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Plausible futures for the Norwegian offshore energy sector: Business as usual, harvest or rebuild?

Per Espen Stoknes [a], Iulie Aslaksen [b,*], Ulrich Goluke [a], Jorgen Randers [a], Per Arild Garnåsjordet [b]

[a] BI Norwegian Business School, Norway
[b] Statistics Norway, Research Department, Norway

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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 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 rebuilding by investing moderately in green offshore energy production could 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 for energy transitioning in producer countries.

1. Introduction

As part of the Paris Agreement, world leaders have agreed to work on rapid and sustained climate action to reduce greenhouse gas emissions. However, investments in fossil fuel have been growing even as countries aim to reduce fossil fuel consumption. The most recent, and previous, reports form the Intergovernmental Panel on Climate Change (IPCC) have pointed to the reed for reduced investments in the petroleum sector (IPCC, 2022). The call for climate action, and implications for energy policy, is supported by numerous international initiatives, e. g. the IEA's Net-Zero scenario supporting the recommendation that there be no in new investment in oil and gas production (IEA, 2021).

Numerous academic studies and policy reports point to the challenges facing petroleum producer economies and energy transition risk (e. g. Caldecott et al., 2016; Hafner and Tagliapietra, 2020; Goldthau and Westphal, 2019; van der Ploeg and Rezai, 2020). Other offshore provinces, including the UK continental shelf (Department for Business, Energy and Industrial Strategy, 2021) have started deliberations on the compatibility of continued oil and gas licensing with the UK's climate objectives. While Denmark decided in 2020 to cancel future licensing rounds, put an end to all North Sea oil and gas exploration, and to end extraction by 2050 (Danish Ministry of Climate Energy and Utilities, 2020). The challenge of both meeting climate goals and maintain petroleum production is particularly evident in Norway, having established under the Paris Agreement a target of beconing a "low emission society" by 2050.

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. Continued offshore investment has become a contentious issue in Norway. There are several campaigns to stop drilling and leave oil in the ground. In 2020 a legal effort to invalidate licenses for new oil exploration in the Arctic by referring to the country's constitutional right to a clean environment was rejected by Norway's Supreme Court. The court concluded that the government did not legally carry the responsibility for emissions stemming from oil Norway has exported, and that drilling permits in the Arctic were not in breach of

* Corresponding author.
E-mail addresses: per.e.stoknes@bi.no (P.E. Stoknes), iulie.aslaksen@ssb.no (I. Aslaksen), goluke@blue-way.net (U. Goluke), jorgen.randers@bi.no (J. Randers), pag@ssb.no (P.A. Garnåsjordet).

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either the Constitution's right to a clean environment or the European Convention on Human Rights (Supreme Court of Norway, 2020). The case has since been raised to the European Court of Human Rights and now represents legal climate risks to petroleum investments in Arctic waters (ENNHRI, 2022).

The political context for the scenario analysis has recently changed significantly (with COVID, Russia-Ukrainian war 2022). In the context of international energy security and policy, we approach this wider societal and political context of climate action and focus on the macroeconomic impact of different investment strategies offshore. Therefore, in the discussion section, we will also discuss the impacts of a high oil price cycle, a policy push to maximise petroleum production during the 2020s, while at the same time accelerating investment in renewables. Norway is a very particular type of producer economy with a relatively small population, large hydrocarbon wealth combined with a well-developed and stable democracy. In the conclusions we also highlight implications of our study for other producer economies.

In previous decades, one top priority for Norwegian policy makers has been to maximise petroleum revenues and reserves while avoiding the Dutch disease and the resource curse through restraining rapid growth in public spending (Bjørnland et al., 2019; Mehlum et al., 2006; Torvik, 2001). In this process Norway has built the world's largest sovereign wealth fund, the *Government Pension Fund Global,* referred to as the oil fund. The petroleum revenues have, through the oil fund, supported and maintained a welfare state providing well-paying jobs, high levels of human development and life satisfaction to its citizens (Helliwell et al., 2019; Moses, 2021; UNDP, 2019). These concerns have historically ranked higher than climate transition risks among policy makers.

In the 2020s however, drivers such as the declining costs of renewable energy and storage combined with rising climate risks, energy security, the costs of carbon taxes and regulations are ushering in peak oil demand (DNV GL, 2020b; Mirzoev et al., 2020; Randall and Warren, 2020) and the age of electricity (Helm, 2017; Helm and Hepburn, 2019; Ram et al., 2019). The key question for the transition to a more sustainable, low-carbon energy sector in Norway is how the fossil offshore-sector will undergo a major structural change in coming decades. The offshore petroleum sector is the largest CO_2 emitting sector with more than 28% of domestic emissions (Norwegian Environment Agency, 2021). Greenhouse gas emissions from Norwegian exports are 530 $MtCO_2$-eq/yr, more than ten times domestic emissions. Reducing Norway's exports of fossil fuels would also contribute to supply-side climate measures (Asheim et al., 2019; Fæhn et al., 2017). Norway's energy supply system holds the potential to be a valuable and reliable partner in meeting the EU's long-term energy and climate goals, specifically in development of a clean, secure, and efficient energy system (Egging and Tomasgard, 2018).

Urgent issues, for energy policy and domestic macroeeconomic policy, at stake for Norwegian policy makers and voters in the 2020s are: What are the consequences for the economy if the government decides on a decline of the petroleum sector from a peak in the 2020s to near zero in 2050? How can the government seek, in this process, to transfer and employ the relevant competence of the ~150.000 employees currently in the offshore energy sector (Brasch et al., 2019; Hungnes and Strøm, 2020), directly and indirectly including industries delivering to the petroleum sector, into low-carbon products and services?

These policy issues are addressed by our overarching research question: *In a long-term perspective, what are the 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 traditional domestic business-as-usual petroleum policies, by 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. However, the energy transition risk landscape has changed (Bang and Lahn, 2020; Caldecott et al., 2016; Hafner and Tagliapietra, 2020; Van de Graaf, 2018), rendering the business-as-usual approach vulnerable to both financial and international regulatory climate risk in a world potentially succeeding with net-zero ambitions (IEA, 2021). With 'Business-as-usual' we mean that the petroleum sector continues to expand as it has in the past until eventually curtailed by lower oil demand, reserves or prices (Scenario 1, baseline). In the alternative pathways, we ask: Could the financial climate risk be reduced by cancelling new investments in the petroleum sector and thereby maximising short-term cash flow (Scenario 2)? Or combining this latter pathway with increasing investments in green offshore products such as offshore wind, to support the transition to a low-carbon or net-zero economy (Scenario 3)? To provide long-term macroeconomic estimates capturing the energy transition, we have adapted the Earth3 model (Randers et al., 2019) to the Norwegian macroeconomy and expanded it with petroleum and renewable offshore energy sectors, to facilitate its use as a "Green Transition Model" (GTM).

2. Three main policy scenarios for the energy transition

During the last decade an average of 186 billion NOK[1] was invested annually in Norwegian offshore capacity (Fig. 1). This capacity generated large volumes of oil and gas, on average 185 Mtoe/yr. Fig. 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 $MtCO_2$-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 and 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).

As the global transition toward a post peak oil-demand, low-carbon and renewable energy system is accelerating (DNV GL, 2020b; Stoknes and Rockström, 2018; 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 (Fig. 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 (Fig. 4).

Based on historic trends and the current policy situation, we

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

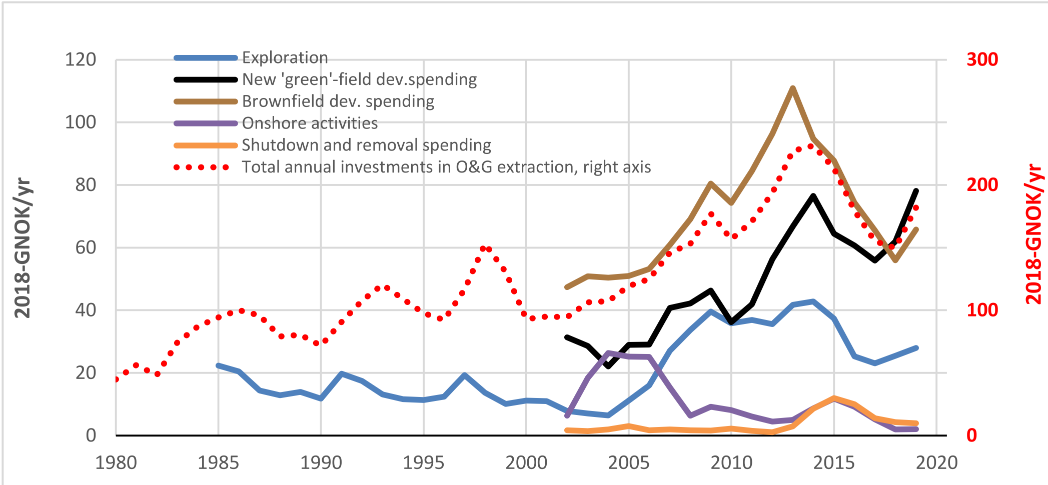
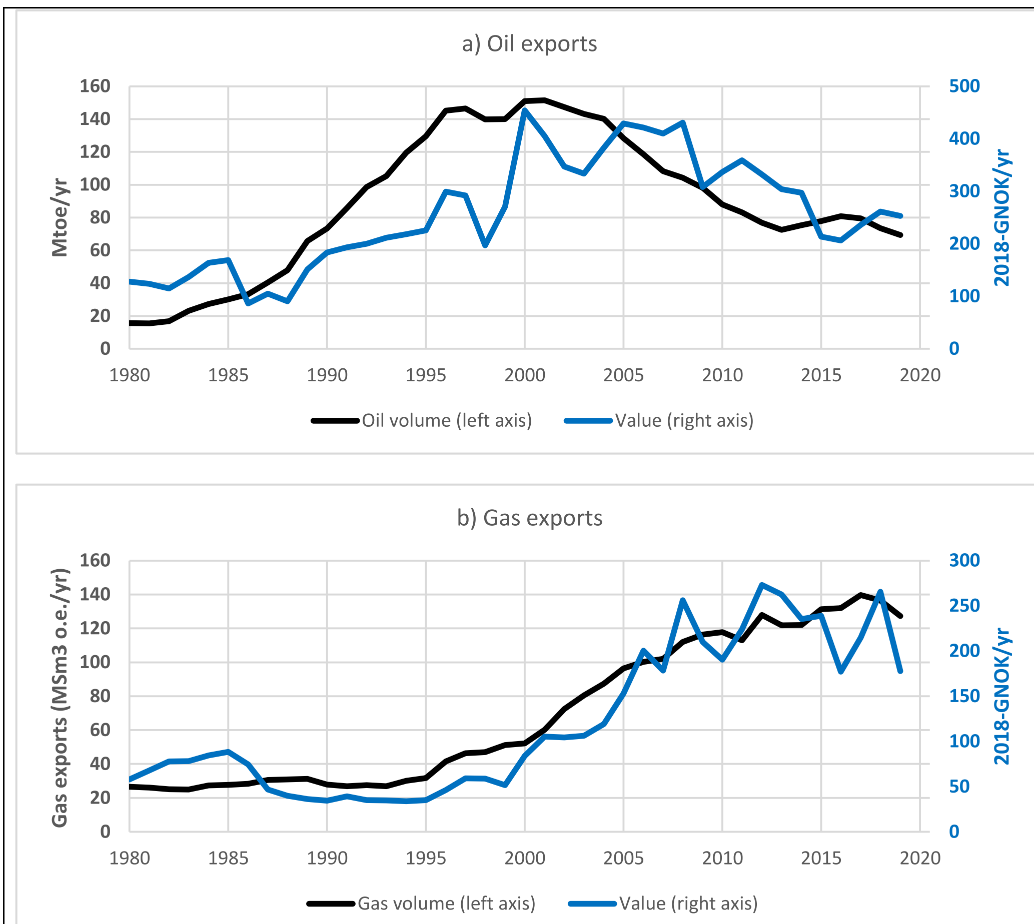


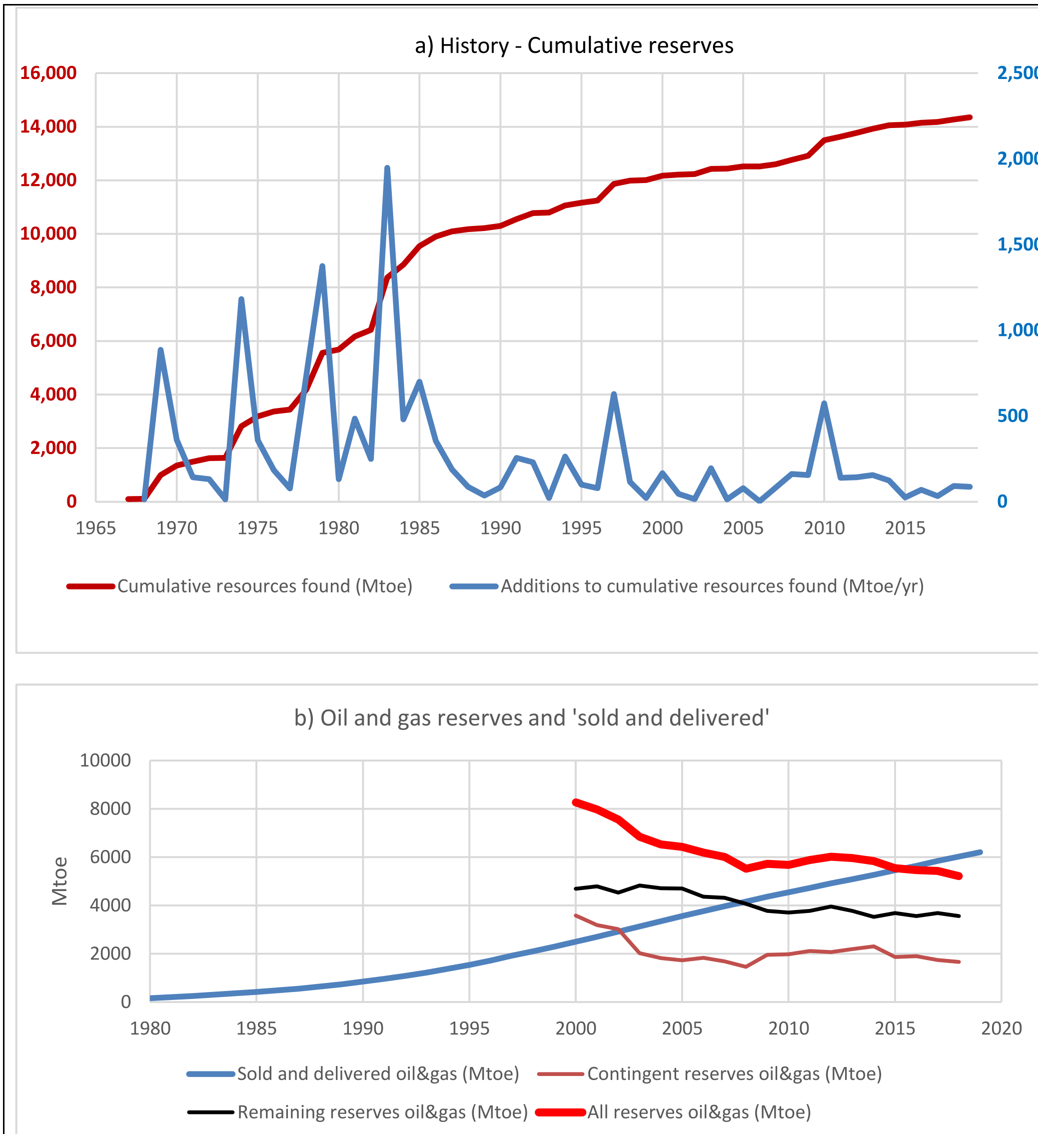
Fig. 1. Annual oil and gas investments in constant prices, 1980–2020 split across exploration, greenfield construction, brownfield developments, onshore activity and shutdown & removal costs. Sum annual investments (dotted line) is shown on the right axis. Data source: Statistics Norway (2020a).



Norwegian a) oil exports in Mtoe/yr (left axis) and b) gas exports in volume MSm³o.e./yr (left axis) and export value (both right axes, billion 2018-NOK/yr). Sources: Statistics Norway (2020a), Table 08800, Norwegian Petroleum (2021).

Fig. 2. Norwegian a) oil exports in Mtoe/yr (left axis) and b) gas exports in volume MSm^{3}o.e./yr (left axis) and export value (both right axes, billion 2018-NOK/yr). Sources: Statistics Norway (2020a), Table 08800, Norwegian Petroleum (2021).

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



Annual additions and cumulative reserves on Norwegian continental shelf (NCS) 1965-2020 in a). 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)

Fig. 3. Annual additions and cumulative reserves on Norwegian continental shelf (NCS) 1965–2020 in a). 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)

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.

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 by 2020. *BAU* means that Norway will stick to its stable, pre-COVID 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 (Fig. 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 (\$ means constant 2018-USD) 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

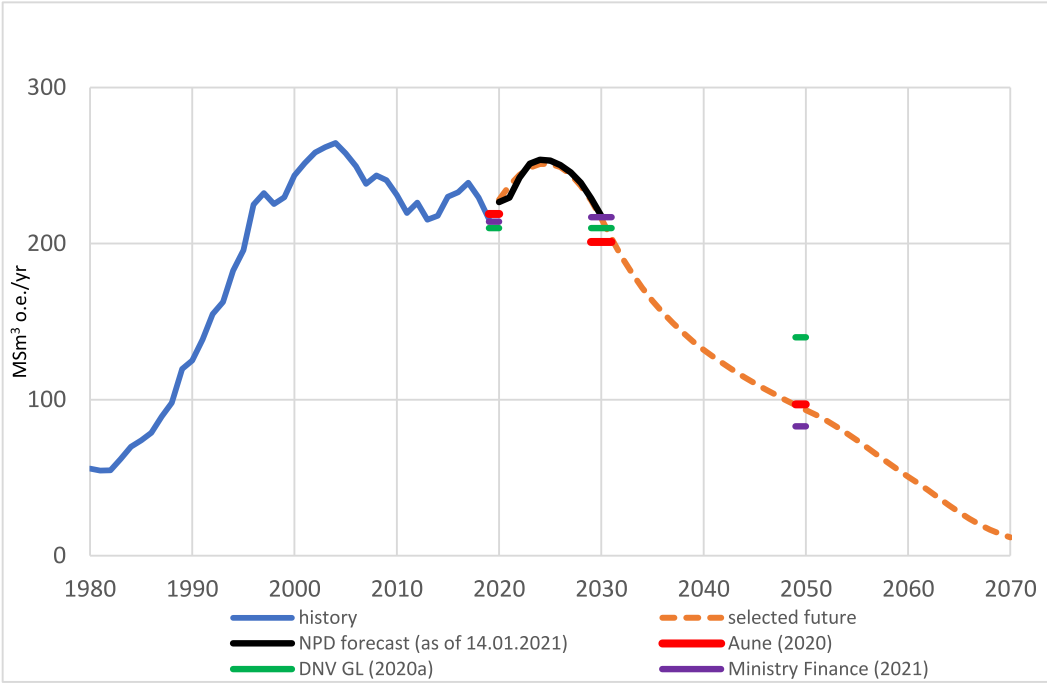


Fig. 4. Historic and expected oil and gas production from NCS with business-as-usual to 2030, 2050 and 2070 in million standard cubic meters of oil equivalents per year. The black line is the official prognosis from Norwegian Petroleum Directorate to 2030. The dotted line is our 1) Business As Usual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

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 and Stoknes, 2018; Leaton, 2013; van der Ploeg and Rezai, 2020). We model this long-term 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 and 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 auctions out suitable offshore wind licenses with tax regulations tailored to ocean wind power, in line with the petroleum tax regime, starting in 2022 to get the first 1.5 GW operational in 2028 (as it takes at least 6 years from auction to operational offshore windfarms).

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 and Neuhoff, 2020; Sartor and 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 profits from harvesting, are assumed to be reinvested into rebuilding the offshore sector with new, sustainable and renewable energy products, mainly for export. We view the public costs of these 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 are 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 long-term 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 – estimate the long-term consequences. See Fig. 5 for overview of model boundaries and main submodules (and Appendix A for details).

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 investments, exchange rates and net government cash flow from offshore activities, the structural non-oil fiscal deficit.

GTM mainly investigates the Norwegian two offshore energy sectors and impacts on mainland macroeconomic variables. It is not a general 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 trends are 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 and 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 A. The whole Excel model itself is available for download in supplemental materials.

Most variables are by default assessed from best-fit extrapolation from historical data time series from 1980 to 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. Assessment 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).

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

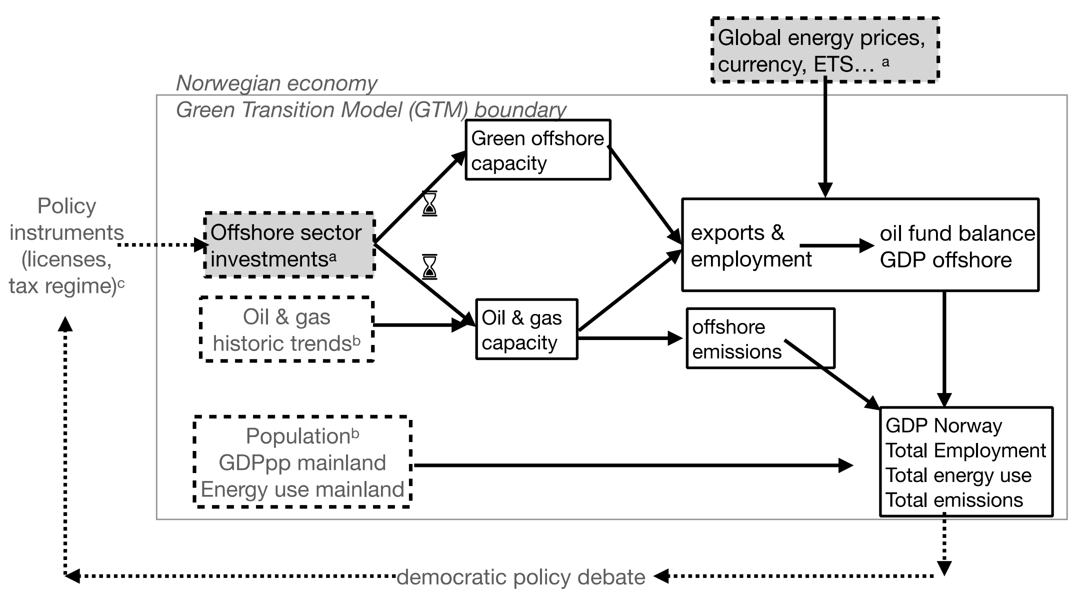


Fig. 5. High-level conceptual depiction of the GTM model, the main submodules (endogenous outputs in solid rectangles) and its outer boundaries. [a]) main input levers (exogenous, dotted grey rectangles), [b]) inputs generated from historic trends (exogenous, dotted white rectangles), [c]) outside of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

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

Table 1. *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:	2020–2070			
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/tCO_2, growing +2%/yr	50	50	50
Norwegian CO_2 tax	NOK/tCO_2 from 2030	2000	2000	2000
Oil fund return on assets	average annual real return	3%	3%	3%

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, 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/tCO_2 from 2021, growing at 2% per year,
- Norwegian CO_2 tax = rising to 2000 NOK/tCO_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 $MtCO_2$-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 key 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 (Fig. 6).

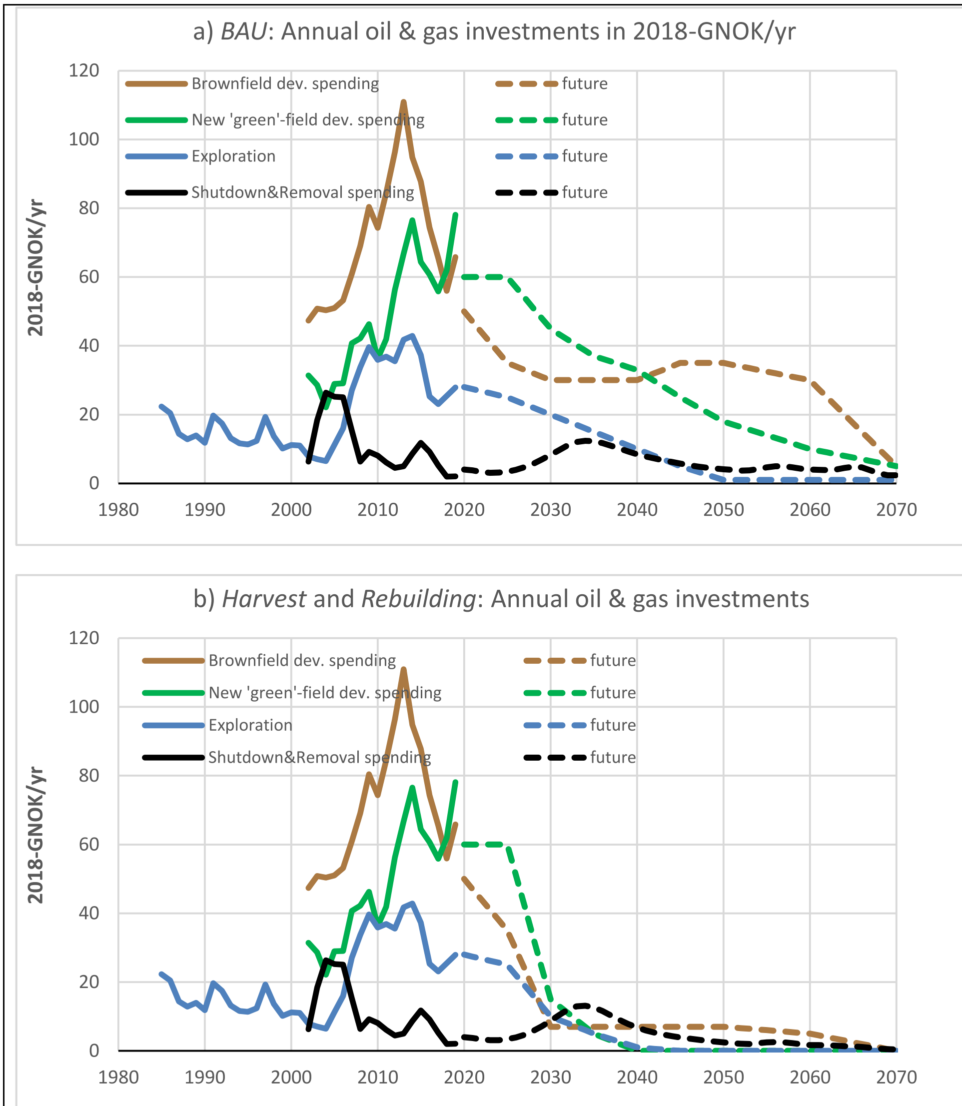
Scenario 2) *Harvest* differs from 1) *BAU* in assuming much lower petroleum investments (Fig. 6b). Both brownfield and greenfield investments decline rapidly after 2025, while the investments in shutdown and removal are kept. Investments in brown- and green-fields decline at a rate of 14% per year after 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 Fig. 7.

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 and Strøm, 2020).

[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.

[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."



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 from 2025 in future O&G investments in scenarios 2) Harvest and 3) Rebuilding are shown in b), dotted lines. Source historic data: Statistics Norway (2020a)

Fig. 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 from 2025 in future O&G investments in scenarios 2) Harvest and 3) Rebuilding are shown in b), dotted lines. Source historic data: Statistics Norway (2020a). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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%, 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 is also (in the beginning of the period) used to electrify the offshore petroleum platforms from floating wind turbines. This improves the annual reduction in offshore emission intensity (MtCO$_2$-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 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

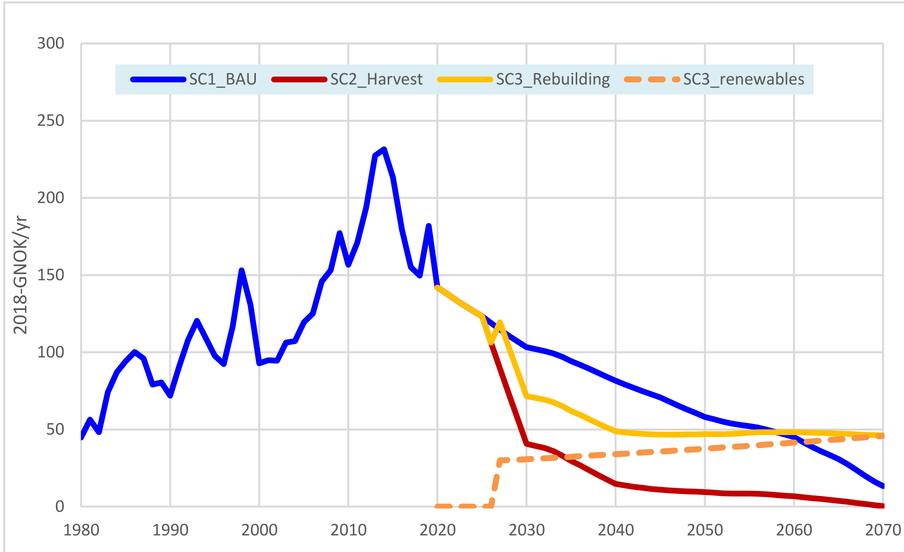


Fig. 7. Historical offshore annual energy investments 1980–2020, and then showing future investment for 2020–2070 in constant billion 2018-NOK for all three scenarios. The investments in green offshore products starts with 30 billion NOK in 2027, and then grows with 1% annually (dotted line). The line for 3) Rebuilding shows the sum of offshore investments (Harvest plus the green energy investments). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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 and 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 (Figs. 6–7), to estimate the long-term effects of each scenario.

4.1. Energy production and exports

All recent publications from Norwegian public agencies and analysts (Aune et al., 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 Fig. 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 Fig. 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 Fig. 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 Fig. 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

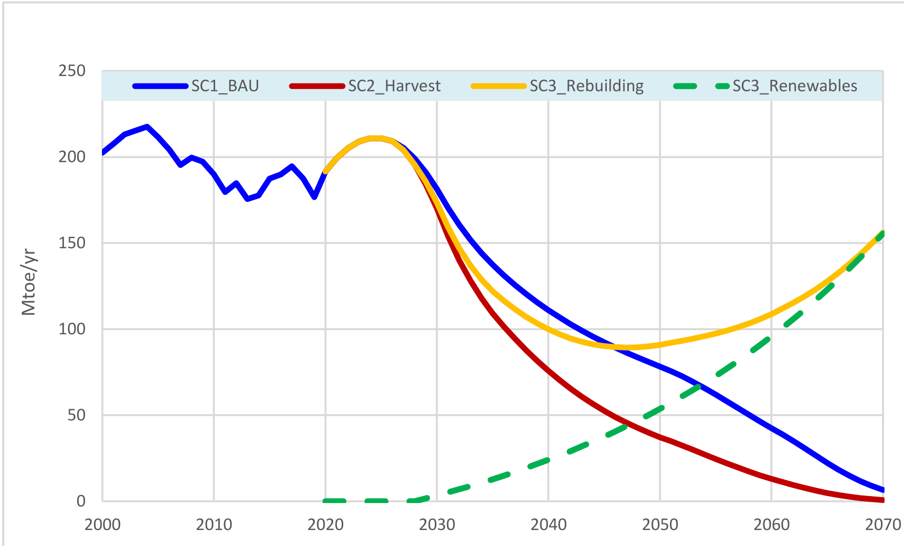


Fig. 8. Energy production in Mtoe per year for 1) BAU, 2) Harvest and 3) Rebuilding. Historical data to 2020, and scenario results 2020–2070. Scenario 3 Rebuilding curve shows petroleum production + power production where 1 Mtoe = 4.4 TWh. Dotted line shows only the renewables production in Scenario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

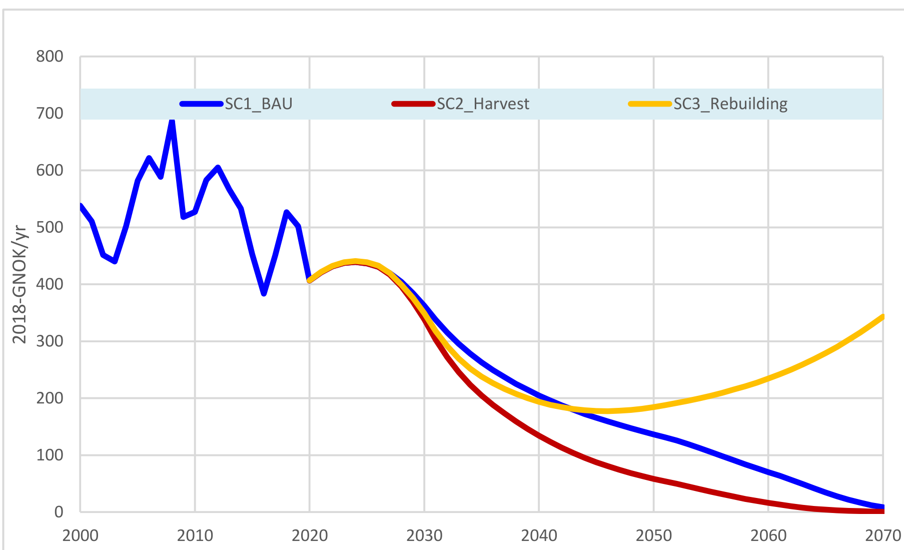


Fig. 9. Offshore energy exports in billion NOK per year for 1) BAU, 2) Harvest and 3) Rebuilding. Historical data to 2020, and scenario results 2020–2070. Scenario 1) and 2) have only petroleum exports, while the 3) Rebuilding curve shows the sum of petroleum + power offshore exports.

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).

The three above energy production trajectories result in long-term offshore exports as shown in Fig. 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*

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 and 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 (Fig. 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

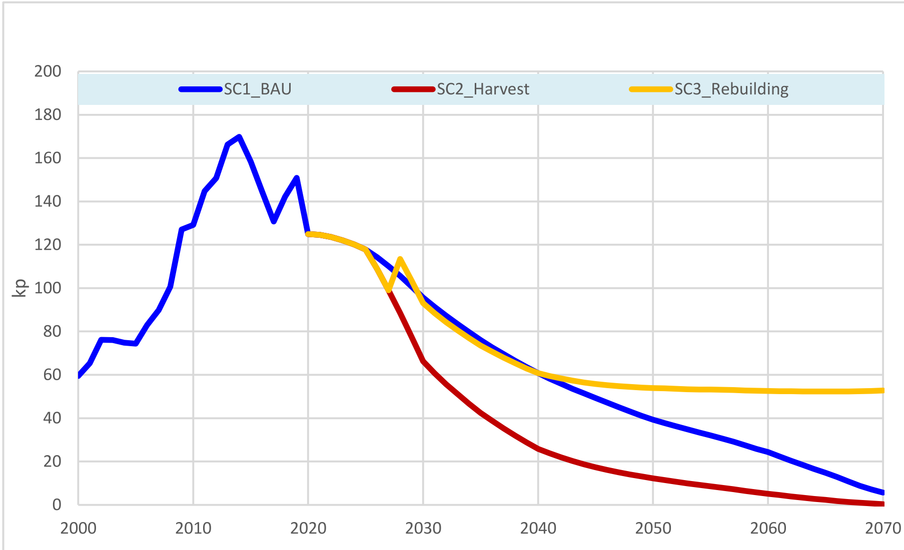


Fig. 10. Offshore energy sector employment, showing the sum of direct + indirect (onshore supplier) jobs in all scenarios, in kp = 1000 persons. The difference between 2) Harvest and 3) Rebuilding from 2025 to 2070 are the new jobs generated in offshore green products. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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 *BAU*, 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.

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 windpower. 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 Fig. 11.

4.3. Economic outcomes: offshore GDP, Norway GDP and oil fund value

Due to declining petroleum reserves, production and exports, the *BAU* scenario shows a gradual decrease in offshore GDP, see Fig. 12. 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 stable allocation of power demand in EU). 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.*

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 Fig. 13 it is clear that Norwegians do not suffer loss of welfare

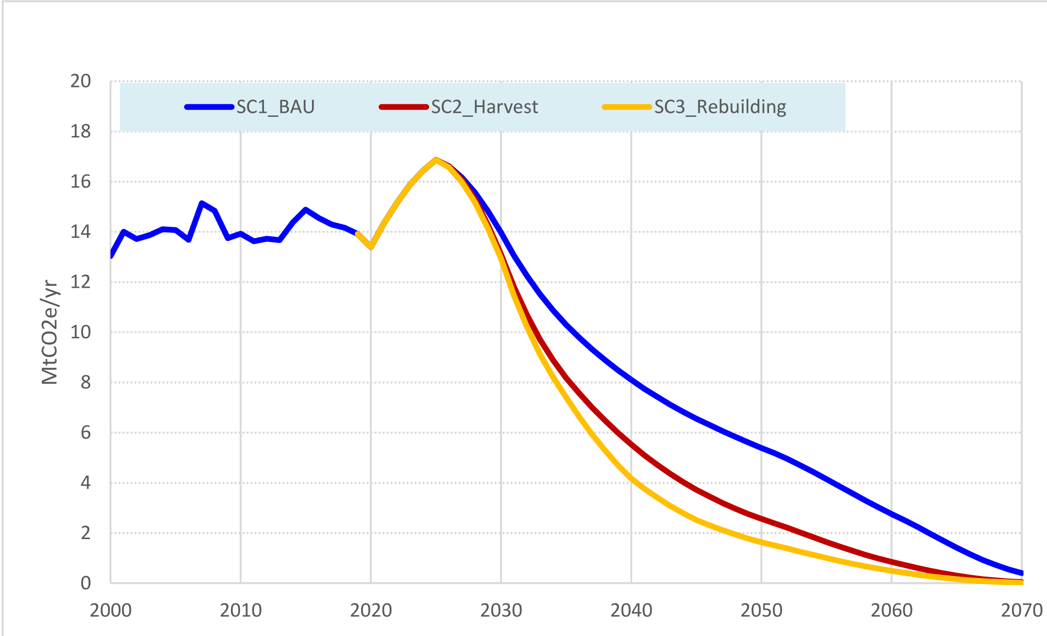


Fig. 11. Historic CO_2-eq emissions from 2000 to 2019 and future projections. The BAU decline from 2020 to 2050 is -65%, while the decline in Harvest is -83% to 2.6 $MtCO_2$-eq, and -86% in Rebuilding to 1.8 $MtCO_2$-eq.

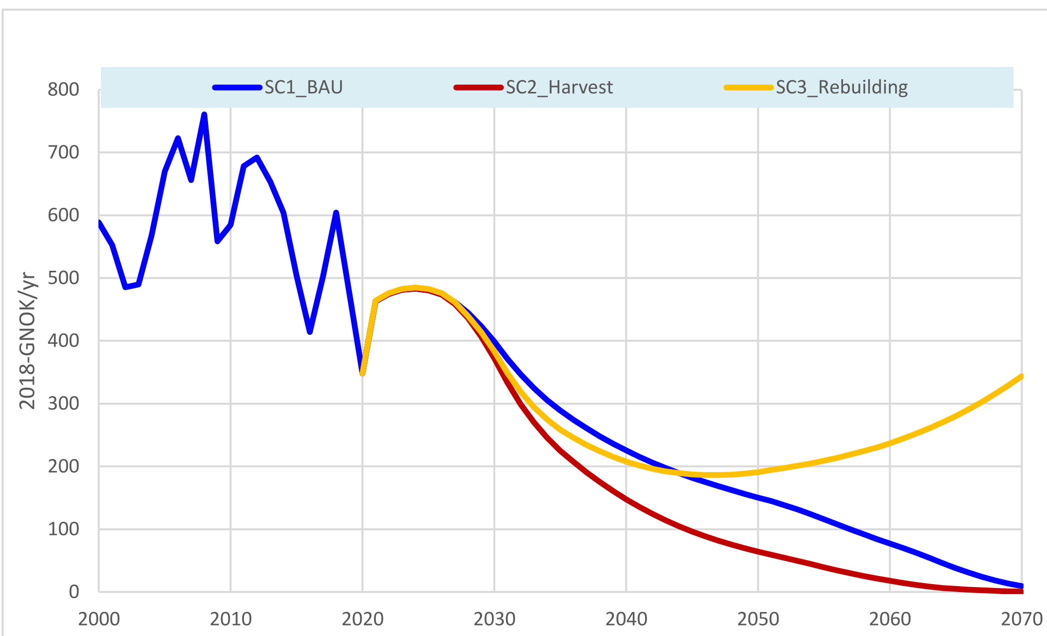


Fig. 12. Offshore sector GDP, showing historic numbers 2000–2020, and the three main scenarios to 2070.

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.

By 2020, the Norwegian oil fund was the world's largest sovereign wealth fund, having grown steeply since 2010 (Fig. 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

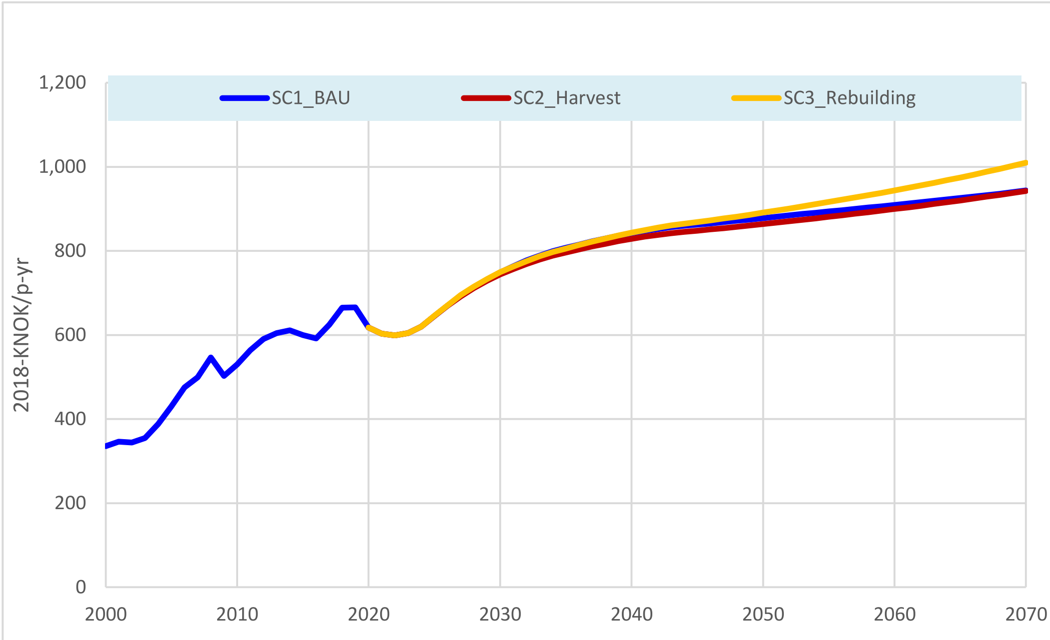


Fig. 13. Norway GDP per person, for all scenarios to 2070.

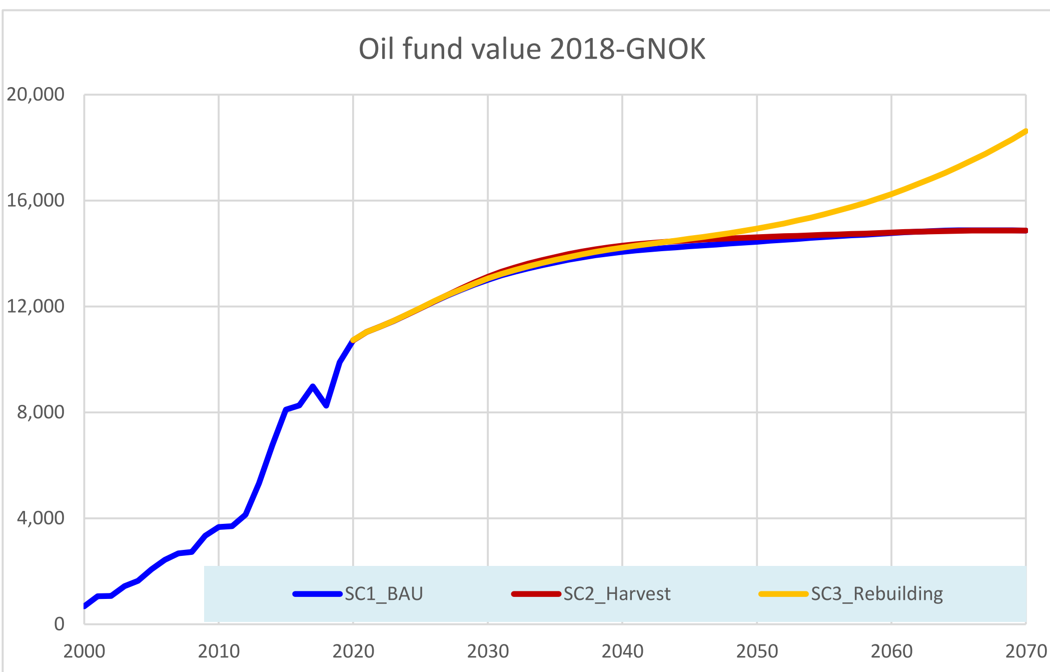


Fig. 14. The value of the Norwegian Government Pension Fund Global, or the "oil fund" for short, in 2018-billion NOK.

budget.

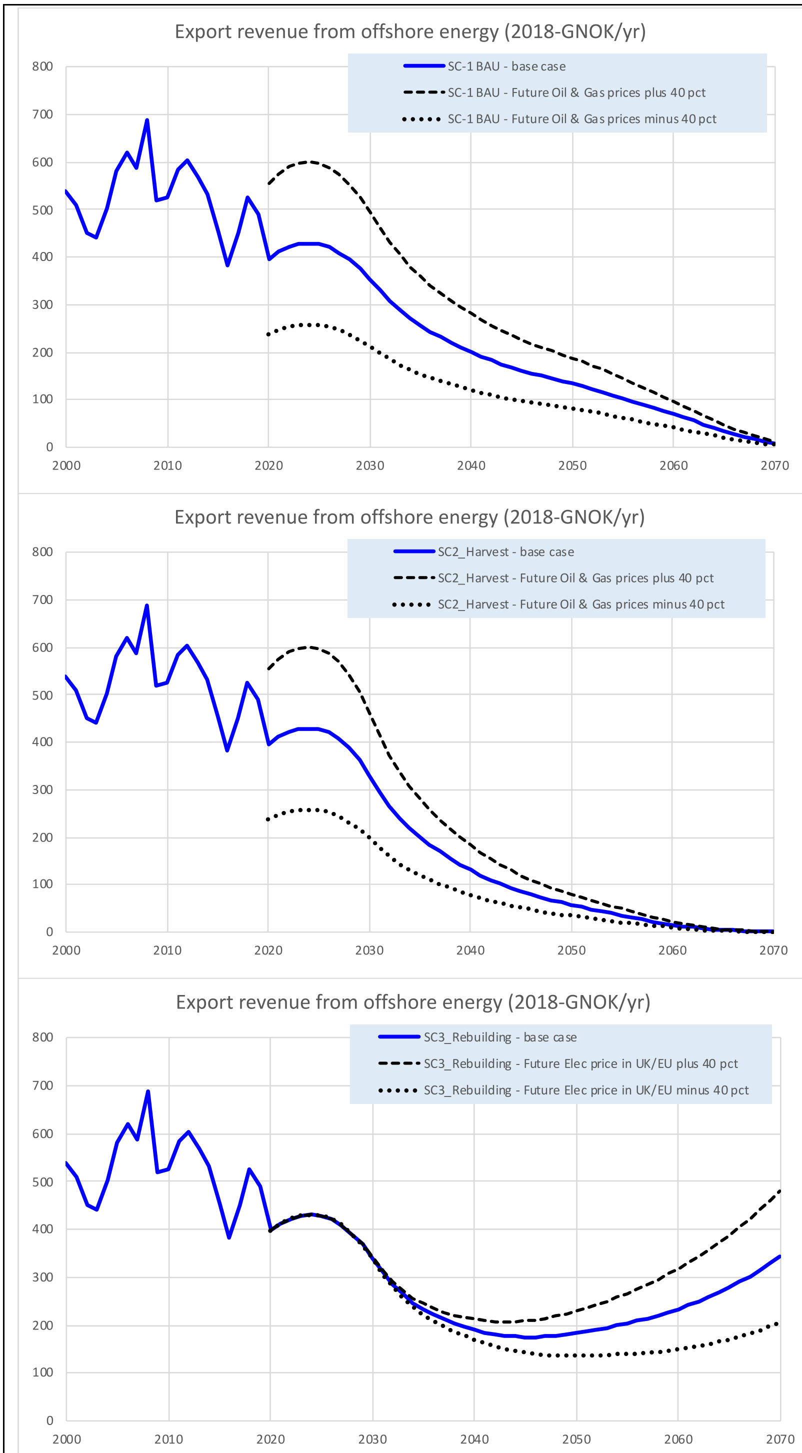
The *Harvest* policy scenario increases the oil fund value by 2% in 2040 relative to *BAU* (14 300 billion NOK vs 14 000 billion NOK). This is in main due to lower expenses in exploration, construction and operations of new fields than in *BAU*, but also results in much lower additions to new petroleum reserves by 2040. During the 2050s, the oil fund contracts compared with BAU and constitutes 280% of the mainland GDP, a number very 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 and 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



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.

Fig. 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.

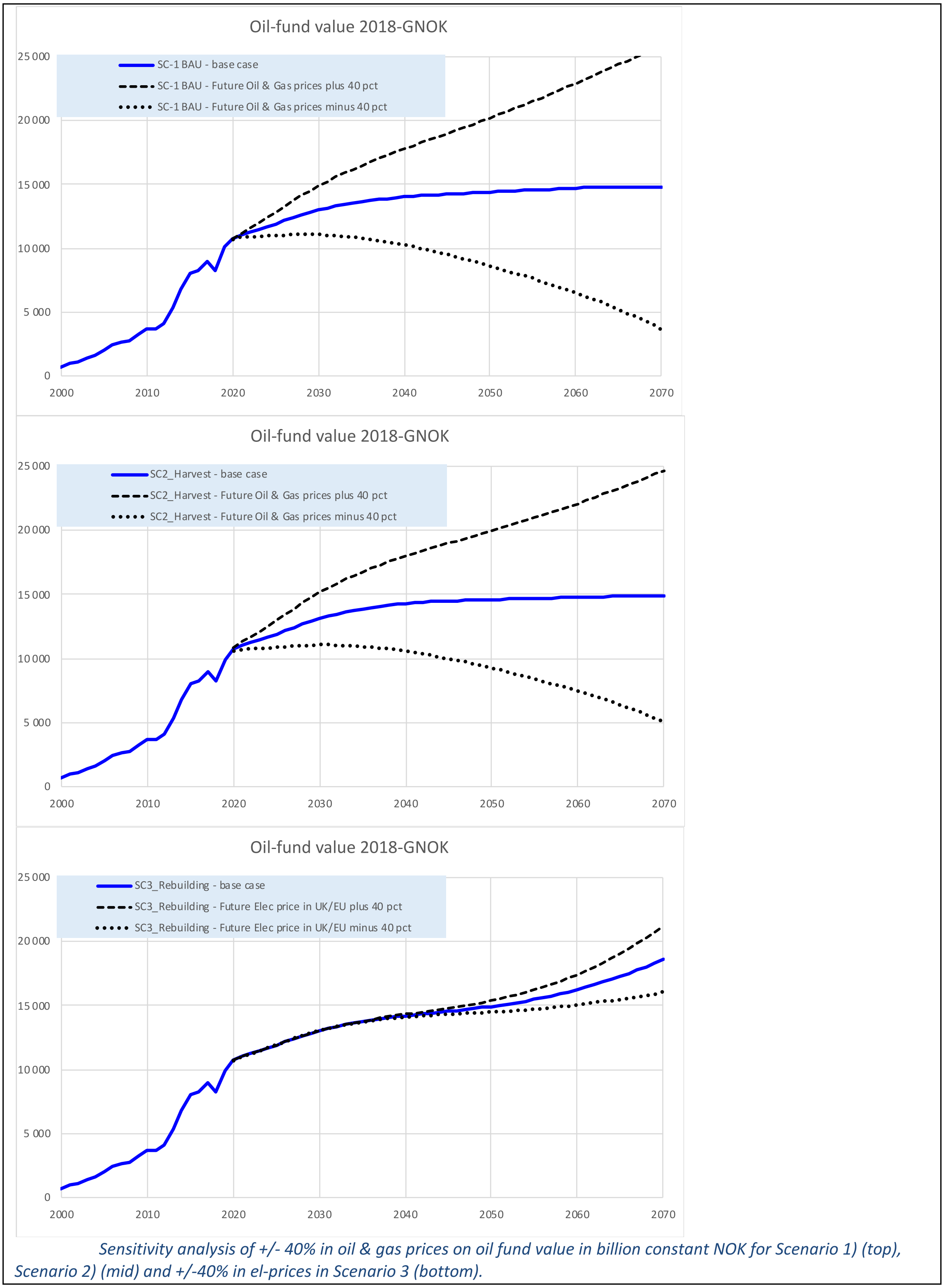


Fig. 16. Sensitivity analysis of ± 40% in oil & gas prices on oil fund value in billion constant NOK for Scenario 1) (top), Scenario 2) (mid) and ± 40% in el-prices in Scenario 3 (bottom).

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 (Figs. 15–17). Specifically, we calculate the impact of oil and gas price increase and decrease with 40%

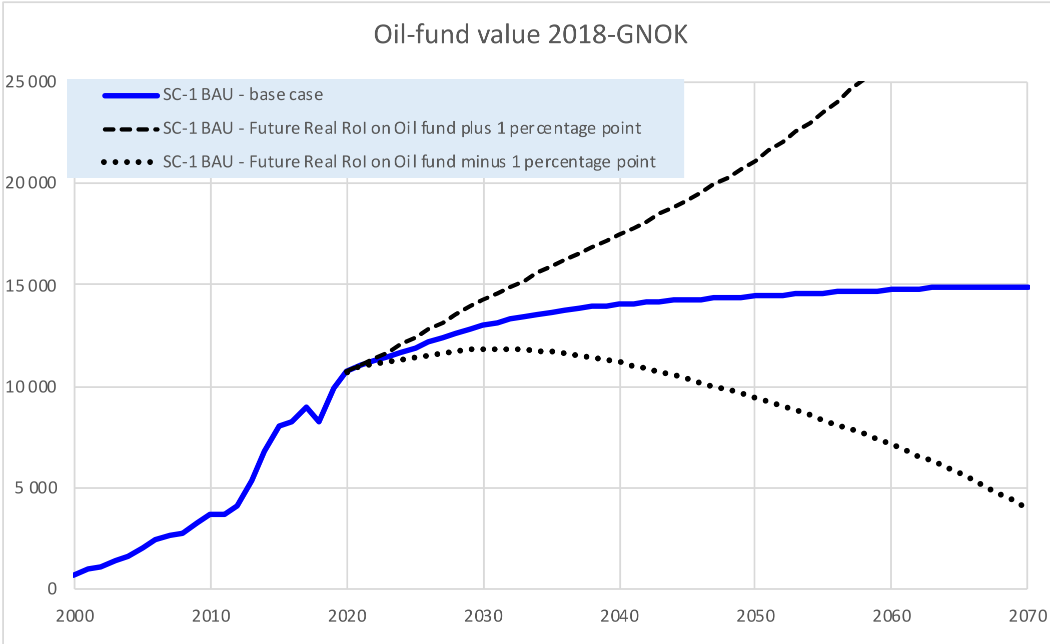


Fig. 17. Sensitivity analysis on Scenario 1: ± 1% in annual real return on the oil fund.

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.

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 (9300 billion NOK relative to 8700 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.

The sensitivity analyses in Figs. 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, Fig. 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 9400 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 petroleum-producer countries under uncertainty*

What transition indicators would be best for monitoring and facilitating adjustments toward the low-emission society? The model outcomes of investments in the offshore energy sector (Figs. 8–14) can be interpreted as a set of forward-looking indicators for monitoring development. Current investments drive the future time paths of the energy sector and the impacts on the mainland economy with a time lag of typically 7–20 years due to long lead times. Hence, by plotting annual developments of offshore investments alongside the model-based graphs, one can see the discrepancies between current investments and scenario pathways 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 frameworks for sustainable development goals (SDGs) now being implemented. 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 alone but requires research-based approaches to capture different aspects of sustainability (Garnåsjordet et al., 2012). Thus, it is relevant to develop model-based indicators to enable feedback to policy makers on future impacts of the current decisions being made (see Fig. 5). Many petroleum-producing countries face uncertainty about the speed and directions on how to navigate the energy transition. Energy transitions are complex processes difficult to characterize (Blazquez et al., 2020). This is where GTM and similar models, that make forward-looking indicators for several senarios, can make a contribution to democratic discourse and decision making.

The political context of the international energy markets has recently (2020–2022) changed significantly. As the EU continues to curtail imports from Russia, and energy imports from Norway are increased, energy analyst inquire whether the transition to renewable energy will be increased or slowed-down. There is also uncertainty regarding the impacts of a extraordinary high prices in the current oil price cycle, the tax-incentives to maximise petroleum production during the 2020s, while at the same time accelerating investment in renewables. In terms of our scenarios, this situation is not *BAU*, nor is it directly *Rebuild*. It is a opportunity to pursue multiple goals, and the challenge is to align the increased profitability with more climate action. We therefore ran a fourth scenario, named *Faster Rebuild*. In this scenario we assume higher oil-price for the 2020's rising to an average 100 $/brl in 2025 and declining back to 50$/brl in 2030. At the same time we increased investments in renewables with 33% from 2027, from 30 GNOK/yr to 40 GNOK/yr annually, in order to more quickly build offshore green capacity. The scenario narrative is that the government increases auctions with favorable tax conditions for investments in green energy products. The main results are that the oil-fund rises 13% above *BAU* (1600 GNOK higher) by 2030, offshore employment is 22% higher than in BAU, and that renewable power production by 2040 reaches 140 TWh/yr, which is 33% higher than in *Rebuild*. This level of 140 TWh turned out to be what the Norwegian government (in May 2022) set as their 2040 target. Offshore CO2-emissions however rise 9% over *BAU* levels by 2030, causing Norway's emissions to decline with just 5%, falling far short of Norway's climate targets unless with high purchases from EU-ETS.

6. Conclusion and policy implications

The global energy transition may usher in an age of stronger climate policies, declining oil demand and mid-to long-term 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 sufficiently in the energy transition to achieve climate goals (Goldthau and Westphal, 2019; Pickl, 2021; Van de Graaf and 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 given a long-term 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 (Fig. 11), and further – as exports increasingly depend on gas sold to an EU whose green deal strategy will wean its economy off gas – is progressively risky.

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 net-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 (along the coast) that will incur a heavy political burden, unless countered by *Rebuilding* policies.

The *Rebuilding* policy scenario indicates that public auctions securing an investment of 30 billion NOK/yr in the construction of innovative green industrial capacity annually from 2027, incentivized through an adjusted offshore tax regime, is enough to avoid any extra decline in the offshore employment below a *BAU* trajectory. This, or an even *Faster Rebuild* policy, holds the potential to transform Norway into a low-carbon energy-exporting, economically viable society also after 2050, with an energy policy aligned with net-zero ambitions.

The implications of our study is that by adapting the GTM to their national economies and resource base, hydrocarbon producing countries can improve their understanding on the transition to green energy sectors in a world of net-zero ambitions. A set of scenarios can help foresight discourses through guidelines that focus attention on the long-term effects of current investments under uncertainty, and broaden the perspective to a better balance between future aspects of sustainability; both the economic, ecological and social (Garnåsjordet et al., 2012).

CRediT authorship contribution statement

Per Espen Stoknes: Conceptualization, the study, created the scenario logic, interviewed industry representatives, wrote the paper, assisted by IA and PAG, and, Project administration. **Iulie Aslaksen:** helped provision data resources, and contributed to writing, Writing – review & editing. **Ulrich Goluke:** gathered data, did data curation and programmed the GTM model in Excel, with verification in collaboration with PES. **Jørgen Randers:** designed the conceptual approach, outlined the scoping of the model with initial, Methodology, notes. **Per Arild Garnåsjordet:** helped provision data resources, and contributed to writing, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2023.113887.

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