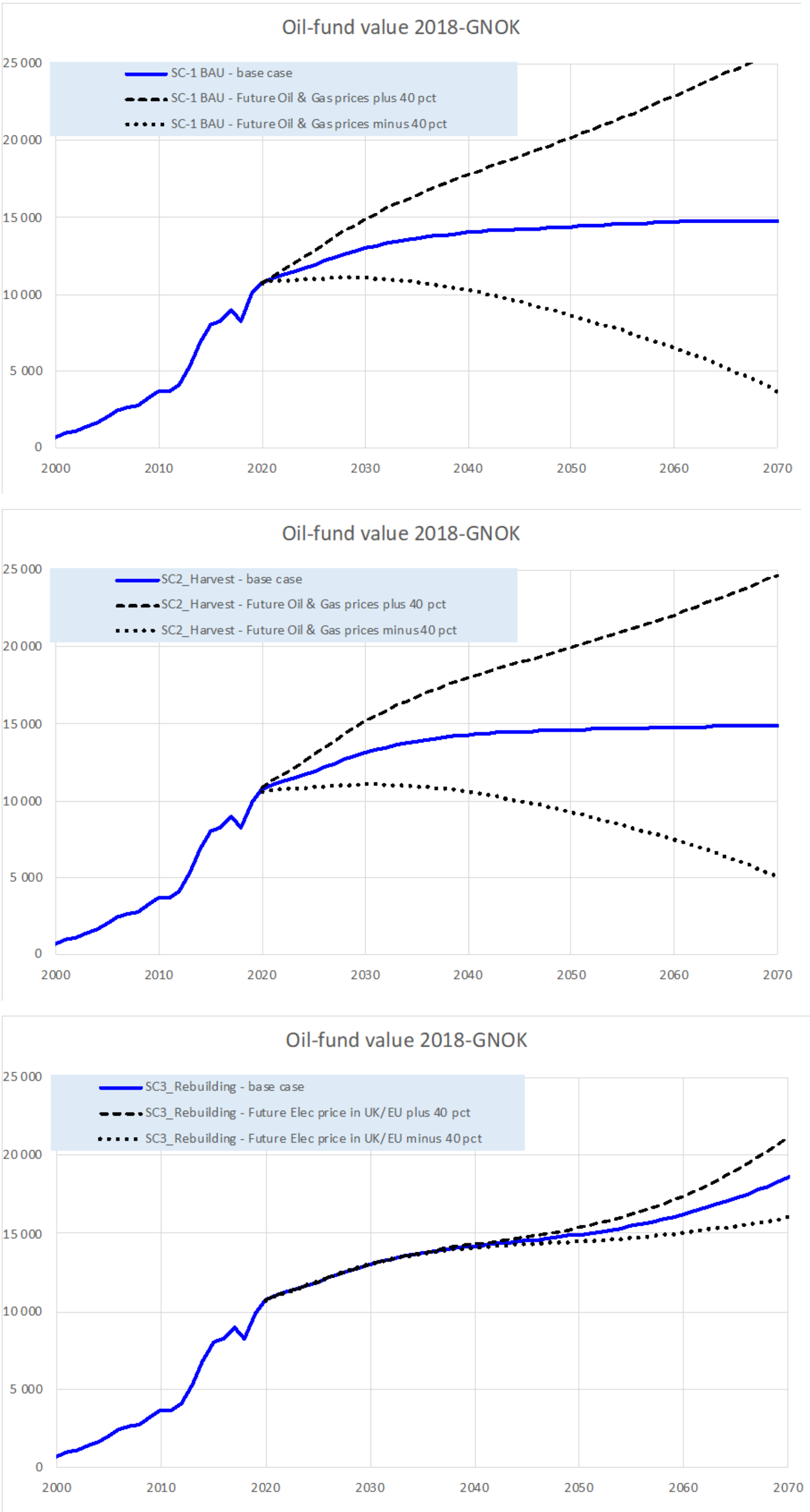
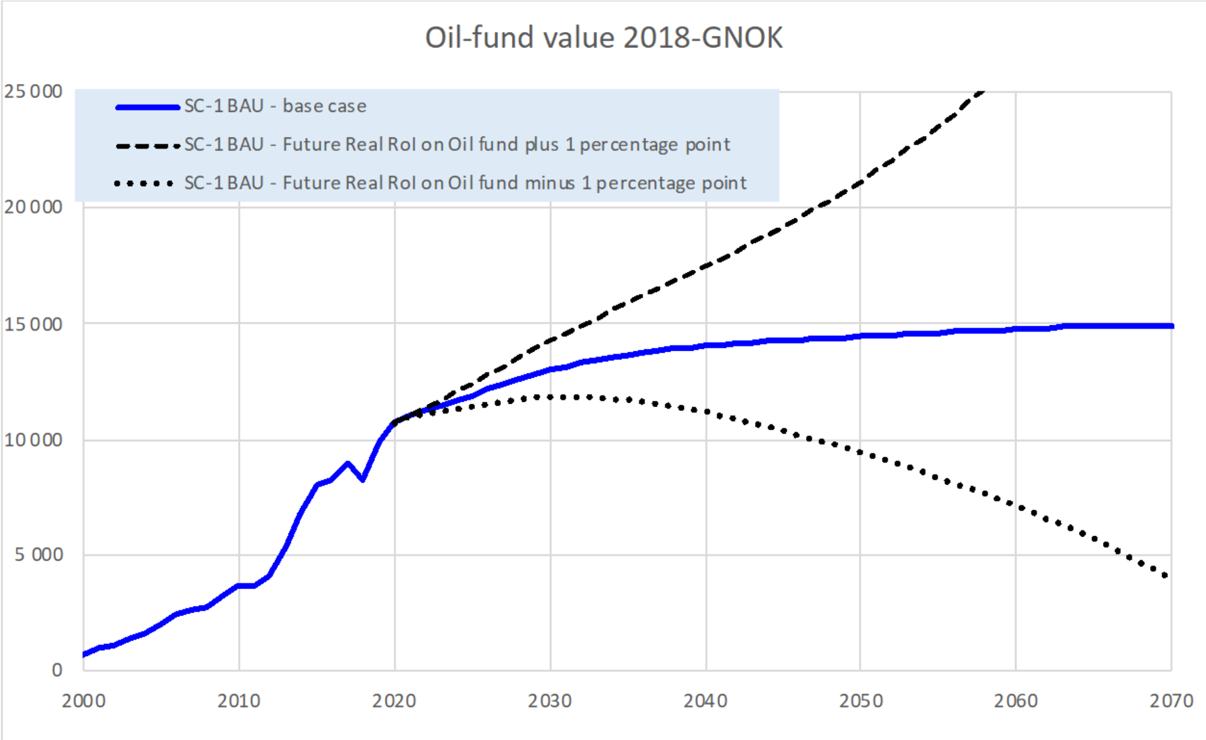


**Figure 17. Sensitivity analysis on Scenario 1: +/- 1% in annual real return on the oil fund.**




The sensitivity analyses in Figures 15-16 show that the general policy options illustrated by *Harvest* and *Rebuilding* appear valid within the broad uncertainty in future energy prices.

The greatest effect on the oil fund balance comes, however, from the real return on the international assets. We ran a sensitivity analysis with +/- 1% per year return on assets (either 4% or 2% annual real return, Figure 17) based on *BAU* policies and stable global energy prices. In the high return condition, the fund reaches 21 000 billion NOK in 2050, while in the low return condition the fund is around 9 400 billion NOK in 2050. This means that the (+/- 33%) variations in real rate of return has a greater impact than the (+/- 40%) variations in energy prices.

## 5.2 Forward-looking indicators for Norway's transition

What transition indicators would be best for monitoring and facilitating adjustments toward the low-carbon society? The model outcomes of investments in the offshore energy sector (Figures 8-14) can be interpreted as a set of forward-looking indicators for monitoring development. Current investments will determine the expected future time paths of the variables of the energy sector and the impacts on the mainland economy. Hence, by plotting actual developments of offshore investments alongside the model-based graphs, one can see the discrepancies between actual and scenario investments and which future outcomes the nation is heading towards. If for instance the current auctions and committed investments in green offshore energy are lower relative to the *Rebuilding* scenario, this would require adjustments of policy instruments in order to ensure the necessary speed of transition toward the low-carbon offshore sector and society as whole.

Indicators for climate transition need to be anchored in the international framework for sustainable development goals (SDGs) now being implemented also in Norway (Norwegian Ministry of Local Government and Modernisation 2021). Sustainability indicators shall, in principle, illustrate trade-offs and synergies between different dimensions of environmental, social and economic sustainability. Experience from previous research suggests that indicators for trade-offs and synergies between divergent societal objectives cannot be gathered directly from statistical data but requires research-based approaches to capture different aspects of sustainability (Garnåsjordet et al., 2012). Thus, it is relevant to develop model-based indicators. The model-based indicator set following from this analysis can be applied to evaluate policy for development of energy production from the Norwegian offshore sector, renewable energy, employment and value added. Hence, trajectories from model-generated scenarios, provide a context for presenting the indicators to enable feedback to policy makers on future impacts of the current decisions being made (see Figure 5).

Another type of indicator for monitoring the transition are the learning curves of floating offshore wind. If this learning curve is not dropping fast enough to be cost-competitive with fixed-bottom offshore wind by 2030, at least -3% per year, further incentives may be needed to align with a future decarbonised offshore sector. Yet another potential indicator is the rate of change in carbon productivity (value added / $tCO_2$-eq per year) of the Norwegian economy as a whole, whether this is high enough to be a fair contribution to the Paris agreement and satisfy the Norwegian Climate Law, in trade-off with other overarching goals, including biodiversity protection. If new trade-offs are taken into account, such as larger concern for marine biodiversity, to ensure that the development is aligned with other SDGs, new priorities and incentives (for instance a nature tax) can be expressed in the scenarios as adjusted investments, leading to a shift in model results and in the model-based indicators, that can contribute to an adjustment of policy.

# 6. Conclusion and policy implications

The global energy transition may usher in an age of stronger climate policies, declining oil demand and low(er) oil prices. If so, oil majors as well as oil producing countries may face a trilemma in choosing between: i) maintaining high investments in the core oil and gas business, ii) preserving short-term dividend payments to shareholders and governments, or iii) investing in the energy transition, given scarce cash flows in a new oil price environment (Goldthau & Westphal, 2019; Pickl, 2021; Van de Graaf & Verbruggen, 2015).

To what extent does this trilemma apply to Norway? In conclusion, our study shows that a *BAU*-policy with high tax incentives for petroleum production may work well economically if oil prices stay at a medium average of 50 $/brl for oil and 5.5 $/Mbtu for gas, or higher, to 2050 and beyond. But following this policy means that domestic climate emissions will remain high (Figure 11), and further – as exports increasingly depend on gas sold to an EU whose green deal strategy will wean its economy off gas – is a progressively riskier assumption.

Choosing a *harvest*-and-exit policy is an economically more robust option in a medium-to-low oil-price world, where EU cuts down on its gas-demand as aimed for in the green deal and if the world delivers on its climate policies. This scenario delivers both a higher oil fund balance in the short and the long term, while in addition increases the likelihood of near-zero domestic emissions by 2050. But this strategy of achieving the objectives for emissions and oil fund balance comes with a trade-off of large jobs-losses that will incur a heavy political burden. It is also a policy that does *not* back up Norwegian green offshore energy industry by providing a stimulating domestic market for innovation and exports of green energy products and technologies.

The *Rebuilding* policy scenario indicates that public auctions securing an investment of 30 billion NOK/yr in the construction of the new green industrial capacity annually from 2027, incentivized through an adjusted oil tax regime, is enough to avoid any extra decline in the offshore employment and competence below a *BAU* trajectory. This policy has the potential to transform Norway into a low-carbon energy-exporting, economically viable society also after 2050.

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# Appendix 1 – GTM model structure overview (28-Mar-2021)

The GTM model structure is quite general and hence suitable for any oil-producing country or region that is considering investing in the energy transition and want to generate what-if-scenarios for their future energy balance, GDP, exports and employment.

The below structure has been assessed for Norway. To apply the GTM on any other region would require at least 20-30 years of historic data on disaggregated investments and outcomes in order to give credibility to any Business-as-usual baseline scenario.

Terminology:

GNOK = giga-NOK = $10^9$ = billion 2018-NOK, i.e. in constant 2018-prices

RoC = rate of change, in percent per year (%/yr).

Mtoe = million tons of oil equivalent = 1.19 MSm$^3$oe, equivalent to 4.4 TWh if converted to power in modern power plants.

OG = Oil & Gas sector

GO = Green Offshore sector

The description below gives a user's guide to the model in the Excel spreadsheet: The numbers in parentheses in left column refer to the line number in the model spreadsheet. The units are given in the right column. To test any input parameter's impacts on outputs, the user can find the relevant scenario tab (1, 2, 3 or 4) search out the "yellow fields" that is relevant in the model (like annual RoC in wages), adjust the value to one's preferred assumption, hit enter, and check the "Comparisons" tab for a summary of the new output compared to other scenarios.

**a) Population** (7) —> RoC in birth-, death, migration rates

**b) Oil & Gas Sector "OG-Offshore"** (60):

*Main Inputs —>*

- -Exploration (60) Investment in "leting & konseptstudier" —> GNOK/yr + RoC Cost per find (GNOK / Mtoe)
- -New 'Green'field dev (126), "utbygging nye felt" —> GNOK/yr + RoC, GNOK/Mtoe
- -Brownfield dev (175) "investering i prod-forlenging" —> GNOK /yr + RoC(GNOK/MToe)
- -Natural decline (224) "nedgang i prod. uten invest." —> RoC pct/yr
- -Stranding (270) "when OPEX/MToe > Revenue/Mtoe" —> yrs "speed of dismantling" + % stranding, shutdown costs
- -OG Production (312) / OPEX operation spend —> MNOKyr + RoC, Opex cost intensity + RoC (learning curve)
- -Shutdown&Removal (355) —> RoC in cost/unit (GNOK/Mtoe), i.e. learning curve
- -Employment Labour intensities (436) —> learning curve RoC in p/(MToe/yr) per activity

| | |
|---|---|
| -Fraction of O&G exports as oil (539) | —> RoC $/brl (618)**+** RoC $/MBtu **+** Fraction exports oil (463) |
| -Operating Costs intensities (557) | —> RoC in MNOK/Mtoe |
| -Wage average per person in O&G (582) | —> RoC NOK/p-yr in average wage |
| -$CO_2$ offset costs and USD/NOK exchange rates (606) | —> RoC EU-ETS $/tCO2; RoC Mt$CO_2$-eq/Mtoe; RoC CO2-Tax |
| -Oil & gas prices (687) | —> RoC Oil price Brent (USD/barrel) |

—> *Main Outputs:*

| | |
|---|---|
| OG total production (328 & 528) | → in Mtoe/yr |
| Total OG Investments, CAPEX (416) | → in GNOK/yr |
| Employment numbers (436) | → in kp/yr |
| Operating expenses OPEX (662) | → in GNOK/yr, [=operations (569) + wages (523) + $CO_2$-costs] |
| Revenues from OG exports (714) | → in GNOK/yr oil (731) + GNOK/yr gas (725) , |
| OG revenues and profits (733) | → in GNOK/yr (Revenue- OPEX - CAPEX) |

————————————————————————

## c) Green Offshore sector "GO-Offshore" (769)

Main Inputs —>

| | |
|---|---|
| -GO Construction spend (777) | —> RoC GNOK/yr; RoC in GNOK/GW, from .learning |
| -Green offshore avg. lifetime (821) | —> Lifetime in yrs |
| -Shutdown&Removal (840) | —> RoC in cost/unit (GNOK/TWh), i.e. learning curve |
| -Production capacity factor (891) | —> pct of full time, i.e. % of 8760 hr/yr |
| -Employment Labour intensities (931) | —> learning curve RoC in p/(MToe/yr) per activity |
| -Maintenance and operations (1057) | —> GNOK/TWh + future RoC |
| -El-price and Export (1134) | —> RoC pct/yr - (ore/kWh) |

—> Outputs:

| | |
|---|---|
| Total GO Investments, CAPEX (908) | → in GNOK/yr |
| Employment numbers total (984) | → in p/yr, (graph at 1010) |
| GO total production (1035) | → in TWh/yr |
| Operating expenses OPEX (1104) | → in GNOK/yr, incl. wages (1086) |
| Revenues (1162) | → in GNOK/yr, |
| Profits (1188) | → in GNOK/yr |

## d) -GDP Norway = Mainland GDP + OG GDP + GO GDP (1248)

Main Inputs —>

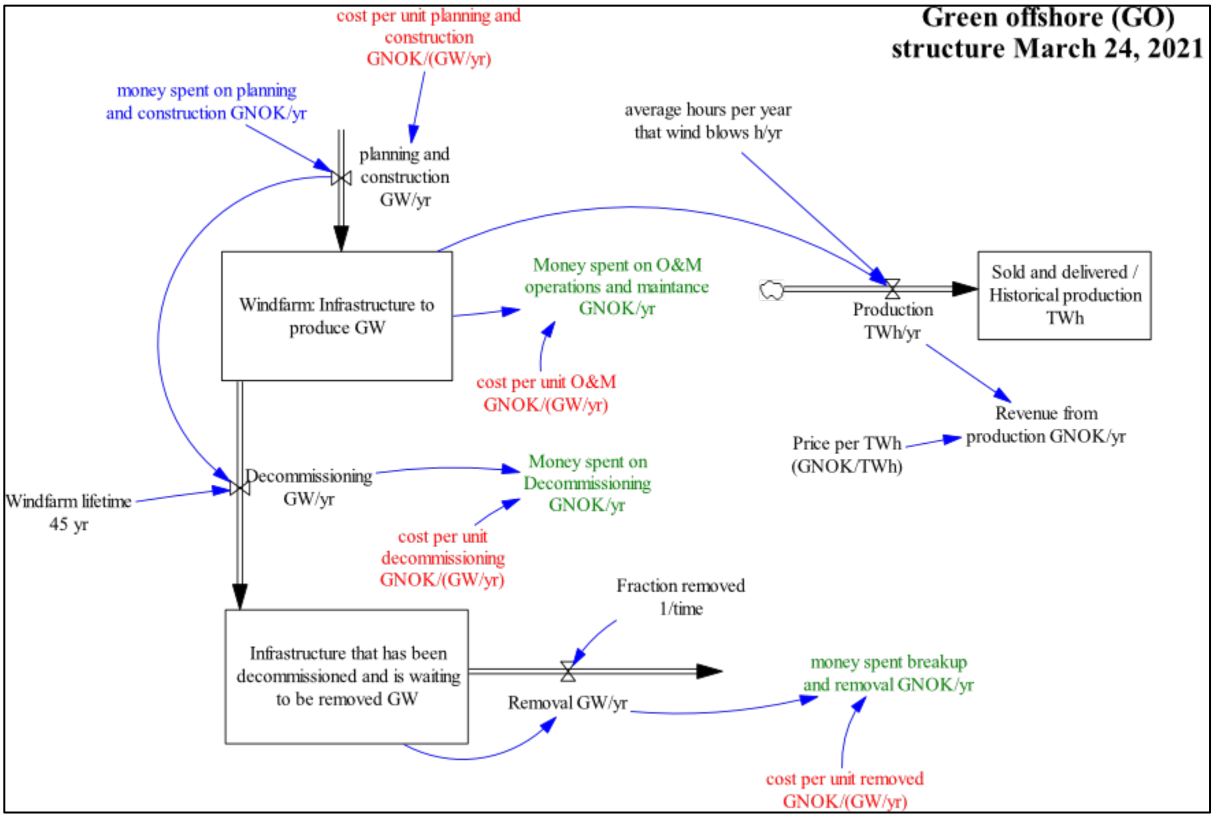
| | |
|---|---|
| -Mainland GDPpp (1241) | —> RoC GNOK/yr + inflation rate |
| -Mainland Employment (1265) | —> RoC Employment intensity mainland (p/2018-MNOK) |
| -Mainland Emissions (1288) | —> RoC Emissions intensity (kg$CO_2$-eq/2018-NOK) |
| -Offshore OG GDP divided by offshore exports (1319) | —> RoC GNOK/GNOK |
| -Offshore GO GDP (1381) | —> pct Import of investments (CAPEX) |
| -Mainland energy use (1479) | —> RoC toe/p-yr ***or*** (1531) by formula: %/yr change in policy, tech and behaviour |
| -Fraction of mainland use renewable (1522) | —> RoC renewable / total |
| -Mainland el price and RE installed capacity (1573) | —> RoC øre/kWh spot el-price + RoC TWh of new renewable installed capacity, |
| -Oil fund and gov. draw on fund (1610) | —> RoC in annual return on portfolio of oil fund (pct/yr in pct/yr) + RoC in NB-underskudd/BNP, RoC exchange rate |

### e) Final Outputs:

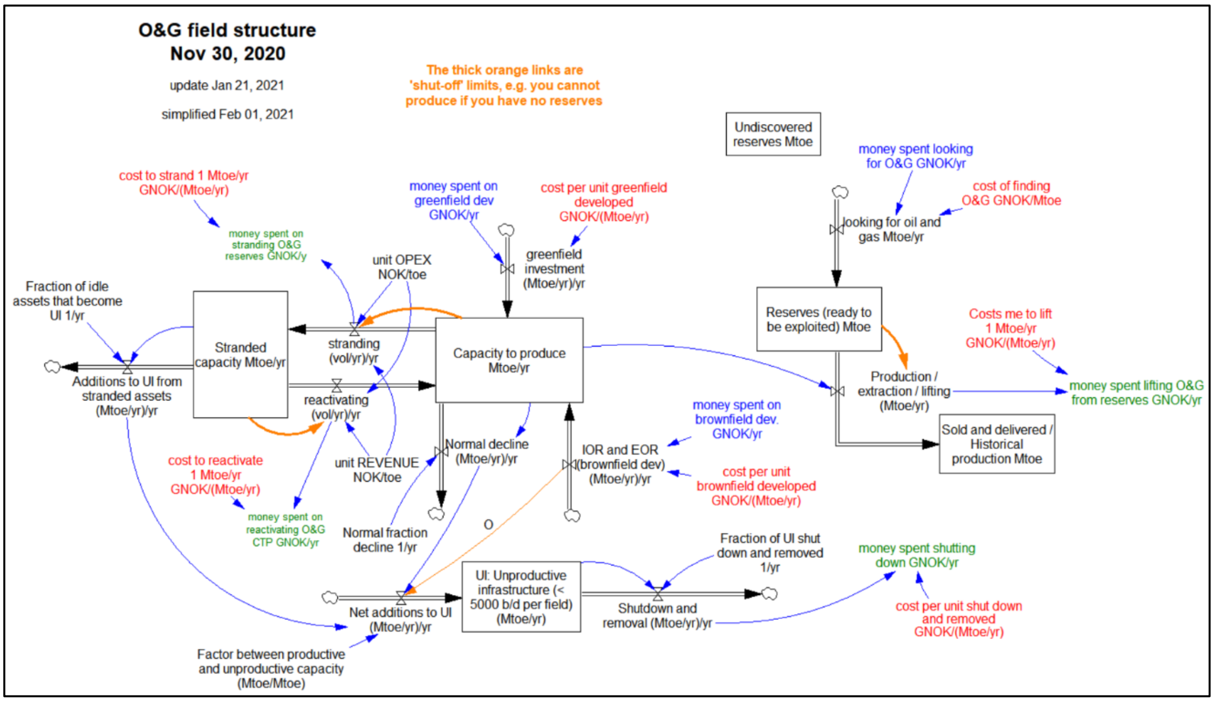
| | |
|---|---|
| -GDP Norway (1400) | → GNOK/yr and NOK/p-yr (graphs at 1509 ff) |
| -OG-offshore GDP (1340) (graph) | → GNOK/yr |
| -OG-offshore emissions (1356) | → MtCO2/yr |
| -GO-offshore GDP (1382) | → GNOK/yr |
| -$CO_2$-eq Emissions (1435) | → Mt$CO_2$-eq/yr |
| -GreenGrowthRate | → RoC of carbon-productivity |
| -total Employment (1456) | → kp |
| -Mainland energy use (1489) | → Energy MToe/yr, power TWh/yr and fossil Mtoe/yr |
| -Value of oil fund (1653) | → GNOK (in 2015-NOK) + net flows GNOK/yr |
| -Net flows to oil fund from OG & GO (1694) | → GNOK/yr |

***Structure of the Green Offshore (GO) Sector submodule in the GTM-model:***

Overview:



***Structure of the Oil & Gas, «OG» Sector submodule in the GTM-model:***




### *Versioning*

The model has been developed in EXCEL® 2019 on a Windows 10 machine. Especially for the dashboard we make extensive use of Macros in VBA and we noticed that, for example, VBA for the Mac on using Microsoft 365 has small differences to the version we used for development. As much as possible, we took care of these idiosyncrasies, but we cannot guarantee that we have fixed all of them. Thus, we encourage anyone to experiment with a copy of the model.

Finally, set recalculation in EXCEL to automatic.