STAFF MEMO

Technological advances and climate measures can influence banks' credit risk

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LARS-TORE TURTVEIT
AND MADELEINE
GOLDSACK

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Technological advances and climate measures can influence banks' credit risk

Lars-Tore Turtveit and Madeleine Goldsack[1]

Climate risk can have implications for financial stability. For Norway, a large oil sector entails a country-specific risk linked to a potential future decline in oil demand. Uncertainty about future climate regulation and technological developments make it demanding to estimate that risk. Empirical analyses of disruptive technologies (Nagy, et al, 2013) used in solar panels and electric car batteries indicate continued technological improvements. Cost analyses, regulations and car producers' plans suggest a potential reduction in oil demand growth by 2025. The European Systemic Risk Board (ESRB, 2016) posits that a gradual shift to lower climate emissions could reduce financial system risk. Insufficient early adaptation involves the risk of abrupt adaptation later. Abrupt effects of climate change, such as natural disasters, can lead to an unexpected and substantial tightening of climate measures and regulations. Available climate-friendly technology enables such measures to be taken. This could make oil-related industries vulnerable to risk. Actual and potential adaptation in the form of enhanced cost-efficiency, restructurings and lower debt raising influences the risk. As adaptation tends to be time-consuming, it would be an advantage to adapt before the changes are visible in the oil market. Banks can map and report on climate change in their own portfolios. Scenario analyses and stress tests can improve risk understanding and influence credit standards. Any increase in capital requirements relating to climate risk in the EU could help accelerate banks' adaptation.

Climate risk, electrification, oil, banks.

[1] We are grateful to Sindre Weme, Pål Winje and Torbjørn Hægeland for useful input and comments.

Contents

1. Climate risk and financial stability

Climate changes and adaptation to climate emission reduction could entail risks for the banking system. Given its large oil sector, Norway may be exposed in particular with regard to adaptation to emission reduction. At the same time, oil producers take into account climate-related risks in their investment decisions (Oslo Economics, 2017), and the financial industry is planning to do so to a greater extent (Finance Norway, 2017). Banks have recently had to cope with a downturn in the oil sector accompanied by increased loan losses. That has increased the focus on risk in the sector and banks may now be better prepared for new downturns. Climate risk is therefore taken into account explicitly and implicitly. Uncertainty surrounding the effects of climate change, future climate regulations and technological advances still make it demanding to estimate risk, and it can be underestimated. Climate risk is therefore of relevance for financial stability.

1.1. Climate risk

2016 was the warmest year ever observed (WMO, 2017). The high temperatures were partly the result of a strong version of the weather phenomenon El Nino. 2017 was the warmest year observed without El Nino, and the third warmest ever observed. Climate gas emissions are the primary factor behind the global warming that has occurred in the period 1951 – 2010 (IPCC, 2014).

Climate risk is commonly divided into physical risk and transition risk. Physical risk linked to climate change involves floods, droughts and other extreme weather. Physical risk can again be divided into chronic and acute physical risks. Chronic physical risk involves a permanent climate change that can, for example, destroy the basis for operating a business (Norwegian Climate Foundation, 2017). Acute physical risks include, for example, flood damage. If insured and uninsured damage and economic losses are substantial, it could contribute to macroeconomic instability, and potentially to political instability and large refugee flows from affected areas.

Transition risk is linked to society's adaptation to lower climate emissions, in response to regulations, market pricing and technological advances. The coal, oil and gas industries are examples of industries exposed to transition risk. Bank loans to these industries can represent a climate-related financial risk. Reduced activity levels and employment in affected industries can have macroeconomic implications. Transition risk may be the most demanding form of climate risk to manage (Bank of England, 2018).

In addition to physical risk and transition risk, which involve real economic costs, economic agents can also be exposed to liability risk. A company that is responsible for substantial climate emissions can be sued, also if the company has shown little willingness to take account of the economic losses associated with stricter climate requirements and new technology (Norwegian Climate Foundation, 2017).

ESRB (2016) argues that a gradual transition to lower climate emission could reduce risk from a systemic risk perspective. Delayed understanding of the risk associated with climate change can entail a too slow and too abrupt adaptation to climate emissions. This may give rise to negative macroeconomic effects of changes in energy use, sharp value declines for carbon-intensive assets and more natural disasters.

Swedish Financial Supervisory Authority (2016) find that financial undertakings probably have a relatively short planning horizon, which means that they do not fully take into account climate risks further out in time. The Bundesbank supports this view, asserting that the financial risk linked to physical risk and transition risk is underestimated, partly owing to the fact that analysts rarely apply a time horizon of more than 5 years (Bundesbank, 2017).

The Norwegian government has appointed a commission of experts charged with assessing climate-related risk factors and their implications for the Norwegian economy, including financial stability.[2]

In this paper, we take a close look at a component of climate risk: Transition risk for the oil sector linked to adaptation to climate change through a fall in oil demand and hence a fall in oil prices and oil investment. The size of the Norwegian petroleum industry is such that an oil price fall constitutes a country-specific risk for Norway. This came into clear evidence after the oil price fall in 2014.

When and how transition risk materialises will have a considerable bearing on the need and possibilities for adaptation among banks. It is therefore relevant to illustrate developments. Potential structural changes in oil demand will likely be technology-based and influenced by regulations. First, we will therefore discuss regulations and some features and time aspects of technological developments. We will then discuss potential consequences of technological advances and the banks' long-term risk and possible adaptation.

2. Transition risk and regulations

Transition risk can typically materialise as a result of a combination of regulatory changes and technological innovations. The latter can reduce costs and entail stricter regulation. At the same time, stricter regulation can boost investment in new technology.

Climate emissions regulations usually involve a ban or an obligation and incentives in the form of taxes and subsidies. The regulations can

[2] Source: "Norwegian Commission on climate risk and the Norwegian economy".

be made known before their implementation. Long notification periods and gradual implementation can reduce transition risk. Some regulations relate to issues other than climate change, such as air and maritime pollution, but can still have a bearing on transition risk.

Regulations of importance for transition risk include existing, planned and unexpected tightening further out in time. The latter can, for example, occur as a result of fears of or after climate-related natural disasters, and can have a substantial impact on transition risk, especially if the regulatory tightening is much more extensive than previously planned and implemented regulations. If the population of countries or regions demand tighter regulations in the wake of a natural disaster, they may be implemented despite potential losses on earlier investments. Available climate-friendly technology makes it possible to tighten regulation. It is therefore demanding to exclude transition risk where alternative climate-friendly technology can be used, which is possible for a number of today's applications for fossil fuels.

An example of the consequences of an unexpected tightening is the planned closure of coal-fired plants in the Netherland by 2030. The plans were announced in 2017, but as late as in 2015 three new coal plants were put in operation.[3] The closure by 2030 will likely mean that over half of the investment costs for those coal plants will be lost (IEEFA, 2016). This illustrates that the risk of unexpected regulatory tightening further out in time should be taken into account in evaluating long-term investments.

Unexpected regulatory tightening is demanding to project. Most scenario analyses of energy markets are based on existing and planned regulations, and when including new and unplanned regulations they are often introduced over time. Since there are a range of examples of unexpected and abrupt regulatory tightening, transition risk may be underestimated.

2.1. Relevant regulations for oil and gas

About 15 percent of global climate emissions were taxed as of November 2017 (World Bank, 2017). Aims of higher and broader taxation can influence oil and gas demand. The Paris Accord from 2015[4] and national climate emission targets are important regulatory. Below is a selection of relevant regulations.

Passenger vehicles are the main source of global oil demand. CO2 emission reduction targets and measures to reduce local air pollution influence vehicle emission regulations. Emission requirements for petrol and diesel cars are generally introduced gradually. According to the International Energy Agency & International Renewable Energy Agency

[3] Source: "Netherlands to close all coal-fired generation by 2030".
[4] In the Paris Agreement, 195 countries have committed to implementing emission reductions to limit global warming to well under 2°C.

(IEA & IRENA, 2017), 3 of 4 new cars globally are encompassed by new regulations. Stricter emission requirements often entail higher production costs.

Taxes and bans on using older diesel cars in city centres are under consideration and are being implemented in many cities. This enhances the attractiveness of alternative technologies, such as electric and hydrogen vehicles, and can create uncertainty about the utility and resale of fossil-fuel vehicles.

Many countries are also considering imposing a ban on new petrol and diesel vehicles from 2030 or 2040.[5] A ban will have a big impact on car sales in those countries in the long term, but can also much earlier influence car producers' development of new cars. This is also the case for China's planned quota system where car producers are penalised if the share of new zero- or low-emission cars is too low. Subsidies such as the Norwegian VAT exemption for zero-emission cars or other countries' rebate programs can also influence the development of new cars and car production, as does the authorities' contribution to the deployment of charging infrastructure.

Regulations can also influence oil demand from sources other than passenger vehicles. Land-based transport is important for oil demand and is impacted by adopted and planned emission regulations in the same way and passenger vehicles. For example, the Port of Los Angeles has a plan for zero-emission trucks by 2035.[6] This could have an impact on the truck industry in large parts of the US. Shipping is also faced with tighter regulations, such as a required reduction in fuel sulphur content from 2020, which could increase the use of gas and reduce the use of oil.

For industry, regulations can also impact oil demand. Plastic-based products can, for example, be exposed to tighter regulations in light of the pollution of oceans. Recycling technologies make this possible. Regulation of property, including energy use, can also affect demand for fossil fuels.

Oil and gas production, refining and freight can also be regulated based on climate considerations. Regulation of energy use in processes such as electrification of the Norwegian shelf and limitations on methane emissions are a few examples.

2.2 Preferences and reputational aspects

A population's preferences and preference changes do not only impact demand for goods and services, but can also influence regulations through political processes, as well as business investment. A large

[5] Source: UK plans to ban sale of new petrol and diesel cars by 2040.
[6] Source: "Snart portas Volvo från LA" [Soon Volvo will be "ported" out of LA], *Dagens Industri*, 9 October 2017 (in Swedish only).

range of investors and funds monitor, or are influenced by, responsible investment principles.[7] Indirectly, this can lead to an increase in investment in renewable energy at the expense of fossil fuel alternatives. Coal and shale oil[8] are examples of projects that are negatively influenced by reputational considerations among investors, and other fossil energy production may also fall into that category.

3. Transition risk and disruptive technologies

Regulations aimed at limiting climate emissions can pave the way for new and disruptive technologies that can replace solutions based, for example, on coal, oil and gas. The potential of disruptive technologies is evident in their high growth rates and rapid cost improvements. Existing market participants and technologies may face financial challenges long before they lose significant market share.

The increasing importance of solar and wind power technologies in the electricity market can serve as an example. According to BNEF (Bloomberg New Energy Finance), these two technologies generated 5 percent of global electricity consumption in 2016. Growth in global electricity generation was 2.2 percent, while growth in solar and wind was approximately 19 percent (BP, 2017). Solar and wind therefore accounted for more than one-third of the growth in global electricity generation. In regions where growth in solar and wind has exceeded total growth in demand for electricity, the profitability of other electricity sources such as coal may come under pressure. This reflects the very low marginal generation costs associated with solar and wind assets after installation. Decreased utilisation of existing technologies such as coal entails weaker profitability and risk of losses.

If the market shares of solar and wind power generation continue to increase, the impact on existing technologies will be amplified. For example, if a coal power plant must be decommissioned before the end of its useful life, it may be referred to as an asset that has lost its value due to underutilisation, ie a "stranded asset".

3.1. Current disruptive technologies

With strong growth, rapid technological improvement and wide-ranging potential applications, lithium-ion battery and solar photovoltaic (PV) technologies stand out as potentially disruptive. A number of other technologies may have potential, but few of them have demonstrated growth rates as high or potential applications with as wide a range.

[7] Source: Principles for Responsible Investment.
[8] Source: KLP on the exclusion of coal and oil sand (in Norwegian only).

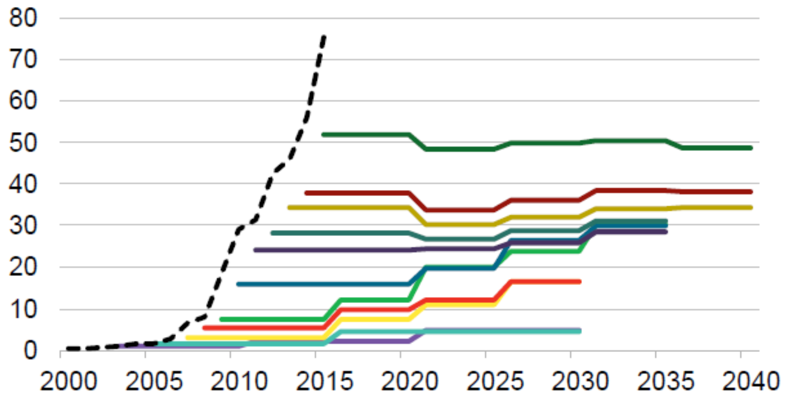
In the ten years prior to 2016, the annual increase in electricity generated by solar panels averaged 50 percent (BP, 2017). Solar panels have wide-ranging potential applications. They can be used in solar power plants (solar farms), integrated into or mounted on installations or buildings and integrated into electric vehicles or ships. One disadvantage of solar panels is that electricity generation can vary considerably depending on available sunlight.

In the period between 2013 and 2017, annual growth in electric vehicle (EV) sales averaged 60 percent.[9] Batteries have a very wide range of applications in consumer electronics, transportation and in the electricity grid. The grid, for example, can benefit from batteries because they can store electricity produced during the day for use at night. EVs can also be used for such interim storage of electricity. In transportation, batteries can be used in for example electric passenger vehicles, buses, trucks, ferries and potentially short-haul aircraft.

3.2. Uncertain future technological advances

Growth estimates for different technologies are often based on expert assessments (Farmer and Lafond, 2016), which tend to underestimate the growth of technologies experiencing particularly rapid growth. One example is solar panels, which the IEA has underestimated on several occasions (Chart 1).

Chart 1: Global solar panel installations. GW. Actual developments shown with broken line, IEA projections in colours[10]



Sources: IEA World Energy Outlook and Bloomberg New Energy Finance

For solar panels, historical developments illustrate a rising importance in the electricity market with the exponential proliferation of new solar panels. However, the IEA has tended to project the rising importance of solar panels in the electricity market as gradual. Extending the trends over time presents completely different scenarios for transition risk.

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[9] Based on data from EV Volumes. Growth is calculated based on the volume of plug-in vehicles and the share of fully electric vehicles among them.
[10] Reference scenario for 2004-09 and New Policies Scenario for 2010-2016.

Estimating future growth for different technologies is demanding. Areas of uncertainty include materials prices, regulations and changes in consumer preferences. An important key assumption is often the developments in costs for the technology, since the most affordable solution is often chosen given existing and expected regulations. Underestimating cost reductions can easily result in underestimations of volume growth.

3.3. Models for technological advances

Statistical models may be an alternative to expert assessments in predicting technological advances and growth. Nagy et al (2013) tested six different models to forecast the cost improvements associated with 62 different technologies. Wright's law produced the best forecasts, followed by Moore's law.

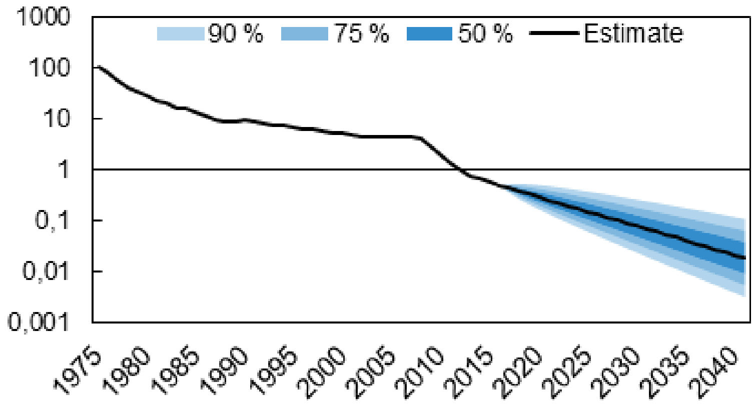
Wright's law is intuitively grasped as a decline in costs with learning and experience. In this model, for each doubling of cumulative production, learning and cost improvements will take place at a constant rate.

Moore's law states that technological improvements will take place, with time the only factor that explicitly affects this. Here, cost improvements do not depend on the level of production. The law derives from an observation made in 1965 by Intel's Gordon Moore that the number of transistors in an integrated circuit doubles about every two years. This has proven to be an accurate extrapolation of developments over the following 50 years. Similar relationships can also be applied to extrapolate cost reductions over time. Moore's law requires few assumptions and is easily communicated, which is why we have chosen to use it here. For more about the different models, see Appendix A.

4. Further advances in solar panels

The cost of solar modules has declined by an average of 12.2 percent annually between 1975 and 2016. Assuming Moore's law applies, these costs will continue to decline by this annual rate (Chart 2). The fan chart illustrates uncertainty based on historical data. Costs are projected to fall from about USD 0.50 per watt (maximum power) in 2016 to approximately USD 0.15 per watt in 2025.

Chart 2: PV module cost per watt-peak according to Moore's law. In 2015 USD. Logarithmic scale



Sources: Bloomberg New Energy Finance and Norges Bank

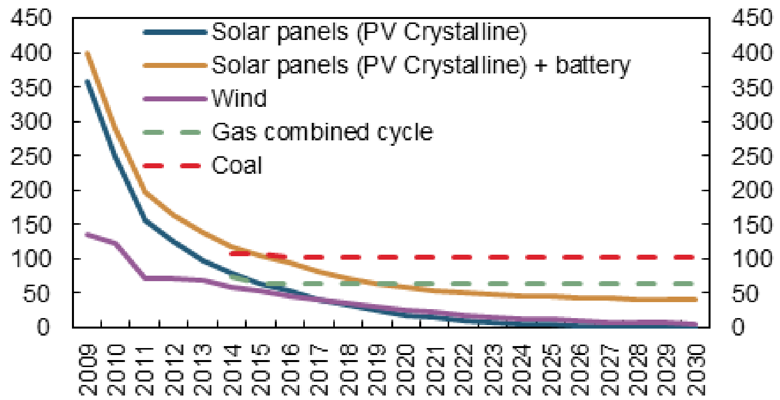
4.1. Cost comparisons of solar panels

The costs associated with solar panels have declined so much that they no longer account for most of the total cost of a solar power plant. US authorities, for example, project module costs at about 1/3 of the total cost of a 100 MW power station in 2017 Q1 (US DOE/NREL, 2017). To assess the competitiveness of solar panels, comparisons with other relevant technologies are necessary.

Unsubsidised electricity generation costs from different energy sources, ie the "levelized cost of electricity" (LCOE)[11] based on Lazard's annual analysis (2016), can serve as a basis of comparison. The cost associated with intermittent solar electricity generation is accounted for by assuming a battery cost of USD 40 per MWh. We have used Moore's law in estimating future costs, while costs for gas and coal power are assumed to be stable at the 2016 level (Chart 3).[12] The LCOE for solar power over the coming years will be lower than for coal power, excluding regulations and costs related to pollution. In the longer term, solar power may also compete with gas power plants.

[11] The "levelized cost of electricity" is an indicator of the average break-even price for a power station. Investment, operation, decommissioning and capital costs are included in the calculation.
[12] With Moore's law, the estimated improvement rate is often faster than the rate forecasted by experts, which is in line with previous observations for solar PV and the basis for the choice of model.
Our implicit assumption is that environmental requirements will counteract any productivity improvements for gas and coal power plants. Real prices for coal power in 2015 were at approximately the same level as in 1890. (Farmer and Lafond, 2016).

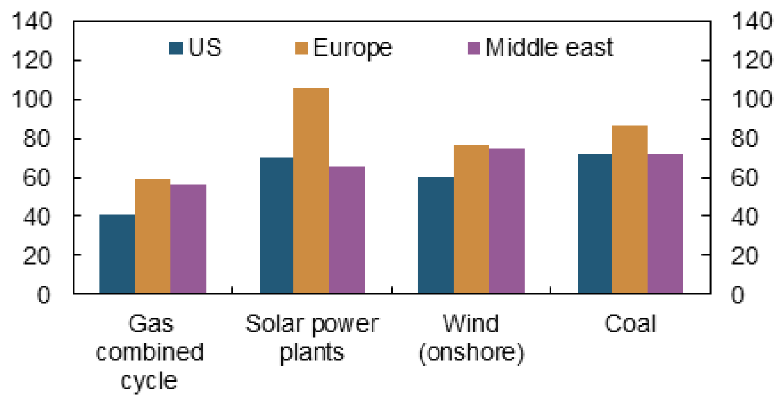
Chart 3: Costs associated with different energy sources. USD LCOE per MWH



Sources: Lazard (2016) and Norges Bank

Local and regional differences such as favourable sun and wind conditions or high transportation costs for gas and coal contribute to different competitive situations across markets (Chart 4). Other political considerations, including promoting regional business activity, can also influence regulation and the competitive situation. Together with the dependence on electricity storage or interaction with other flexible technologies, this complicates technological forecasting. According to Moore's law, however, there is still potential for further cost improvements and growth in solar electricity generation. This can result in lower electricity costs in a number of markets and can thus represent an increasing transition risk for, for example, coal power plants. Lower electricity costs will also stimulate electrified transportation at the expense of oil-based transportation.

Chart 4: Regional electricity generation costs. LCOE. USD per MWh. 2017



Sources: Energy Intelligence and Norges Bank

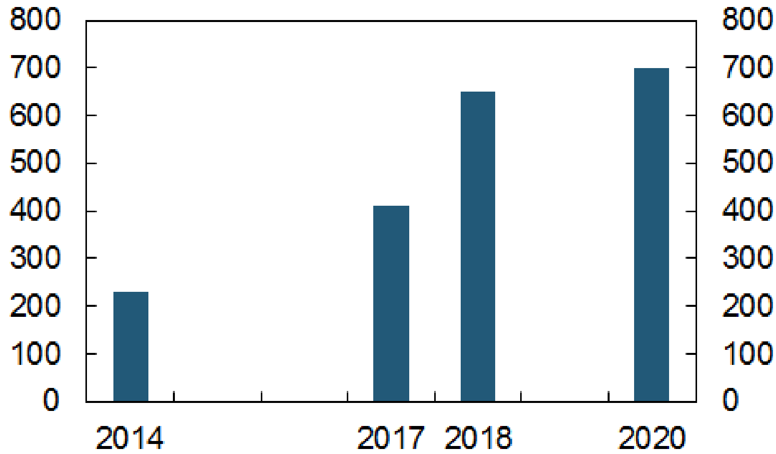
5. Further advances in vehicle batteries

5.1. Projected battery costs according to Moore's law

According to BNEF, battery costs per kilowatt hour (kWh) for plug-in electric vehicles (PHEVs, HEVs and EVs) have fallen by 20 percent annually between 2010 and 2017, increasing the attractiveness of EVs.

A challenge for battery technology forecasting is dealing with materials costs. Commodity prices can rise when growth is strong, at the same time there is the potential for battery manufacturers to replace some of the materials used or to use them more efficiently. An improvement in the ratio of kWh to both volume and weight over time suggests the latter. Volkswagen AG (2017) assumes a substantial improvement in the ratio between storage capacity (Wh) and volume (litre) ahead (Chart 5).

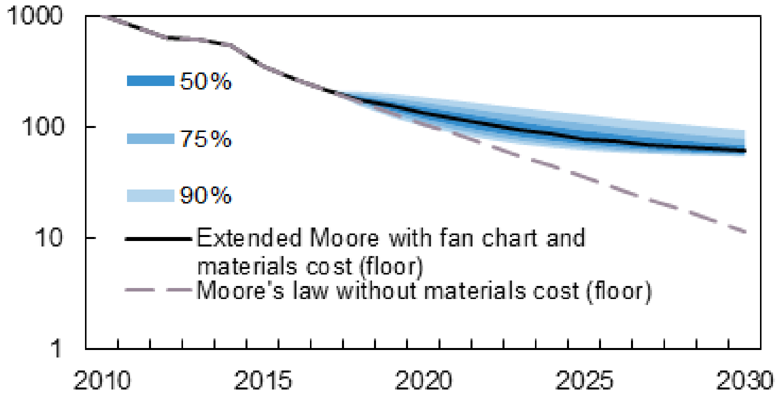
Chart 5: Storage capacity by EV battery volume. Wh/litre



Sources: Volkswagen AG September 2017 and Norges Bank

The IEA *World Energy Outlook 2016* assumes a floor for battery costs at USD 80 per kWh. Schmidt et al (2017) assume a materials cost for batteries of USD 52 per kWh. We assume the latter materials cost for one of our forecasts, even if there is reason to believe that this can change substantially over time. Materials costs provide the battery cost floor, which means that annual cost reductions will be less pronounced than the result of Moore's law without a floor (Chart 6).

Chart 6: Battery pack cost forecasts according to Moore's law. USD 2015 per kWh



Sources: Bloomberg New Energy Finance (BNEF) and Norges Bank

The different cost projections shown here for 2020 are higher than those of Tesla and Volkswagen, but they are lower than the IEA's. A more detailed comparison is made in Appendix B.

5.2. Sensitivity analysis for batteries

Lower battery costs will increase the competitiveness of EVs. This can be illustrated by performing a sensitivity analysis. On the basis of a present value analysis, we have included diesel and electricity taxes but excluded one-time taxes and other road taxes and vehicle tolls in estimating the necessary battery cost at which a buyer would be indifferent to the choice (break-even point) between purchasing a diesel or electric vehicle (see discussion in Appendix C). The costs associated with the purchase of a diesel vehicle are assumed to be constant. Differences in national electricity and diesel prices are the drivers of differences across countries.[13]

Relatively low electricity prices and relatively high diesel prices are the reasons why break-even is achieved in Norway first among the countries we have studied (Table 1). According to whether Moore's law is assumed with or without a price floor, the break-even point will be reached in large countries such as the UK, France and China in the period between 2019 and 2021. This can contribute to rapid growth in the number of EVs in these countries.

[13] Annual average for overall electricity prices (with taxes and grid tariffs) for households in 2015. Figures for China are from 2014. Sources: Eurostat, Climatescope and Energy Collective. Diesel prices from June 2017.

Table 1: Sensitivity analysis electric and diesel vehicles, break-even point. Battery cost USD per kWh and years to achieve break-even

	Break-even (USD per kWh)	Battery cost without price floor	Battery cost with price floor
Norway	211	2017	2017
Sweden	169	2018	2019
UK	152	2019	2019
France	149	2019	2020
China	125	2020	2021
Denmark	90	2021	2024
US	80	2022	2025
Germany	77	2022	2026

Sources: Kittner et al. (2017), BNEF (2016), Eurostat, Fuel Prices Europe, globalpetrolprices.com, Global Climatescope, Bloomberg New Energy Finance and Norges Bank

It appears that the US will achieve break-even point by 2025. If fuel prices were reduced by more than 30 percent of the June 2017 level, the US will never achieve break-even under the assumptions of floor costs and stable electricity prices. If fuel prices doubled from the June 2017 level, the US will achieve break-even in 2019.[14] The growth of EVs will therefore be particularly sensitive to changes in oil prices and fuel taxes. According to data from the EIA and the IEA, the US accounts for one-fifth of global demand for petrol and diesel.[15]

If the IEA assumption of a USD 80 per kWh cost floor for batteries materialises, and given the electricity and diesel prices applied here, EVs will not be particularly attractive in the US or Germany. The cost floor for batteries can therefore play a substantial role in determining the size of the EVs' long-run market share. At the same time, producing petrol and diesel vehicles may become more costly owing to increasingly strict emission standards. These costs have not been included in the sensitivity analysis, but may nevertheless have an impact.

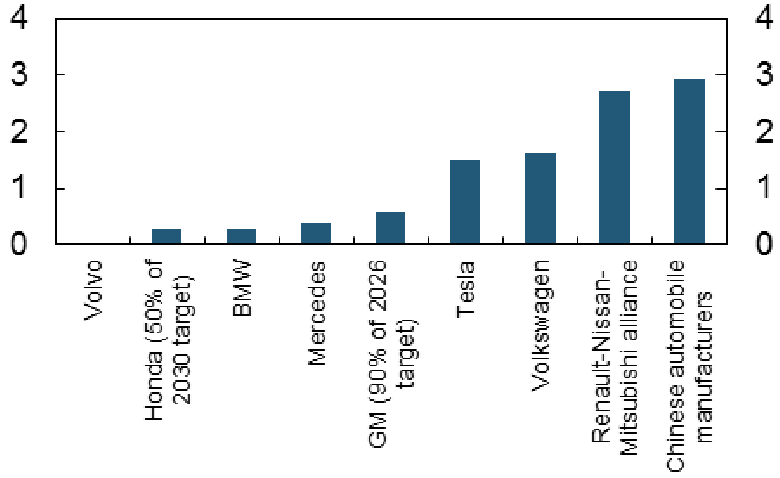
5.3. Automobile manufacturers' plans to market EVs

The combined total sales volume of electrified vehicles planned by a number of automobile manufacturers in 2025 is around 10.5 million units (Chart 7).[16] Excluding Chinese automobile manufacturers and Tesla, these manufacturers represent around one-third of global vehicle sales in 2015. If this reduced sample is representative of other

[14] For example, it is conceivable that oil prices will rise or that further climate events such as the natural disasters in New Orleans and Houston might stimulate increased fuel taxation in the US.
[15] According to the EIA, around 11m barrels are consumed daily in the US, while global consumption was around 45m barrels according to the IEA (2015).
[16] Plans at end-2017. We assume the term EV (electric vehicle) means 65 percent fully electric vehicles and 35 percent hybrid vehicles, approximately the same as the sales breakdown in 2016. We exclude the latter hybrid vehicles here. Honda is included with 50 percent of the target for 2030. For Tesla, "a few millions" is understood as 1.5m.

automobile manufacturers, the sum of all plans would total around 17 million vehicles.

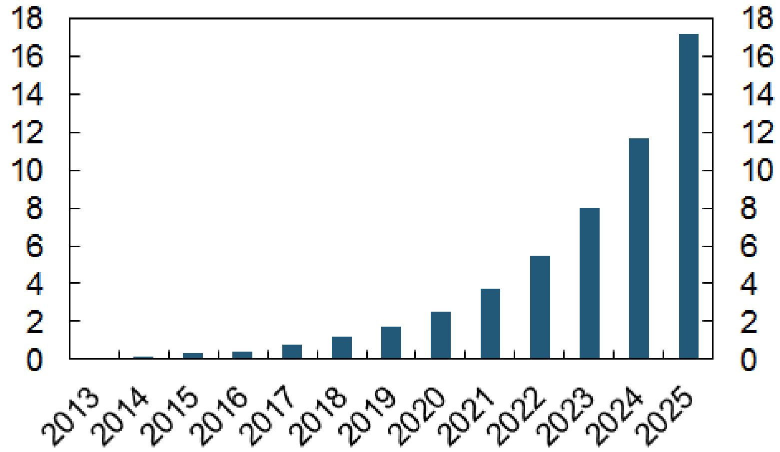
Chart *7: Projected and planned EV sales for 2025 at end-2017. In millions of vehicles*



Sources: IEA *World Energy Outlook 2016*, BNEF, Volkswagen, China Electric Car Network, Daimler, Tesla, Honda, GM, Volvo, BMW, *Financial Times* and Norges Bank

Automobile manufacturers' plans for electrification in 2025 can be used to project a scenario for EV sales. If EV sales are to reach 17m by 2025, sales must increase exponentially, at 47 percent per year (Chart 8). In the period between 2013 and 2017, annual growth was 60 percent. Automobile manufacturers' plans thus represent an approximate continuation of the growth rate from last year with increasing importance for the automobile market.

Chart 8: Projections and automobile manufacturers' plans for EV sales. Millions of vehicles



Sources: EV Volumes, IEA *World Energy Outlook 2016*, BNEF, Volkswagen, China Electric Car Network, Daimler, Tesla, Honda, GM, Volvo, BMW, *Financial Times* and Norges Bank

6. Implications for the oil market

Greater electrification of the transport sector will impact global oil demand because little oil is used in electricity generation. According to the IEA *World Energy Outlook 2016*[17], oil demand has increased by an annual average of 1.3 percent in the period between 2000 and 2015 (Table 2). In the passenger vehicle subsegment, annual growth in oil demand has been 1.8 percent.

Table 2: Global oil demand. In millions of barrels per day

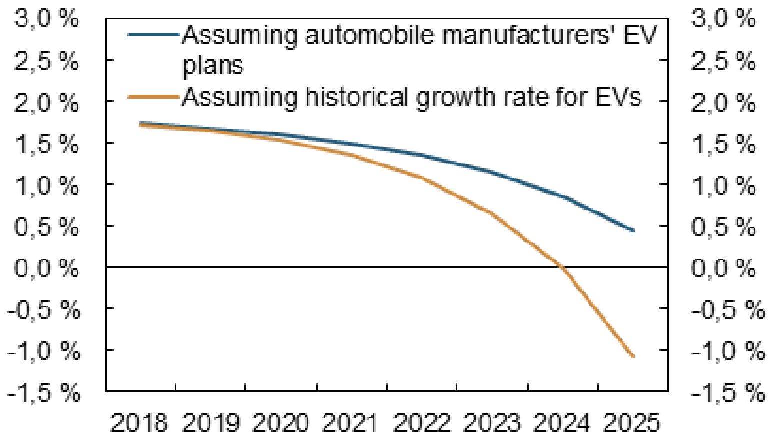
Sector	**Oil demand in 2000**	**Oil demand in 2015**	**Average annual growth 2000-2015 (%)**
Transport	39	51,7	1,9 %
- Passenger vehicles	18,2	23,9	1,8 %
- Maritime	3,7	5	2,0 %
- Freight	11,9	16,3	2,1 %
- Aviation	4,6	5,8	1,6 %
Industry	14,4	17	1,1 %
- Steam and process heat	6,1	5,8	-0,3 %
- Petrochemical feedstocks	8,1	10,7	1,9 %
Buildings	7,7	7,6	-0,1 %
Power generation	6,1	5,4	-0,8 %
Other	9,4	10,8	0,9 %
Total	**76,7**	**92,5**	**1,3 %**

Source: IEA *World Energy Outlook 2016*

To illustrate the effect oil demand has on automobile manufacturers' plans, we assume 3 percent annual growth in new vehicle sales.[18] Scrapping vehicles is assumed to have the same growth rate, but from a lower level. The stock of petrol and diesel vehicles therefore increases over the entire period leading up to 2025, even though EV sales grow by 47 percent per year. Growth in oil demand from passenger vehicles will then gradually decline faster to 0.4 percent in 2015 (Chart 9).[19]

[17] We use the *World Energy Outlook* from 2016 rather than from 2017 because of the availability of detailed oil demand segmentation.
[18] Busses and other forms of passenger transportation are assumed to follow the same trend as passenger vehicles.
[19] We assume that underlying growth in oil demand corresponds with growth in the period between 2000 and 2015.

Chart 9: Annual growth in oil demand for passenger vehicles. Percent

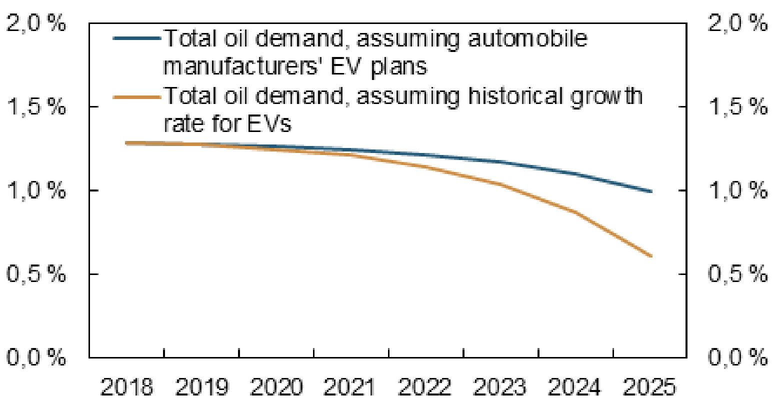


Sources: IEA *World Energy Outlook 2016* and Norges Bank

On the basis of Nagy et al (2013), it may also be relevant to assume the historical rate of 60 percent annual sales growth for EVs. If this assumption is used, growth in oil demand for passenger vehicles could fall to -1.1 percent in 2025. Growth will nevertheless slow at some point because of the market saturation of EVs.

Passenger vehicles accounted for one-fourth of total oil demand in 2015. Given the assumption that growth in oil demand excluding passenger vehicles will be stable in the period to 2025, the decline in growth will be moderate over the next three years (Chart 10). The growth in demand may however weaken in a number of segments. The substantial effects of increased electrification or use of alternative fuels may also be relevant for transport/freight, buildings and electricity generation (Table 2). All together, these segments and passenger vehicles account for more than half of total oil demand. The potential for changes in oil demand is therefore greater than the effect from passenger vehicles alone. A description of relevant product development and technological advances in transport is provided in Appendix D.

Chart 10: Annual growth in total oil demand. Percent

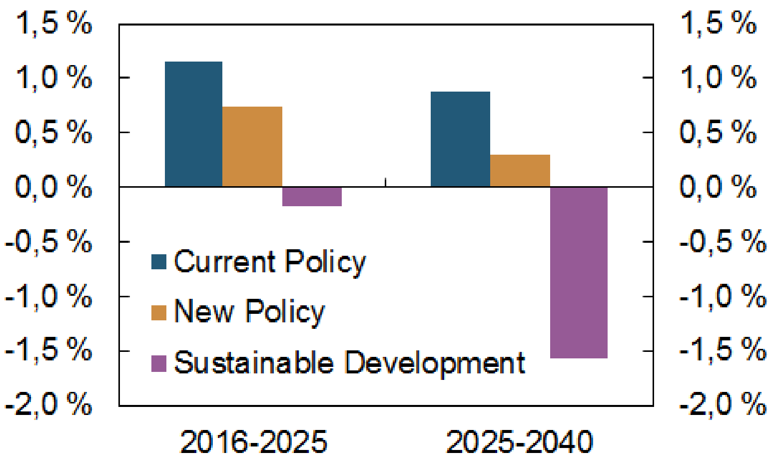


Sources: IEA *World Energy Outlook 2016* and Norges Bank

6.1. Other scenarios for oil demand

Global oil demand may become higher than in the scenario based on automobile manufacturers' plans. In this paper, we focus on transition risk resulting from the possibility of lower-than-expected oil demand. A number of energy organisations and companies regularly present scenarios for future oil demand, as do a number of environmental organisations. The scenarios presented in the IEA *World Energy Outlook* often attract the most attention. They also assume a somewhat faster negative trend. Growth in the oil demand is weaker in the period between 2025 and 2040 than in the period between 2016 and 2025 in all scenarios (Chart 11). The IEA's New Policy scenario is based on the policy plans of different countries. Many of the plans were made in connection with the Paris Agreement. In 2017, the IEA also presented Current Policy and Sustainable Development scenarios.

Chart 11: IEA World Energy Outlook 2017 *oil demand scenarios. Average annual growth in oil demand. Percent*



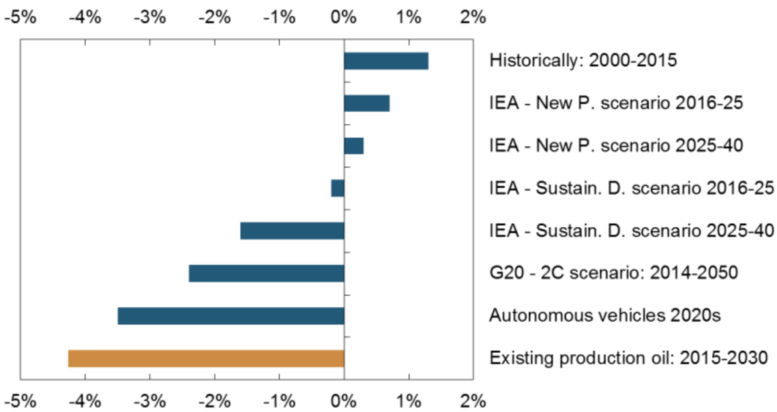
Source: IEA *World Energy Outlook 2017*

Vehicle electrification may have a greater impact if widespread transport sector electrification is combined with autonomous passenger transport and robotic freight. Autonomous vehicles can be driven a substantially longer distance per unit of time than conventional vehicles. A possible starting point is that the annual number of kilometres driven by conventional taxis is often four to six times higher than that of corresponding private vehicles. In most countries, EVs have higher investment costs and lower operating costs than petrol and diesel vehicles. Owing to the longer distance driven by autonomous vehicles per unit of time, a high share of such vehicles will therefore be electric rather than petrol- or diesel-powered. In this way, the potentially high market shares of new autonomous vehicles may have a greater impact on energy demand, with older vehicles becoming of less importance.

It is however highly uncertain when autonomous vehicles with regulatory approval will become a reality. The effects will also depend on whether approvals are granted simultaneously in a number of large markets such as China, the EU and the US at more or less the same time. On the basis of automobile manufacturers' investments, it is possible that autonomous vehicles will be adopted on a larger scale by 2040 (General Motors, 2017).

Arbib and Seba (2017)[20] present a scenario in which autonomous vehicles receive regulatory approval in the early 2020s. In the scenario, oil demand falls from 100 million to 70 million barrels per day over the course of the 2020s, which corresponds to an average annual decline of 3.5 percent for the period. This illustrates the significant impact that autonomous vehicles can have on oil demand.

Chart 12: Historical and projected annual growth in oil demand and production. Percent



Sources: IEA World Energy Outlook 2017, IEA & IRENA (2017), Arbib & Seba (2017) and Norges Bank

Highly restrictive climate change mitigation measures and regulations can also contribute to a reduction in oil demand. IEA and IRENA (2017) have constructed such a scenario for G20 countries with a 66 percent probability of reaching the 2 degree climate change target. The scenario implies an approximately 2.4 percent annual decline in global demand for oil in the period between 2014 and 2050. This scenario assumes declining percentage growth for renewable technologies such as solar panels and EVs, but high efficiency gains in energy consumption in both buildings and transport as well as growth in carbon capture and storage.

The different scenarios discussed here illustrate considerable variation and uncertainty regarding projections for future growth in global oil demand (Chart 12). Based on IEA and IRENA (2017), current oil production appears to fall more rapidly towards 2030 than the demand for oil in all the scenarios discussed here. The scenarios are based on

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[20] A publication by the think tank RethinkX.

many highly uncertain assumptions, and the weakest periods can become weaker than the average that is illustrated in Chart 12.

6.2. Possible impacts on oil prices

In the scenarios with weakened demand, the risk of low oil prices increases. The impact of lower oil demand on oil prices depends on a number of factors. Both oil supply and demand are less price sensitive in the short term than in the long term because adjustments take time. The experience from the fall in oil prices in 2014 reflects this. A low oil price further out would also likely have a dampening effect on investment in new oil production.

A marked rise in oil prices from the current level may lead to overdevelopment in new production capacity at the same time as oil demand slows in response to higher prices and, in the longer term, a faster transition to renewable energy. High oil prices may thus increase longer-term risk. The oil industry has been highly cyclical, as attested by the falls in oil prices in 1986 and 2014.

OPEC's willingness and ability to stabilise oil prices may also have an impact. OPEC's decision at the end of 2014 to seek to reclaim market share rather than to stabilise prices was an important reason why oil prices continued to fall. Increased production led to a substantial excess supply that drove global oil inventories ever higher, with oil prices remaining low. An important reason why oil prices recovered was that over the course of 2016, OPEC and a number of other countries decided to limit the excess supply of oil and to lower global oil inventories. Oil prices were under USD 30 per barrel at the beginning of 2016. At the beginning of June 2018, prices were around USD 75 per barrel, while long-term futures prices for the beginning of the 2020s indicated somewhat lower oil prices.

Oil prices at current levels can expedite the transition to the use of non-fossil fuels in several areas dominated by oil. OPEC will likely want to compete for the remaining oil demand and thus increase production. OPEC has substantial oil resources that can be extracted at very low cost. In this respect, it is possible that the scenarios with weakened oil demand can increase the risk of low oil prices over a longer period as well.

7. Impact on the oil industry and banks

7.1. Possible effects on oil producers

For oil producers[21], the effects of the scenarios with lower oil demand depend on several factors. Following the decline in prices in 2014, producers initially slashed investment, which in isolation improved cash flow. Lower dividend pay-outs reduced financing needs. Producers then made substantial cost cuts and reduced the break-even prices of new development projects by more than half. Petroleum investment on the Norwegian continental shelf is expected to pick up in 2018, after having fallen markedly in the preceding years.[22]

A significant uncertainty for the Norwegian continental shelf is the availability of new profitable discoveries. For example, forecasts by the Norwegian Oil and Gas Association (2017) indicate a decline in oil investment on the Norwegian shelf in 2021 and 2022, reflecting the small number of new large projects. Lower oil investment does not necessarily pose a financial challenge to oil producers in the short and medium term, but it may do so to oil service companies.

The cost level and the ability to reduce the costs associated with exploiting available discoveries are crucial for oil producers. Given the flexibility of investments and the uncertainty surrounding future discoveries and cost levels, judging transition risk for oil producers is demanding. However, declining oil demand may increase the risk of low oil prices in the long term, which increases risk for oil producers whose investment is highly leveraged.

7.2. Long-term risk for the oil service industry

The oil service industry may be more at risk than oil producers in scenarios with weak oil demand and low oil investment. Following the fall in oil prices in 2014, segments of the oil service industry have been affected differently. Participants whose activities are earlier in the value chain, exploration in particular, have been particularly hard hit. These segments' cyclical risk has therefore become apparent. In the event of a structural decline, more segments would likely be harder hit, reflecting the fact that longer downturns with lower oil investment may also have a greater impact on operators further along the value chain.

Lower oil prices can result in lower investment and a reprioritisation of projects. Projects with short repayment periods will often be given priority in the face of increased uncertainty. This may favour land-based projects or projects that can make use of existing infrastructure. The

[21] Here, oil producers are defined as companies (oil companies) that produce oil, while the oil service industry comprises providers of goods and services to oil producers.
[22] See Norges Bank's June 2018 *Monetary Policy Report*.

Norwegian oil service industry is exposed more to offshore projects than to land-based projects. The level of activity will therefore be impacted by whether and to what extent offshore projects are competitive. Equinor announced lower break-even prices for a number of its projects during the downturn after 2014. The Norwegian oil service industry has contributed to the cost cuts. US land-based projects have also cut costs in recent years. Relative cost developments for offshore projects may therefore prove to be substantial.

A number of oil service companies in the supply and drilling segments have had difficulties servicing their debts during the post-2014 downturn. Some of them may also be vulnerable if a new downturn occurs before the pre-2014 debt is sufficiently repaid or restructured. At the same time, this experience can lead to more prudent borrowing. An example of this is the start-up Borr Drilling, which had an equity ratio of 89 percent at the end of 2017. By comparison, according to Nervik, Hjelseth, Turvteit and Winje (2016), the average equity ratio for oil service companies on Oslo Børs was around 40 percent at the end of 2015. Higher equity ratios reduce the risk to creditors.

The ability of the oil service industry to compensate for potentially lower oil sector activity with greater activity in other sectors may reduce risk. According to Sandvig Brander, Brekke and Naug (2016), towards the end of 2015, a sample of oil service companies estimated that 13 percent of their oil sector activity could be replaced by increased activity in other sectors. In early 2015, the same companies estimated that only 5 percent could be replaced. In longer downturns, the potential for replacing activity may increase over time, reducing the risk associated with structurally declining oil demand.

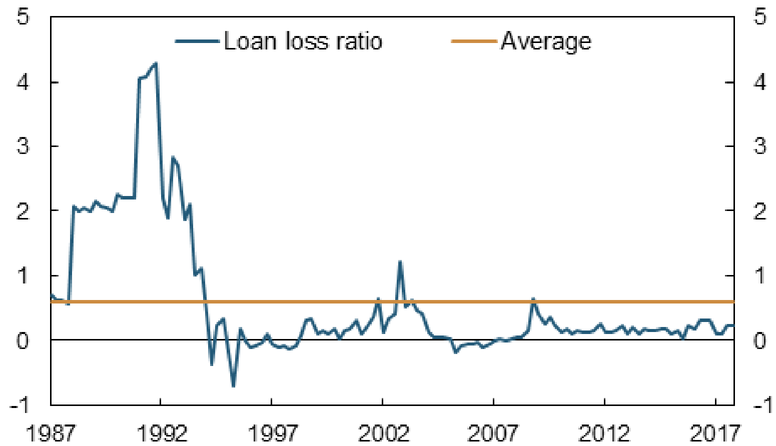
A substantial acceleration in technological advances and the adoption of climate regulation, along with an abrupt adjustment to lower oil demand further out, may have an impact on the oil service industry's access to new financing. Higher equity ratios, more cost-efficient operations, longer contracts with oil companies and long-term financing may reduce this risk.

7.3. Long-term risk for banks

Falling global demand for oil may have macroeconomic implications in Norway. For example, demand from the oil industry declined by an average of 0.4 percent of mainland GDP per year in the period between 1993 and 2002. In a scenario where the oil sector is being scaled back over the long term to 2040, Cappelen et al (2013) have estimated that the negative GDP impulses will be of the same magnitude. The oil industry's demand for goods and services is then assumed to decline by half in the period between 2015 and 2040. Weaker growth can increase the risk of banks' credit losses, but depends on the speed at which any scaling back takes place and other developments in the economy.

Banks' risk in scenarios with falling oil demand depends on the risk of oil-related exposures and any other risks that may arise as a result of spillover effects. Credit losses have been very moderate following the fall in oil prices in 2014, and they decreased in 2017 (Chart 13). Banks' risk may be greater in a structural decline than in a cyclical downturn. The reason is the risk that the debt servicing capacities of oil-related companies fail to recover. This may also reduce investors' willingness to inject new capital into these companies. Consequences can be lower collateral values, higher probabilities of default and therefore higher bank losses. In this perspective, the historically high cumulative industry-specific credit losses in fish farming and hatcheries of 23 percent of lending in the period between 2002 and 2006 can serve as a possible yardstick.[23] According to Nervik Hjelseth, Turtveit and Winje (2016), the loss-absorbing capacity of earnings for banks with the greatest oil-related exposures was approximately 21 percent of oil-related loans at the end of 2015. Banks' earnings are therefore a substantial buffer even against very high credit losses. This is particularly the case if losses occur over several years, which may be likely during a structural decline. In the event of an operating loss, capital beyond the minimum requirement may be used to absorb credit losses.

Chart 13: Credit losses[24] as a percentage of gross lending. Annualised. All banks and mortgage companies in Norway. 1987 Q1 – 2017 Q4

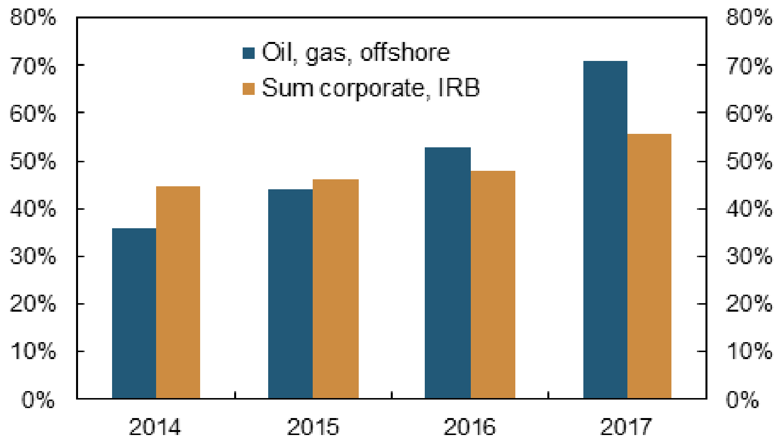


Source: Norges Bank

After a long upturn, the risk on oil-related exposures increased following the fall in oil prices in 2014. For example, around 12 percent of DNBs oil-related loans were nonperforming or were problem loans at the end of 2016, while corresponding figures for other exposures can be estimated to have been less than 1 percent. Developments have resulted in increased risk weights for DNBs lending to oil, gas and offshore segments (Chart 14).

[23] Source: Banks and financial undertakings' financial reporting to Norwegian authorities (Orbof).
[24] Annual figures up to and including 1991. Annual values are evenly distributed across quarters.

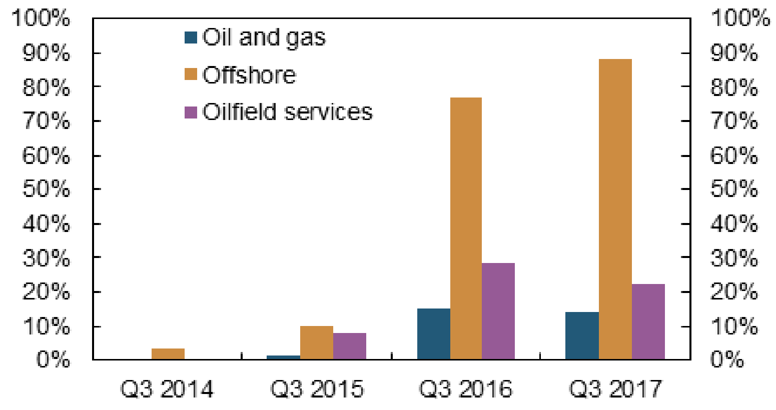
Chart 14: DNBs risk weights for relevant segments. Percent. 2014 – 2017



Source: DNB

For DNB, risk in the offshore segment in particular has increased (Chart 15). In a structural decline, risk may increase in several segments. Risk weights are based on historical loan losses and therefore do not necessarily capture new structural climate risk.

Chart 15: Share of DNBs oil-related exposures where PD[25] is higher than 0.75 percent. Share of EAD[26]. By segment.



Source: DNB

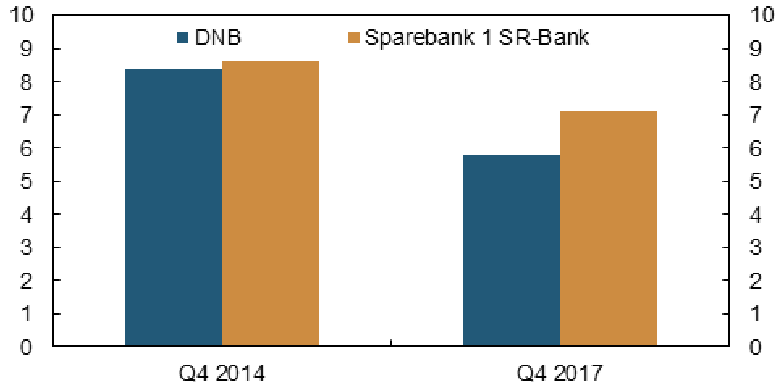
Higher risk weights may be an effective risk management tool since they raise the threshold for providing new loans by requiring banks to hold more capital against them. They may also entail higher lending rates on these types of loans or contribute to tighter loan conditions. This could in turn reduce the attractiveness of bank financing for oil companies and thus reduce banks' exposure and risk.

[25] Probability of default.
[26] Exposure at default.

Banks' future oil-related exposures are uncertain. According to Finanstilsynet (Financial Supervisory Authority of Norway), 5 percent of the 16 largest banks' credit exposures in 2015 was to the oil sector. The Norwegian banks with the greatest oil exposures, DNB and Sparebank 1 SR-Bank, have reduced their exposures from 2014 (Chart 16). The reductions could be a result of stricter risk assessments, but also of weaker demand for loans.

The potential for large losses for banks overall will probably first arise if there are substantial spillovers from a structural decline in the oil-related sector to other parts of the economy. Stress tests conducted by Norges Bank show that banks' capital buffers are sufficient to absorb losses in the event of a pronounced downturn in the Norwegian economy. Banks may nevertheless tighten lending, which could amplify an economic downturn. Changes to time-varying buffer requirements and opportunities to raise fresh equity capital may reduce these effects (Norges Bank, 2017).

Chart 16: Oil-related exposures. Share of EAD. Percent



Sources: DNB and Sparebank 1 SR-Bank

Materially slower oil demand growth is likely to occur several years in the future. Much could change in the years ahead and banks have ample opportunity to make adjustments.

7.4. Possible adjustments by banks

Banks can make several different adjustments to reduce climate risk, particularly based on long-term profitability considerations. Climate risk disclosures in financial reporting can provide greater internal focus on such risk and lead to its reduction. More detailed disclosures can also reduce banks' liability risk to investors. According to the Task Force on Climate-related Financial Disclosures (TCFD, 2017), financial reporting should describe how organisations' governance, strategy, risk management, metrics and targets address its climate-related risks and opportunities. Finansinspektionen (Financial Supervisory Authority of Sweden) (2016) also points out a greater need for information and transparency on climate risk in the financial sector. Investors are likely to demand such information. Investor concerns about climate risk may impact banks' funding costs and equity prices. After the fall in oil prices in 2014, several of the banks with the highest exposures to the oil sector provided regularly updated risk assessments of their own exposures to oil in their financial reporting. Similar actions can also be taken to a greater extent with regard to climate risk.

In the introduction, we pointed out that Finansinspektionen (2016) and Bundesbank (2017) had expressed concerns regarding short planning horizons among financial institutions and analysts. The short horizons may in part prevent some banks from taking full account of climate risks that may materialise much further ahead. As indicated by Finansinspektionen, possible solutions include stress tests and scenario analyses by financial institutions to improve their own understanding and reduce climate risk. In addition to developing and conducting climate stress tests, De Nederlandsche Bank (2017) will also include climate risk more explicitly in its supervision.

The measures proposed by TCFD (2017), Finansinspektionen (2016) and Den nederlandsche Bank (2017) may entail adjustments for banks' lending exposures. A number of Norwegian banks take climate considerations into account in fund management, daily operations and credit standards, and Finance Norway (2018) recommends that banks follow TCFD (2017) recommendations. DNB is participating in a pilot project to implement TCFD (2017) recommendations, which can make climate risk a more important factor in granting new loans.[27] Ongena et al (2018) document some increase in lending margins to fossil fuel companies by banks participating in the project. For the most part, there are also signs of reduced maturities for such loans since the Paris Agreement was signed in 2015.

Changes in banks' capital requirements may, if made, also have an impact on banks' credit standards. In March 2018, the European Commission put forward an action plan on financing sustainable growth.[28] The Commission signalled that it would assess the possibilities for adjusting banks' capital requirements based on climate risk.

Maturities on corporate loans are normally several years. It may therefore take time for changes in credit standards for new loans to be fully reflected in loan portfolios. This suggests that any changes to lending standards should be made before changes are observable in the oil market or other markets that are exposed to climate change and to measures to mitigate climate change.

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[27] Source: UNEP Finance Initiative (2017): Norway's DNB is twelfth leading bank to join UNEP FI's TCFD implementation pilot project.
[28] Source: European Commission action plan on financing sustainable growth.

8. Conclusion

Together with empirical analyses of disruptive technologies (Nagy et al, 2013) applied to solar panel and EV battery technologies, cost analyses, adopted and planned regulations, and automobile manufacturers' plans suggest that the transition to lower growth in oil demand may be speeding up. The risk associated with not adjusting enough in advance may then be an abrupt adjustment later on. Such an adjustment may be driven by the realisation that climate change can have serious impacts such as natural disasters or by the fear of such disasters. This could result in unexpected and substantial tightening of emissions regulations and weaker-than-expected oil demand.

In most scenarios, existing oil production is likely to decline faster than demand, and there is therefore a need for investment in new global oil production in the long term. This will dampen the downside risk for oil prices and investments. Norwegian oil service companies are nevertheless at risk if the rise in oil demand begins to slow markedly. Implemented and possible adjustments related to cost efficiency, restructurings and less use of leverage reduce this risk.

Banks' credit risk may be higher in a structural decline than in a cyclical downturn. The risk is affected by how oil service companies and banks adjust. As the transition to lower oil demand speeds up and because adjustments take time, it may be appropriate to make adjustments before changes in the oil market are visible. Banks can, for example, determine and disclose the climate risk in their portfolios. They can also make use of analyses of stress testing scenarios. This can improve their understanding of risk and have an impact on new lending, which in turn may reduce risk over time. Finance Norway's (2018) recommendations may be an indication that banks will implement such measures. An increase in capital requirements in the EU to address climate risk may expedite banks' adjustments.

Challenges for the banking sector as a whole are not likely to arise until there are substantial spillovers from a structural decline in oil-related industries to other parts of the economy.

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Appendix

A. Wright's law and Moore's law

Wright's law

Wright's law is intuitively grasped as a decline in costs with learning and experience. In this model, for each doubling of cumulative production, learning will take place at a constant rate to generate a learning curve. The relevant unit cost of renewable energy is the "levelized cost of electricity" (LCOE)[29].The model finds that the LCOE falls with each cumulative doubling of production.

According to Beckman, S. and Rosenfield, D. B. (2007), there are several reasons that costs fall over time. The learning effect is due to:

- Labour efficiency improvements and internal experience
- Process redesign, standardisation and automation
- Increased scale and volume
- Shared experience outside and improvements in the value chain

The advantage of Wright's law is that considers cost developments to be integral to production growth. If no production or investment is undertaken, neither will improvements and cost reductions be achieved. This makes the model flexible. A drawback with Wright is that a forecast for future production is necessary for projecting future cost.

On the basis of Nagy et al (2013), Wright's law can be formulated as follows:

$$P_t = Bx_t^{-w}$$

P_t: Unit cost of a technology at time t, in real terms

B: Constant (*b=log B*, where b is the constant in the log-log fit regression)

x_t: Cumulative production at time t

w: Regression gradient where $r = 1 - 2^{-w}$, which is the experience rate (cost decline) for each doubling of production. We find *w* by a linear regression of the logarithms of P_t and x_t.

[29] The "levellzed cost of electricity" is the net present value of the unit cost of electricity over the lifetime of a generating asset. Investment, operation, decommissioning and capital costs are included in the estimation.

Moore's law

Moore's law states that technological improvements will take place, with time the only factor that explicitly affects this. The law derives from an observation made in 1965 by Intel's Gordon Moore that the number of transistors in an integrated circuit doubles about every two years. This has proved to be an accurate extrapolation of developments over the following 50 years. Similar relationships can also be applied to extrapolate cost reductions over time.

Under Moore's law, the rate of improvement over time is constant and can thus be used directly to forecast further developments in technology. A drawback is the absence of factors other than time that affect developments.

On the basis of Nagy et al (2013), Moore's law can be formulated as follows:

$$P_t = Be^{-mt}$$

P_t: Unit cost of a technology at time t, in real terms

m: Exponential rate of change (Cost change per year = e^{-m} -1)

t: Time in the future

B: Constant (*b=log B*, where b is the constant in the log-log fit regression)

Moore's law with uncertainty band

Farmer and Lafond (2016) explore a method for making distributional forecasts on the basis of an empirically validated stochastic process. This results in a forecast with an uncertainty band, validated by testing across industries with the aid of stochastic processes. By analysing 53 technologies in an out-of-sample forecast, they find that most technologies empirically follow a random walk with drift. They use Moore's law as the starting point for this process. Forecast errors will then grow with time, even if the parameters are perfectly estimated. This is due to unpredictable random shocks. With the aid of this forecast, probabilities of possible outcomes can be estimated in addition to the quality of the estimate.

There are a number of examples of structural shifts that change the costs of a technology. Even if such shifts or shocks occur, their magnitude or frequency is insufficient as a refutation of Moore's law for cost extrapolation. What Farmer and Lafond (2016) show empirically is that a long-run trend for each technology exists and can be captured by historical time series without direct information about the underlying technology-specific narrative. The model generates the error in closed form, which can then be pooled and analysed. On this basis, autocorrelated noise is included with the same parameters for all technologies through the analysis of the error. It is this parameter that produces the outcome probabilities for each technology based on the technology-specific historical data.

Farmer and Lafond (2016) believe that an extension of Moore provides a better result than Moore with a stationary trend, but not that this model is necessarily better than others, such as eg Wright. They add that models that include parameters for production, patents and R&D may provide even better forecasts. The model is simplified by assuming that even if drift and volatility are technology-specific, all technologies follow the same random walk. Mathematically, this means that the error distribution is independent of drift, standard deviation and time horizon and can therefore be pooled for different technologies and at different time horizons. In addition, an autocorrelation parameter is included on the basis of the empirical finding of a positive parameter. This makes it possible to extrapolate a normal forecast distribution of future costs.

Assumptions in the model:

- Extending Moore's law to assume that the logarithm of cost follows a random walk with drift and autocorrelated noise
- Noise is assumed to have a Student *t* distribution (<50 observations), and with an *m* higher than 5, the forecast can be assumed to have a normal distribution
- The error is separated into two parts: Error in the average trend and error in unpredictable random shocks
- The trend is found by using as much historical data as possible, that is, with historical data at both end points in the time series.

The mathematical model, extended Moore's law with drift:

$$y_{t+\tau} \sim N(y_t + \hat{\mu}\tau, \frac{\widehat{K} A^*}{1+\theta^2})$$

$$\hat{\mu} = \frac{y_t - y_{t-m}}{m}$$

$$\widehat{K}^2 = \frac{1}{m-1} \sum_{i=t-m}^{t-1} [y_{i+1} - y_i - \hat{\mu}]^2$$

$$A^* = -2\theta + (1 + \frac{2(m-1)\theta}{m} + \theta^2)(\tau + \frac{\tau^2}{m})$$

y_t: Logarithm of the unit cost at time t[30] $(y_t = \log P_t)$

τ: Future time horizon

$\hat{\mu}$: Estimated trend/cost drift with time

θ: Autocorrelation for noise, set empirically at 0.63

$\widehat{K}^2$: Estimated variation

A^*: Constant term for the noise estimate

m: Number of data points in the trailing sample[31]

Comparison of Moore's law and Wright's law

A combination of exponentially decreasing costs and exponentially increasing production will yield similar results for both Moore's law and Wright's law, referred to as Sahal's conjecture (Nagy et al, 2013). On the basis of production and cost data for 62 technologies, Nagy et al (2013) find that production tends to increase exponentially, similar to historical developments for new solar panels (Chart 1).

Nagy et al (2013) and Farmer and Lafond (2016) are surprised at the similarity of Moore's and Wright's forecasts, even though their explanatory variables are different. Sahal's conjecture shows that Wright's law and Moore's law coincide (Nagy et al, 2013). If cumulative production grows exponentially at rate *g*, Moore and Wright share the correlation *m*=*w***g*. This can be used to find *m*, *w*, or *g* if two of the others are known. For example, the rate of production growth necessary to maintain both Moore's and Wright's rate can be found.

Sahal's conjecture: $X_t = Ae^{gt} = Ae^{\frac{m}{w}t}$

Moore describes exponentially decreasing costs with time, while Wright describes exponentially decreasing costs at a given level of cumulative production. Moore's law and Wright's law coincide for different technologies, which show exponential growth in cumulative production (Chart 17).

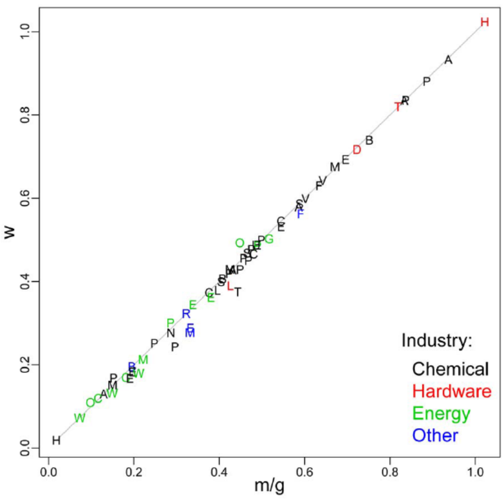
In the paragraph above, rates *m*, *w* and *g* are exponential. For a more intuitive understanding, they can be expressed as follows:

- r_m Annual decrease in cost, where $r_m = 1 - e^{-m}$

[30] Here y_t is the latest cost and only τ is changed for the forecast $(t = t_0)$.
[31] Equal to the number of data points in a rolling window. Empirically demonstrated that a forecast is possible if $m \geq 5$, with the best result with the highest possible m.

- r_g Annual growth in cumulative production, where $r_g = e^g - 1$
- r_w Decrease in cost per cumulative doubling of production, where $r_w = 1 - 2^{-w}$

Chart 17: Wright's law and Moore's law combined with Sahal's conjecture



Source: Farmer and Lafond (2016)

B. Comparison of cost projections

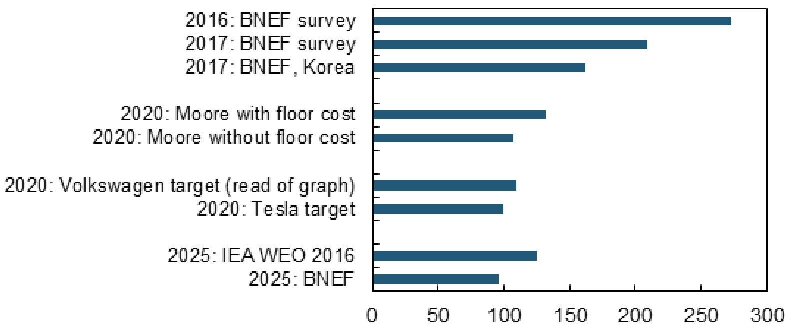
Projections based on Moore's law vary between USD 107 and USD 132 per kWh for 2020 (Chart 6 and Chart 18). These projections represent an extrapolation of the average cost in the BNEF survey, which in 2017 was USD 209 per kWh. The cost decrease may appear to be large, but already in 2017, BNEF estimates that some Korean manufacturers can produce batteries for as little as USD 162 per kWh.

Elon Musk, the CEO of Tesla, has previously expressed disappointment if the company do not reach its target of USD 100 per kWh by 2020. In September 2017, Volkswagen announced a battery cost target for 2020 of under EUR 100 per kWh 2020 and presented a graph showing battery costs lower than this.

The IEA *World Energy Outlook 2016* projects battery costs of USD 125 per kWh in 2025 and BNEF projects USD 96 per kWh for the same year.

The cost projections for 2020, here based on Moore's law, are higher than the possible cost-leading targets of Tesla and Volkswagen, while they are lower than IEA projections, which assume a slower cost decrease.

Chart 18: Historical battery costs, projections (Moore's law) and targets going forward. USD per kWh



Sources: IEA, BNEF, Volkswagen, Tesla and Norges Bank

C. Sensitivity analyses for electric vehicles (EVs)

We perform a present value analysis with a 6 percent discount rate that takes into account partial financing of the vehicle. We assume the annual Norwegian driving distance, according to Statistics Norway, and that the vehicle has a useful life of 20 years and is driven 231 000 kilometres over that period.

More than 300 000 vehicles were provisionally ordered when Tesla presented its Model 3 in 2016. Its range was reported to be at least 215 US miles or at least 346 kilometres according to the EPA standard. This may be a sufficient range for the mass market. The smallest battery pack for the Model 3 is 50 kWh, and we assume 60 kWh to take into account somewhat larger vehicles.

EV batteries are expensive, while other costs, such as for the motor and gearbox, will be lower than for vehicles with combustion engines. Here these costs are assumed to amount to EUR 2000. More stringent emission standards in Europe will push up these costs further, but this is not taken into consideration in the sensitivity analysis.

Household electricity prices, fuel prices and exchange rates were gathered on 9 June 2017. We assume that households can charge at the electricity price, which is possible for those that can charge their vehicle at home. Higher costs associated with charging elsewhere are not taken into account.

Omitted from the assumptions are various one-time charges, vehicle tolls or maintenance expenses for EVs and vehicles with combustion engines. The latter may be conservative for EVs, since they have fewer moving parts that wear out. Battery packs are often guaranteed to retain at least 70-75 percent of original capacity at 100 000 miles or 160 000 kilometres driven, which represents 69 percent of the useful life in our analysis.

D. Technological advances in transport

Over the next five years, most automobile manufacturers have plans to launch new electric passenger cars. Several of the large German auto manufacturers plan for electric passenger cars to account for 15–25 percent of sales in 2025.[32] The projections for electric passenger cars have risen substantially in recent years and may continue to change, but the trend towards more electric passenger cars is clear.

A number of manufacturers offer electric busses and short-distance delivery vehicles. Given a focus on local air quality, these segments have the potential for a high degree of electrification as battery costs fall. Other reasonably stationary utility vehicles and construction machinery should also have the potential for increased electrification. The same applies to vessels used for short distances. Norwegian companies are involved in the design and construction of such vessels and can thus profit from increased electrification. Owing to more stringent emission standards from 2020, liquefied natural gas (LNG) propulsion is more likely for vessels for longer distances.

Long-distance goods transport is, for now, a more uncertain segment for electric transport, while it accounts for a substantial portion of global fuel consumption.[33] New vehicle technologies for goods transport may quickly have a considerable impact on fuel consumption, as the driving distance for these vehicles normally substantially declines with vehicle age owing to wear and tear.

Currently, there are few manufacturers of EVs in this segment with a range of more than 200 kilometres. However, Tesla is accepting orders for lorries with a range of up to 800 kilometres, with deliveries planned to begin in 2019. Even though fewer than a thousand such lorries have presumably been ordered as of December 2017, this development may prompt other manufacturers to develop similar products. For example, the US company Navistar, with an 11 percent share of the domestic market, claims that it will have more electric lorries on the road than Tesla in 2025.[34] Further cost declines for batteries and expectations of lower weight and volume relative to storage capacity may support this development. Another possibility is for this segment to be covered more by other technologies, such as hydrogen, which according to BNEF the Chinese authorities are considering.

The Norwegian company Asko AS has a fleet of 600 trucks, and according to *Teknisk Ukeblad*, the ambition is for all to be powered by

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[32] Daimler (Mercedes) projects 15-25 percent fully electric vehicles, for BMW the figure is 15-25 percent electric vehicles in general and Volkswagen projects sales of up to 3 million electric vehicles versus total motor vehicle sales of around 10 million. Sources: Automobile manufacturers' investor relations presentations.
[33] Land-based freight represents around 1/6 of global oil demand (Source: IEA). Rail accounts for a small portion of the energy consumption for land-based freight and is electrified in some regions. Growth in rail freight can improve fuel efficiency. Source: International Union of Railways, *Rail Transport and Environment Facts & Figures*, September 2015.
[34] Source: Navistar CEO to Tesla: We'll Have More Electric Trucks Than You.

renewables in the form of hydrogen or electricity by 2026. For now, few other companies have such radical plans, but our observations also indicate that few oil market participants assume that a substantial portion of land-based goods transport will be powered by renewable energy over the next 15 years. This may therefore represent an underappreciated transition risk.

Nor do many oil market participants expect that air transport will be electrified. According to the Norwegian National Transport Plan (2017), electric aircraft have undergone a rapid evolution, and a number of aircraft manufacturers are now working on electric aircraft projects. Avinor, the operator of most civil airports in Norway, will work together with relevant manufacturers and airlines and has announced a goal for all short-haul air traffic in Norway to be electric by 2040.[35]

[35] Source: Norsk luftfart skal bli elektrisk i 2040 [Norwegian aviation to be electric in 2040] (in Norwegian only).