Oil Market Futures

FINAL US REPORT

A report for the Energy Foundation

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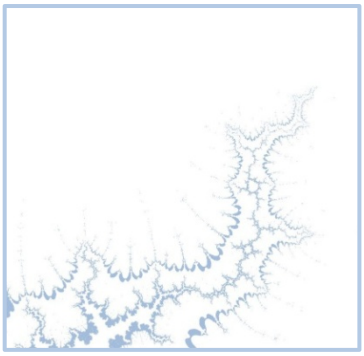

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Contents

Key messages

- Policies to tackle climate change are likely to lead to lower oil prices, according to the results of this analysis. As governments start implementing the Paris Agreement, they will increasingly need to cut carbon emissions from transport by curbing the combustion of petroleum fuels. Lower oil prices will prevail in this lower-demand scenario, compared to a business-as-usual scenario where oil demand would rise unchecked and in line with economic growth and expanding mobility trends.
- Amid today's low oil prices, it is easy to forget the long-term fundamentals. The sharp fall in oil prices since mid-2014 has created considerable uncertainty in global energy markets. Although initial reductions in the oil price were due to low-cost US shale oil production and OPEC's response, more recently the volatility in prices has been due to short-term market uncertainty in light of unprecedented levels of oil stocks in rich countries, slowing economic growth in China, new supplies from Iran, among other factors. This follows a period in which geopolitical factors, such as conflict in Ukraine and the rise of the Islamic State in Iraq, helped push oil prices to $100-$120 per barrel over the period 2011-2014.
- While short-term factors, such as geopolitics, speculation and sentiment, play a role in setting spot prices for oil, in the long-term the most important factors are those that affect the marginal cost of development. One such factor is the imperative to tackle climate change.
- Governments are meeting this challenge by setting policies that signal a long-term direction of travel for investment in low-carbon solutions. For example, the US has set a target to reduce greenhouse gas emissions by 28% by 2025 in-line with a long-term ambition to reduce greenhouse gas emissions by more than 80% by the middle of the century. In the time horizon of 2025-2050, it is most relevant to consider oil markets in terms of the long-term fundamentals.
- In a world without climate policies to drive investment in low-carbon technologies, this study finds that global demand for oil would grow from 94 million barrels per day (mbpd) in 2015 to 112 mbpd in 2030, an increase of 19%. By 2050, demand would grow by a further 35% to 151 mbpd, primarily driven by economic growth in Asia and higher demand for aviation.
- The global crude oil market in 2015 had an excess of 2 mbpd of supply over demand due to rapid increases in US production and OPEC's strategic response to maintain market share. However, anticipated growth in oil demand out to 2020 should absorb this over-supply, and existing production will continue to decline, aggravated by under-investment amid current low oil prices. This would lead to a situation in the 2020s where significant investment in new non-OPEC production capacity is needed, and oil prices will need to rise to around $80 per barrel to stimulate that production. Ultimately, without major new finds or step changes in production techniques, increasing demand would push world prices above

$90 per barrel by 2030 and over $130 per barrel by 2050 (in 2014 prices).

- By contrast, in a world where climate policies are being implemented to drive investment in low-carbon technologies, demand for oil will be significantly lower than in a business-as-usual case: by around 11 mbpd in 2030 and by 60 mbpd in 2050. This analysis found that vehicle efficiency standards implemented globally between 2000-2015 have already prevented the consumption of around 5 billion barrels of oil. In our Technology Potential scenario, policies that further push vehicle efficiency and electric-drive technologies into the market and reduce fuel consumption by aircraft and ships could lead to an inflexion point in 2025, after which oil consumption would steadily decline. Cumulatively, these policies could cut oil demand by 260 billion barrels between 2015 and 2050.
- This reduction in demand delays the need to invest in extracting increasingly expensive oil from non-conventional sources, and the long-term market price of oil would settle around a stable band between $83 and $87 per barrel from 2030 to 2050. In other words, the global deployment of technologies to mitigate CO_2 emissions would cause oil prices to be lower than they would otherwise be in a business-as-usual scenario: Around 8.5% lower in 2030; 24% lower in 2040; and 33% lower in 2050, according to the results of this analysis.
- The central findings of this study reinforce the findings of the International Energy Agency (IEA). In the World Energy Outlook (2015), the IEA projects that if mankind constrains atmospheric greenhouse gas emissions below 450 parts per million - a level generally seen as consistent with meeting the 2°C climate target - the global demand for oil in 2030 would be around 86 mbpd, compared to 104 mbpd in a scenario based on current policies.
- While the IEA study uses slightly different assumptions, it finds a comparable impact on oil prices: Prices would settle around $90 per barrel after 2030, rather than increasing to around $150 per barrel by 2040 in the current policies scenario.
- The US economy will be better off in the long run as a result of lower oil prices, despite the lost revenue for US oil producers. The US, which produced around 9.5 mbpd of oil in 2015, would see a small reduction in GDP arising from the fall in production to meet lower global demand for oil in the TECH scenario. However, this would be more than offset by the impact of lower oil prices, which lead to a net positive impact on the US economy.
- Lower oil prices reduce inflationary pressure on consumers, increasing real incomes and allowing for more expenditure on other goods and services that provide larger domestic value-added for the US economy.
  As a result of the lower oil prices modelled in this analysis, US average incomes would be 0.4% higher by 2030 and 1.3% higher by 2050, relative to business-as-usual. US GDP would be 0.2% higher by 2030 and 0.5% higher by 2050. This would drive a 0.1% net increase in employment by

2050, equivalent to more than 172,000 extra jobs, which would mostly be created in the service sectors, reflecting typical household consumption patterns.

- It is important to note that the economic benefits described above are the result of oil price impacts in isolation. The transition modelled here would also lead to other important shifts in spending in the US economy. Economic impacts can be derived from the increased investment in low-carbon technologies and energy sources, as well as from more efficient mobility, which allows a shift in spending away from mobility and towards other areas of the economy. The study “Fuelling Europe’s Future”[1] shows that, for Europe, such a transition for cars and vans alone could deliver an additional 1% to EU GDP by 2050.
- This study also delivers important insights into the long-term viability of exploration for unconventional oil sources. At the level of demand projected in the Technology Potential scenario, it would not be profitable to extract oil from the Artic; from many deep-water oil reserves; as well as from in-situ tar sands.
- In summary, if implemented globally, policies to tackle carbon emissions for transport will lower global oil prices, with a positive impact on many oil-importing economies and important implications for the profitability, or not, of unconventional oil extraction.

[1] See Fuelling Europe’s Future, for more details.

Executive Summary

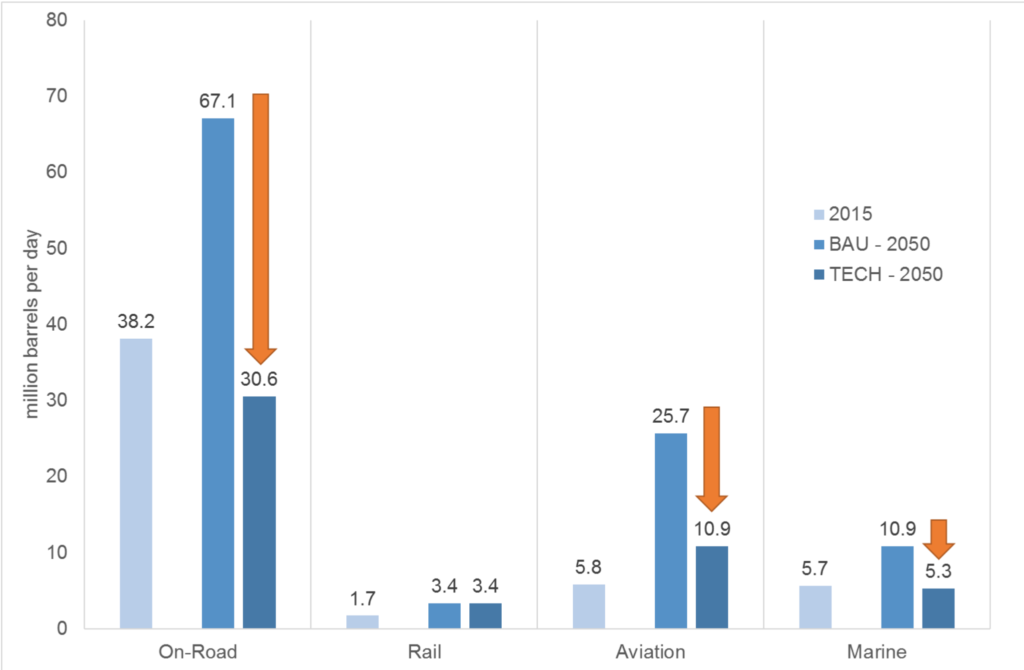
The scope of the study

- The European Climate Foundation commissioned Cambridge Econometrics (CE), the International Council on Clean Transportation (ICCT) and Pöyry Management Consulting to carry out research into the potential of transport technology to reduce oil consumption and its subsequent impact on oil prices and the wider economy, by:
  - developing alternative but plausible scenarios for global oil demand, which the ICCT developed by applying its policy and technology framework for transport
  - analysing oil production and prices in response to changes in demand, through the application of Pöyry's Cronos oil market model
  - modelling the wider economic impact of changes in crude oil prices, through the application of CE's macroeconomic model E3ME to understand the impact on the US economy
- To improve the robustness of the findings, a series of sensitivities were undertaken to explore differences in demand projections and future supply expectations and supplier behaviour. Throughout the project, the research team consulted with stakeholders with a working interest in climate and energy policy who provided feedback and expert knowledge.

Oil demand scenarios

- Two main scenarios of oil demand from transport were developed:
  - The Business-As-Usual (BAU) scenario takes into account the technology-forcing policies that have been adopted to date for on-road vehicles, aircraft, and marine vessels. Policies include the 95gCO2/ km regulation for passenger cars and 147gCO2/km for light commercial vehicles in the EU in 2021 and 2020 respectively; light-duty vehicle standards for 2017-2025 in the US and Canada as well as Phase 1 regulations for Heavy-Duty Vehicles (HDV); Light-Duty Vehicle (LDV) regulation in China, Japan, India, South Korea, Brazil and Mexico; heavy-duty vehicle regulation in Japan and China; and the Energy Efficiency Design Index and the Ship Energy Efficiency Management Plan rules in the marine sector.
  - The Technology Potential (TECH) scenario presents the ICCT's view of the plausible adoption of transport technologies over the projection period. It considers the strengthening of technology-forcing policies for LDVs and HDVs, passenger aviation and international marine. It assumes an extension of existing vehicle efficiency regulations, as well as an expansion of these policies to the rest of the world.
- Modelling the scenarios leads to two very different projections of world transport oil demand (see Figure ES.1). By 2050, policies that push vehicle efficiency and electric-drive technologies into the market and reduce fuel consumption of aircraft and marine vessels (consistent with the TECH scenario) could reduce annual oil consumption after its peak in 2025, and avert a doubling of transportation oil demand from 2015 to 2050 that is projected under the BAU scenario. Cumulatively, the policies and technologies associated with the TECH scenario could cut oil demand by 260 billion barrels from 2015 to 2050 compared to the BAU scenario. Notably, the scale of these potential savings (56.9 mbpd) in 2050 is greater than the total level of transportation oil demand in 2015 (51.4 mbpd).

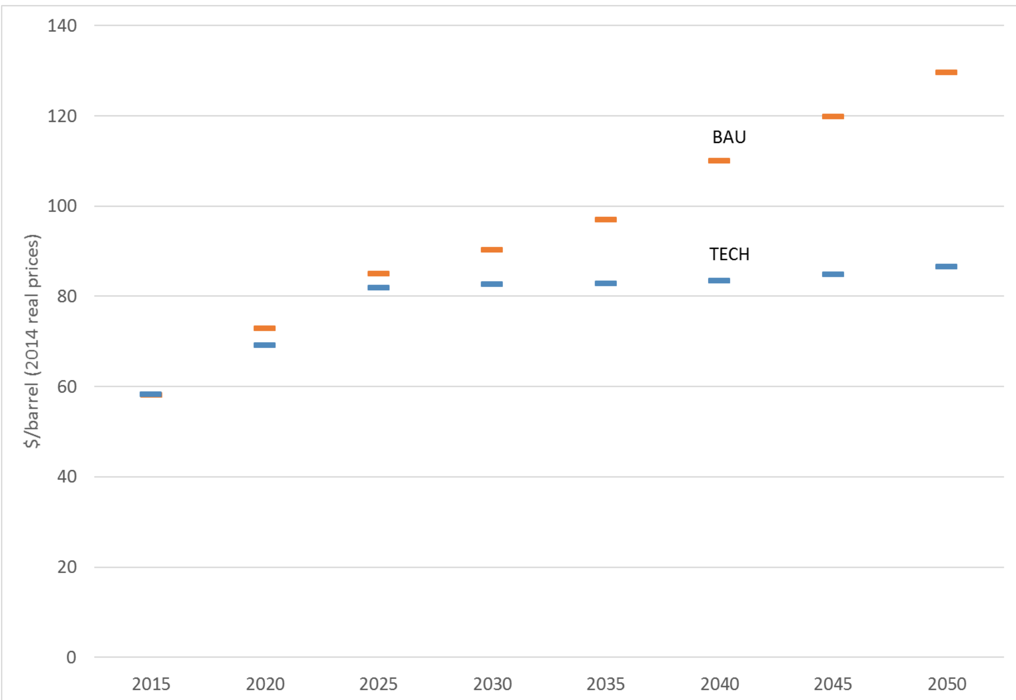
Figure ES.1: Global oil demand from transport



Oil prices

- Reducing oil demand by 11 mb/d in 2030 and 33 mb/d in 2040 (the difference between the TECH and BAU scenarios) could reduce oil prices by $8/barrel and $27/barrel, respectively (see Figure ES.2). This reduction would save an average of $330 billion in crude oil consumption each year between 2020 and 2030.
- This difference may be as high as $37/barrel in 2040 if the incremental

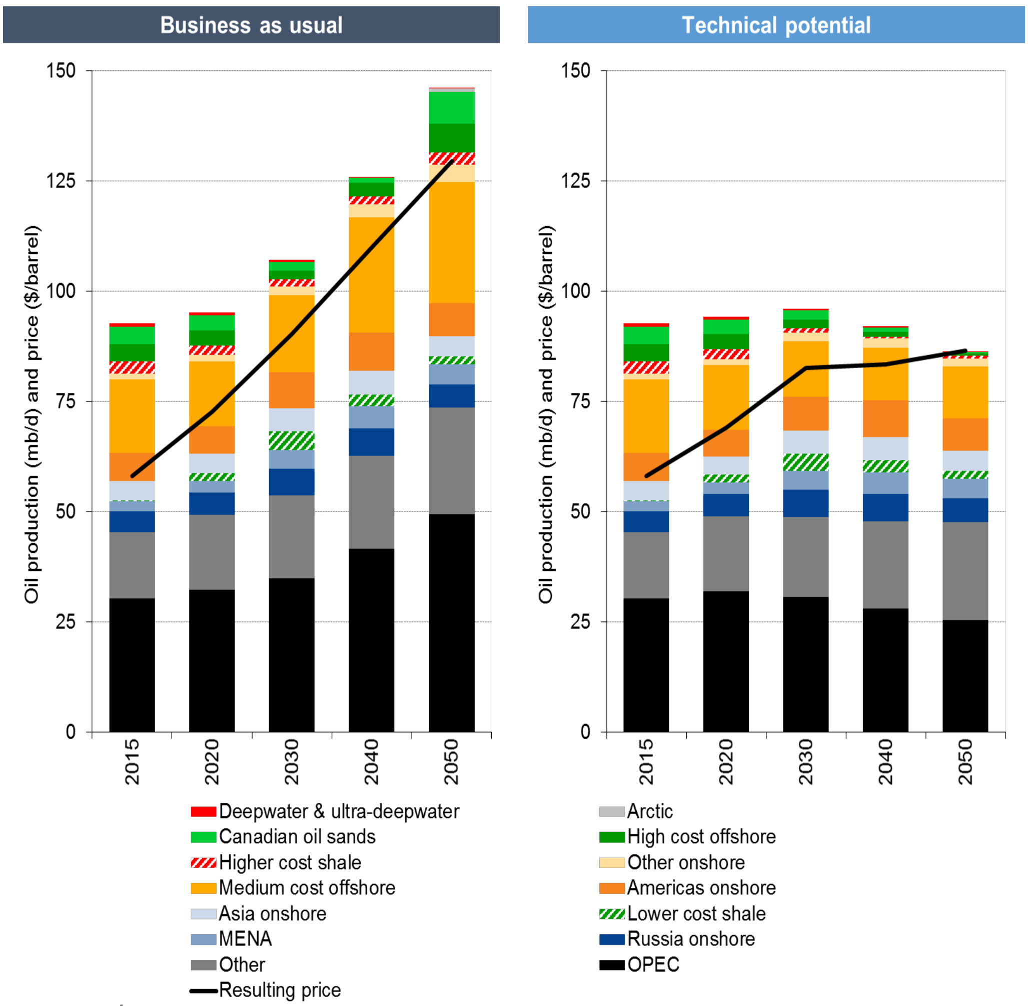
Figure ES.2: Oil price projections



reserves required in a high demand scenario are more difficult to access. When taking a more conservative assumption for non-OPEC source availability, more expensive sources are required both in the TECH and the BAU scenario. The price reduction potential in this case increases to 15% in 2030 and to 29% in 2040.

- The modelling of long-term market fundamentals projects that for the BAU scenario, oil prices will recover to $80/barrel by around 2020. The oil market in 2015 had an excess of 2 million barrels per day of supply over demand due to rapid increases in US production and OPEC's strategic response to maintain their market share. Oil demand will continue to grow to 2020 and existing production is projected to decline, causing prices to return to $80/barrel after 2020 under the scenarios used in this study.
- If OPEC pursued a more aggressive strategy, prices could be reduced further by 1.5-4% compared to the TECH scenario from the late 2030s. Performing a sensitivity on the TECH scenario with OPEC pursuing a strategy to increase its market share led to price decreases from $82.7/barrel to $81.5/barrel in 2030, and from $83.5/barrel to $81.0/barrel in 2040.

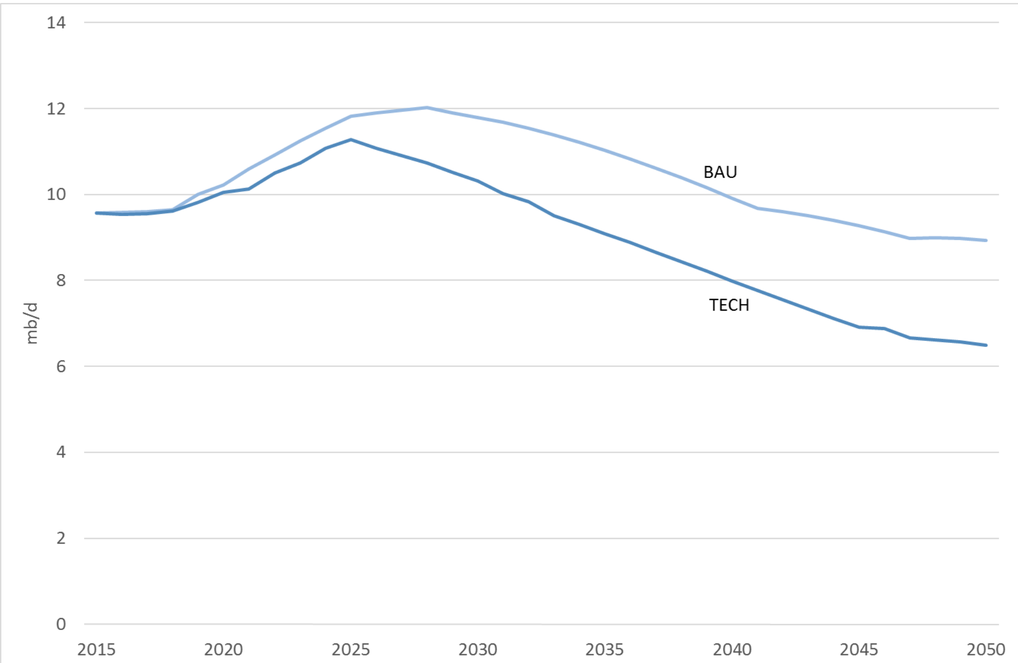
Figure ES.3: Oil production by source



Oil production

- As prices return to $80/barrel in the 2020s in both scenarios, U.S. shale oil will return to production growth since most US shale is economical at this price. Although US shale oil production growth has been more resilient than expected in response to lower prices, the second half of 2015 has seen a reversal of production growth and a fall in production is expected in 2016 in light of very low prices. Around 75% of shale resources are economical to produce at prices above $80/barrel and therefore as prices recover in all the scenarios we see an increase in US production until 2025 from around 9.5 mb/d in 2015 to 11.3 mb/d by 2025 in both scenarios (see Figure ES.4). After this date, more and more lower-cost shale oil sources are expected to be mostly depleted and more expensive sources are not economical at the $80/barrel price that is maintained in the TECH scenario. As a result, U.S. production decreases from 2025, reaching 6.5mb/d in 2050 in the TECH scenario while in the BAU scenario, more shale sources are produced due to meet the higher demand.
- In this case, OPEC market share could increase from 40% to 44% in 2040 and to 48% in 2050. As prices return to $80/barrel in the 2020s in both scenarios, U.S. shale oil will return to production growth (see figure ES.3). We believe that around 75% of shale resources are economical to produce at prices above $80/barrel, and therefore as prices recover in all the scenarios we see an increase in US production until 2025
- Given the very high cost of ultra-deepwater and Arctic sources, these would only be available at prices significantly above $100/barrel. Reduced oil demand and lower prices are therefore expected to lead to prevent the need for production from deepwater and Arctic sources. While in the BAU scenario, some of these sources are being developed in the 2040s, they are not economically recoverable in the TECH scenario.

Figure ES.4: US oil production



Impacts on the US economy

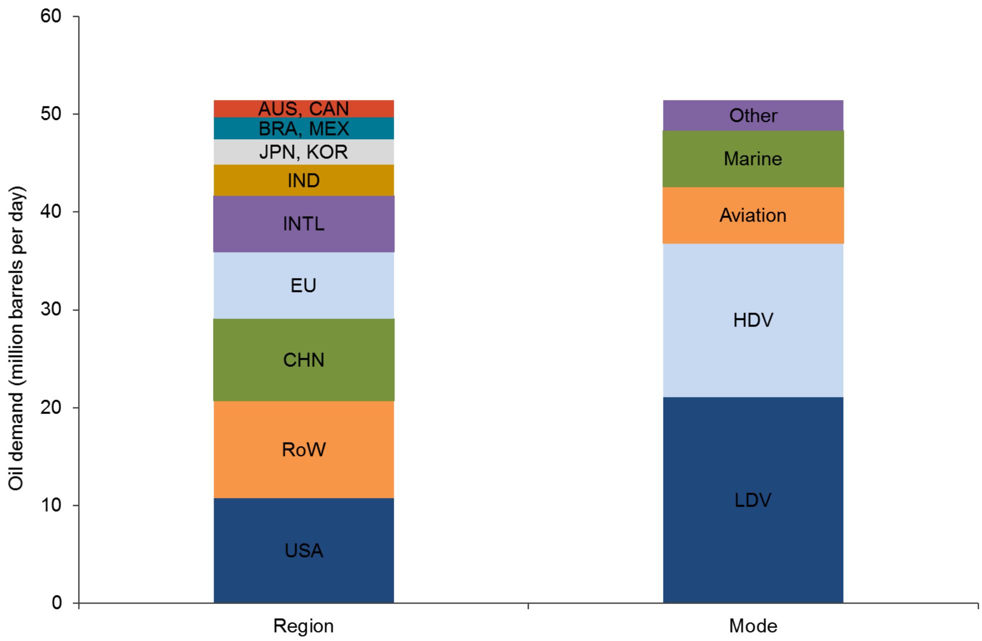
- The US benefits from the oil market effects associated with a global transition to more efficient modes of transport. However, the impacts and economic flows following lower oil prices in the US economy are somewhat different to those in the EU, as reported in the European version of this study.
- The net impact on GDP as a result of the lower oil prices and production in the TECH scenario is 0.4-0.5% by 2050, which is similar in scale to the GDP impact in the EU. The GDP impact can be decomposed into two impacts working in opposite directions. There is a positive GDP impact arising from lower oil prices of around 0.1-0.2% by 2030 and 0.6-0.7% by 2050. However, the US is a large producer of oil and as a result of the fall in global oil demand, there is a small reduction in US oil production which leads to a -0.2% impact on GDP by 2050.
- The net impact on employment following the oil price and oil production changes in the TECH scenario reaches 0.1% (172,000 jobs) by 2050. The oil extraction sector has a low labour intensity, so the negative impact on employment in the US oil extraction sector and its supply chain is small, equivalent to a reduction of around 15,000 jobs by 2050).

1 Oil demand scenarios

1.1 Scenario definition

In 2015, the global transportation sector consumed more than 51 million barrels of oil per day (mbpd) (see Figure 1.1). While passenger aviation and international marine each account for roughly 11% of this total, on-road vehicles account for most of the volume of fossil fuels consumed for transportation. In regional terms, the U.S., EU, and China together account for just over half of the global total.

Figure 1.1: Oil demand from transport by region and by mode, 2015



This study estimates global oil demand in all transport sectors – on-road, rail, marine, and aviation – to 2050, as well as the potential to reduce oil demand with the implementation of technology-forcing policies. Technology-forcing policies include those that trigger improvements in vehicle efficiency and the uptake of new vehicle technologies (e.g., electric-drive vehicles), as well as improvements in the efficiency of new and in-use aircraft and marine vessels. Beyond current shares of alternative fuels, the main scenarios in this study do not consider increasing biofuels shares because of a lack of consensus in how to assess the life-cycle carbon effects of different fuel pathways, open questions about the effects of biofuel policies on food production, and concern about the ability to develop and commercialize truly low-carbon biofuels. The potential impacts of biofuels and unforeseen efficiency technologies are addressed as sensitivity scenarios.

Three main scenarios are considered in the analysis:

Reference scenario

The reference (REF) scenario is a counterfactual scenario in which technology-forcing policies put in place after 2000 are not accounted for. The REF scenario is compared to the BAU scenario only for the period 2000-2015 to determine the historical impact of adopted technology-forcing policies on oil consumption in the transport sector. These results are used to determine the historical impact of policies included in the BAU scenario on oil prices to date.

The REF assumes no further improvements to the efficiency of light-duty vehicles (LDVs) after the year 2000, and no further improvements after 2010 for heavy-duty vehicles (HDVs). Since sales of electric-drive vehicles are concentrated in regions that have promoted the deployment of these vehicles with fiscal and non-fiscal incentives, the REF case assumes a global market share of less than 0.5% for electric-drive vehicles. For marine and air transport, REF assumes no change from the BAU before 2015.

Business-As-Usual scenario

The business-as-usual (BAU) scenario takes into account the technology-forcing policies that have been adopted to date for on-road vehicles, aircraft, and marine vessels. Table 1.1 summarizes the policies that have been adopted to promote the efficiency of LDVs, HDVs, aircraft, and marine vessels in major markets and internationally.[2] International policy forums include the International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO) for aircraft and marine vessels, respectively. These adopted policies are included in the BAU scenario and described in detail in the ICCT's State of Clean Transport Policy publication.[3]

Table 1.1 Adopted efficiency policies in the BAU scenario[4]

Region	Policies (latest model year)
China	LDV Phase 3 (2020)[5]; HDV Phase 2 (2015)
EU	PC 95 gCO_2/km (2021); LCV 147 gCO_2/km (2020)
US	LDV 2017-2025; HDV Phase 1 (2014-2018)
Japan	LDV (2020); HDV (2015)
Brazil	LDV Inovar-Auto (2017)
India	LDV (2022)
Russia	N/A
Canada	LDV 2017-2025; HDV Phase 1 (2014-2018)
South Korea	LDV (2020)
Australia	N/A

[2] Miller, J. & Façanha, C. (2014). The State of Clean Transport Policy: a 2014 synthesis of vehicle and fuel policy developments. International Council on Clean Transportation.

[3] Ibid.

[4] Sourced from Miller, J. & Façanha, C. (2014). The State of Clean Transport Policy: a 2014 synthesis of vehicle and fuel policy developments. International Council on Clean Transportation.

[5] At the time of this analysis, China's Phase 4 standard for passenger cars had not yet been finalized. The generalized impacts of Phase 4 are included in the TECH scenario.

Mexico	LDV (2016)
International	Marine EEDI / SEEMP; No Aviation CO_2 standard

Electric vehicles are not expected to play a large role under the BAU scenario

The ICCT has reviewed the literature[6] on future scenarios for electric-drive vehicle uptake, finding that these estimates vary greatly across studies.[7] These studies assess three major types of electric-drive technology: plug-in hybrid (PHEV), full-battery electric (BEV), and hydrogen fuel cell (FCEV). While the term plug-in electric (PEV) includes only PHEV and BEV, this study considers all three electric-drive technologies, including hydrogen FCEV. Generally, earlier studies that assumed greater technical advancement (e.g., in battery technology) and increased policy support (e.g., research and development, infrastructure, regulation) find that leading markets could achieve a 20-50% market share (in terms of new vehicle sales) in the 2025-2030 timeframe. Many of these studies applied back-casting approaches to determine what is needed for long-term climate stabilization. Other studies that considered more conservative supply constraints, lesser policy support, and lesser technical advancement generally found that the electric vehicle market in various leading countries could remain as low as 5% of new vehicle sales in the 2025-2030 timeframe.[8]

Several leading markets have adopted a combination of policies to promote sales of electric-drive vehicles. These leading markets include the US (especially California), EU (especially Norway and the Netherlands), China, Japan, and South Korea.[9] Although there are several relatively high electric vehicle uptake areas (e.g., Norway, Netherlands, California), plug-in electric vehicle (PEV) shares for Europe, the US, China, and Japan were each below 1% in 2014. In total, approximately 300,000 PEVs were sold in 2014, equivalent to 0.5% of world 2014 car sales.[10]

Efficiency and CO_2 regulatory requirements at currently adopted levels (e.g., 95 gCO_2/km in Europe and 54.5 mpg in the US) will not be sufficient to push electric vehicles into the fleet in significant levels without sustained electric-vehicle-specific policy support, even as technology costs decrease over time.[11,12] To date, there is only one binding policy to require electric-drive

[6] BCG (2011); Bharat Book (2014); CARB (2011); Element Energy (2013); ETS Insights (2014); Greene et al (2013; 2014); IEA (2011); IEA (2013); JD Power (2013).

[7] Lutsey, N. (2015). Transition to a global zero-emission vehicle fleet: A collaborative agenda for governments. International Council on Clean Transportation. Retrieved from http://www.theicct.org/transition-global-zero-emission-vehicle-fleet-collaborative-agenda-governments

[8] Ibid.

[9] Lutsey, N. (2015). Transition to a global zero-emission vehicle fleet: A collaborative agenda for governments. International Council on Clean Transportation. Retrieved from http://www.theicct.org/transition-global-zero-emission-vehicle-fleet-collaborative-agenda-governments

[10] Ibid.

[11] Meszler, D., German, J., Mock, P., & Bandivadekar, A. (2013). Summary of mass reduction impacts on EU cost curves. International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_MassReductionImpacts_feb2013.pdf

[12] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration (U.S. EPA and NHTSA) (2012). 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule.

vehicles, California's Zero Emission Vehicle (ZEV) program. The ZEV program requires an increase in California's electric-drive vehicle market share from 3% in 2014 to 15-20% of new vehicles in 2025.[13] California represented about 2% of world automobile sales and about 19% of worldwide electric vehicle sales in 2014. Other than the ZEV program, fiscal incentive policy is another major driver of PEV sales worldwide.[14] In addition, there are many consumer-oriented national and local activities, including preferential access (parking, low emission zone, carpool lane, etc.), public charging infrastructure support, and consumer awareness campaigns that are in place to promote electric-drive technologies.[15]

As with vehicle efficiency standards, the BAU scenario does not assume expanded adoption of policies to promote electric-drive vehicles. Based on the ICCT's review of the literature on future scenarios for electric-drive vehicle uptake, and complemented by ICCT's findings on the impacts of electric-drive policies adopted to date, the BAU scenario assumes that sales of electric-drive vehicles in leading markets will increase from 0.5% in 2014 to 3-5% of new vehicle sales in 2030. Electric-drive sales shares in other markets are assumed to remain at less than 1% in the absence of supporting policies.

The average fuel economy of new aircraft increased 1.15% annually from 2010 to 2015.[16] In the absence of an adopted global CO_2 standard for aircraft, the BAU scenario assumes no further improvements after 2015. For marine, the BAU assumes successful implementation of the Energy Efficiency Design Index (EEDI), which requires new vessels to be up to 30% more efficient by 2025 compared to a 2005 baseline.

Technology Potential scenario

The Technology Potential (TECH) scenario considers the strengthening of technology-forcing policies for LDVs and HDVs, passenger aviation and international marine. It assumes an extension of vehicle efficiency standards in markets with pre-existing policies, as well as an expansion of these policies to the rest of the world. The annual rates of improvement for LDV efficiency are based on the mid-range scenario in a comprehensive technology assessment conducted by the National Research Council (NRC) (Table 1.2).[17] These rates are differentiated by LDV technology, including internal combustion engines (ICE) and hybrids as well as electric-drive vehicles. For those regions without pre-existing standards, this study assumes efficiency improvements starting in 2020.

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[13] Ibid.

[14] Mock, P., and Yang, Z. (2014). Driving electrification: A global comparison of fiscal policy for electric vehicles. International Council on Clean Transportation. Retrieved from http://www.theicct.org/driving-electrification-global-comparison-fiscal-policy-electric-vehicles

[15] Lutsey, N., Searle, S., Chambliss, S., & Bandivadekar, A. (2015). Assessment of leading electric vehicle promotion activities in United States cities. International Council on Clean Transportation. Retrieved from http://www.theicct.org/leading-us-city-electric-vehicle-activities

[16] Kharina, A. & Rutherford, D. (2015). Fuel efficiency trends for new commercial jet aircraft: 1960 to 2014. International Council on Clean Transportation. Retrieved from http://www.theicct.org/fuel-efficiency-trends-new-commercial-jet-aircraft-1960-2014

[17] National Research Council (2013) Transitions to Alternative Vehicles and Fuels. National Academies Press. http://www.nap.edu/catalog.php?record_id=18264

Table 1.2 Annual light duty vehicle efficiency improvements in the TECH scenario

Vehicle technology	Years 1-10	Years 11-20	Years 21-30
ICE/hybrid	4.0%	3.0%	2.2%
BEV	2.1%	1.7%	1.5%
FCEV	2.4%	2.0%	1.8%

Figure 1.2 New passenger car efficiency trends in the TECH scenario

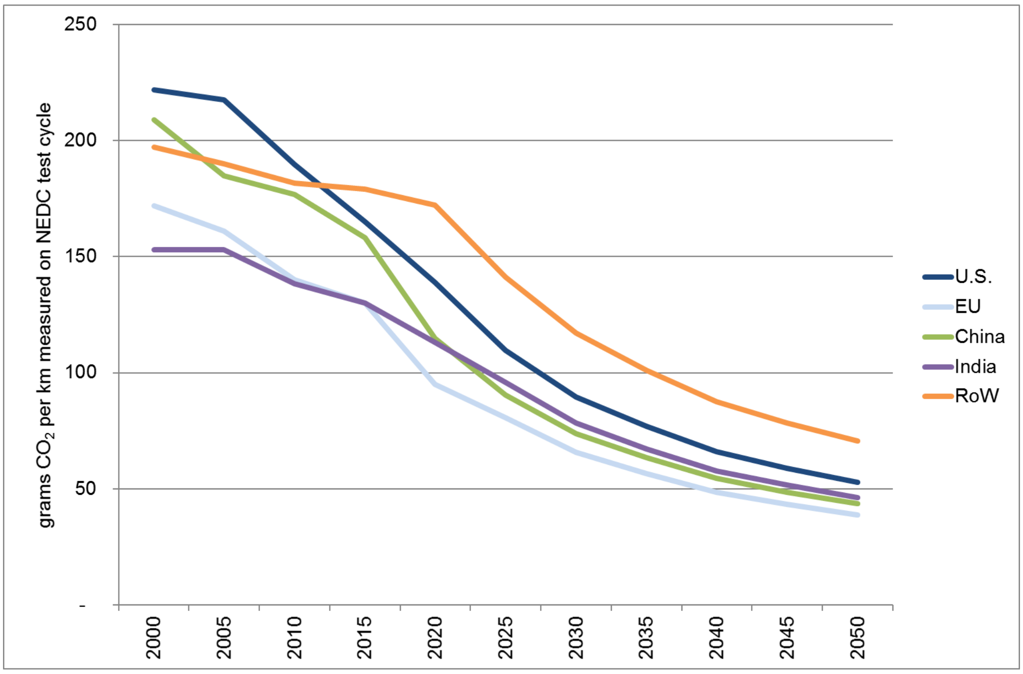
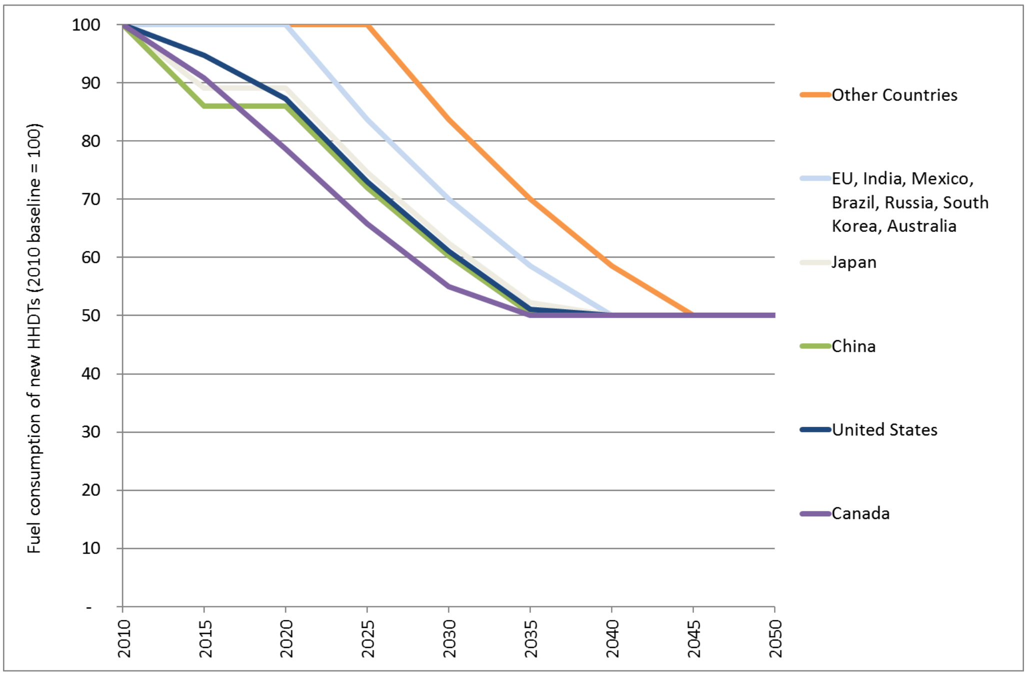


Figure 1.2 illustrates the effects of these improvements on test cycle CO_2 rates in four major markets; the trend in other regions is shown as a sales-weighted average. The CO_2 rates of new vehicles as measured on laboratory test cycles (shown in Figure 1.2) are converted to real-world rates based on the observed gap between regulatory requirements and in-use vehicle efficiency in the EU.[18] This study considers a 35% gap for LDVs in the EU and a 25% gap for other regions. The TECH scenario assumes that this differential decreases by ten percentage points from 2030-2050 as a result of improvements to regulatory testing procedures.

[18] Tietge, U., Zacharof, N., Mock, P., Franco, V., German, J., Bandivadekar, A. (ICCT), Ligterink, N. (TNO), Lambrecht, U. (IFEU) (2015). From laboratory to road: A 2015 update. Retrieved from http://www.theicct.org/laboratory-road-2015-update

Studies have found a technical potential to reduce the fuel consumption of most types of HDVs by 40% to 50% from 2009 to 2020.[19] The TECH scenario assumes annual improvements of 3.5% in each region until fuel consumption

Figure 1.3 Heavy heavy-duty trucks efficiency trends in TECH scenario



rates are 50% below their respective 2010 levels. Figure 1.3 illustrates these assumptions for new heavy duty trucks in each region. Countries that have already adopted HDV efficiency standards (US, Canada, Japan, and China) are assumed to extend these standards. Other major vehicle markets are assumed to improve HDV efficiency starting in 2020, with the rest of the world following these major markets starting in 2025.

Because of the significant uncertainty associated with post-2030 extrapolations, these assumptions are meant as indicative of possible technology potential based on leading studies. In addition, these assumed vehicle efficiency improvements match well with established, politically-realistic goals that governments have implemented in their first, second, and third phases of efficiency regulations. The lesser percent-per-year efficiency gains in later years reflect that best available long-term technology study (NRC, 2013), as referenced above.

As previously indicated, the TECH scenario includes increasingly stringent regulations for LDV efficiency; however, it is uncertain precisely what levels of electric-drive vehicle uptake will result from extending these standards through 2030 and beyond. Based on the ICCT's review of studies of the underlying technology and market factors, the long-term transition to an electric-drive

[19] National Research Council (2010), National Research Council (2014), ICCT (Meszler et al, 2015), and TIAX (2009) for the US market; AEA-Ricardo (2011) and TIAX (Law et al, 2011) for the European market.

fleet will require sustained consumer incentives, public outreach, public charging infrastructure and more stringent regulatory standards.[20]

To date, California has adopted among the most comprehensive systems for electric-drive vehicle promotion in a major market (i.e., requiring over 1 million new vehicles per year).[21,22] California's policy support system includes direct electric-drive vehicle regulation, progressive long-term CO_2 standards, fuel provider regulations, utility policies, fiscal consumer incentives, additional consumer perks, consumer awareness programs, and committed long-term financing. Several European markets like the Netherlands and Norway have similar support activities in place and have experienced similarly high electric vehicle market shares. As a result, the TECH scenario models the most progressive electric-drive vehicle uptake scenario after California's projected 15-20% electric-drive vehicle sales share in 2025. The TECH scenario assumes that leading markets (US, EU, China, Japan, and South Korea) implement similar policies at a 5-year lag, achieving 20% electric-drive vehicle sales share by 2030. In 2030, 45% of new electric-drive vehicles are assumed to be plug-in hybrid, 45% battery electric, and 10% hydrogen fuel cell vehicles. The rest of the world is assumed to follow these leading markets at a 5 to 10-year delay.

Compared to vehicle efficiency technologies, electric-drive technologies are less mature and are still undergoing major technology, scale, and cost changes. The TECH potential considers a shift in which 80% of new LDV sales in leading markets are electric-drive in 2050, along with 60% of sales in other regions (RoW). Several governments have long-term goals to fully transition their passenger vehicle fleet to electric-drive in the 2040-2050 timeframe; this illustrative scenario is consistent with several of the leading markets meeting such goals.[23] Figure 1.4 illustrates the modeled sales shares of electric-drive LDVs in the BAU and TECH scenarios.

The TECH scenario assumes successful implementation of progressive global CO_2 standards for aircraft, resulting in new aircraft that consume 64% less fuel per revenue passenger-km by 2050 compared to a 2010 baseline. In addition, it considers the impact of global market-based measures equivalent to roughly three times the stringency of the EU Emission Trading Scheme (ETS) for

[20] Lutsey, N. (2015). Transition to a global zero-emission vehicle fleet: A collaborative agenda for governments. International Council on Clean Transportation. Retrieved from http://www.theicct.org/transition-global-zero-emission-vehicle-fleet-collaborative-agenda-governments

[21] California Air Resources Board (CARB) (2011) Initial Statement of Reasons: 2012 proposed amendments to the California Zero Emission Vehicle program regulations. Sacramento, CA. Available at: http://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf

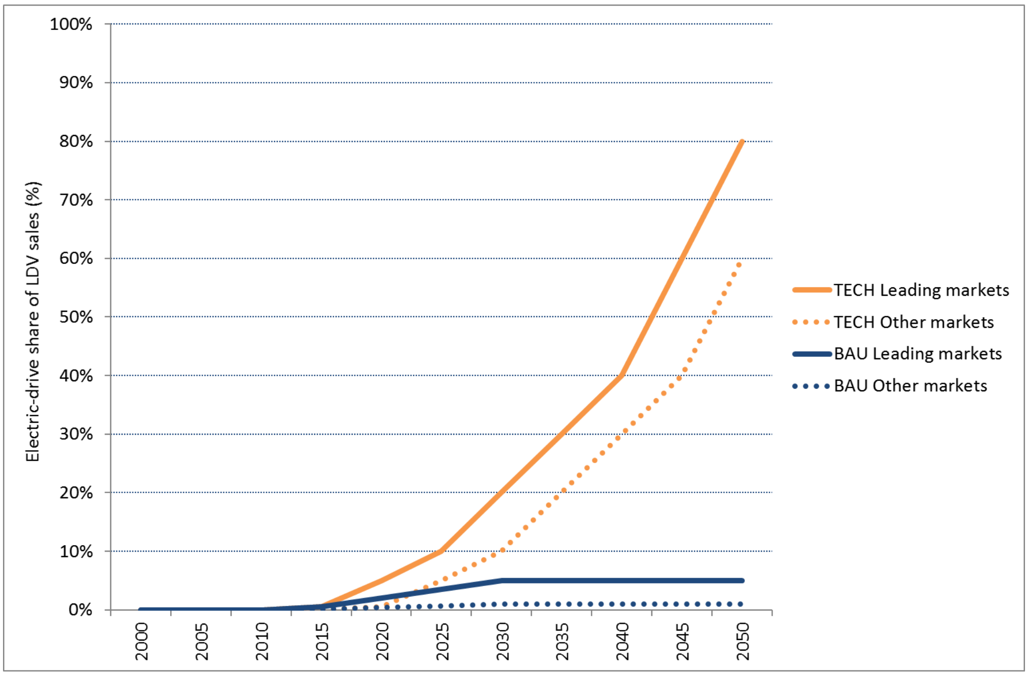
[22] Lutsey, N., Searle, S., Chambliss, S., & Bandivadekar, A. (2015). Assessment of leading electric vehicle promotion activities in United States cities. International Council on Clean Transportation. Retrieved from http://theicct.org/leading-us-city-electric-vehicle-activities

[23] Lutsey (2015). Global climate change mitigation potential from a transition to electric vehicles. Retrieved from http://zevalliance.org/content/global-ev-2050-ghg-mitigation-potential

aviation. These global measures are modeled as decreasing aviation activity by roughly 18% in 2050 compared to the BAU scenario.[24]

For marine, the TECH scenario assumes technology improvements beyond the EEDI that reduce fuel consumption of new marine vessels by 1.5% per year from 2025-2040. Additional improvements to the operational efficiency of ships are assumed to reduce fuel consumption of in-use vessels by 1.1% per year from 2015-2035. These assumptions are based on the "Operational and EEDI+ Technology" scenario evaluated in an ICCT study of the long-term potential for increased shipping efficiency.[25]

Figure 1.4 Uptake rates of electric-drive LDVs by scenario and region



1.2 Oil demand projections

Figure 1.5 indicates total projected transportation oil demand in the REF, BAU and TECH scenarios. Based on a comparison of the REF and BAU results, vehicle efficiency standards implemented between 2000-2015 have saved an estimated 5 billion barrels of oil. By 2050, policies that push vehicle efficiency and electric-drive technologies into the market and reduce fuel consumption of aircraft and marine vessels (consistent with the TECH scenario) could reduce annual oil consumption after its peak in 2025, and avert a doubling of

[24] Façanha, C., Blumberg, K., & Miller, J. (2012). Global Transportation Energy and Climate Roadmap. International Council on Clean Transportation. November. Retrieved from http://www.theicct.org/global-transportation-energy-and-climate-roadmap

[25] Wang, H., & Lutsey, N. (2013). Long-term potential for increased shipping efficiency. International Council on Clean Transportation. Available from http://www.theicct.org/long-term-potential-increased-shipping-efficiency

transportation oil demand from 2015 to 2050. Cumulatively, the policies and technologies associated with the TECH scenario could cut oil demand by 260 billion barrels between 2015 and 2050 compared to the BAU scenario. Notably, the scale of these potential savings (56.9 mbpd) in 2050 is greater than the total level of transportation oil demand in 2015 (51.4 mbpd).

Figure 1.5 Transportation oil use in the REF, BAU and TECH scenarios

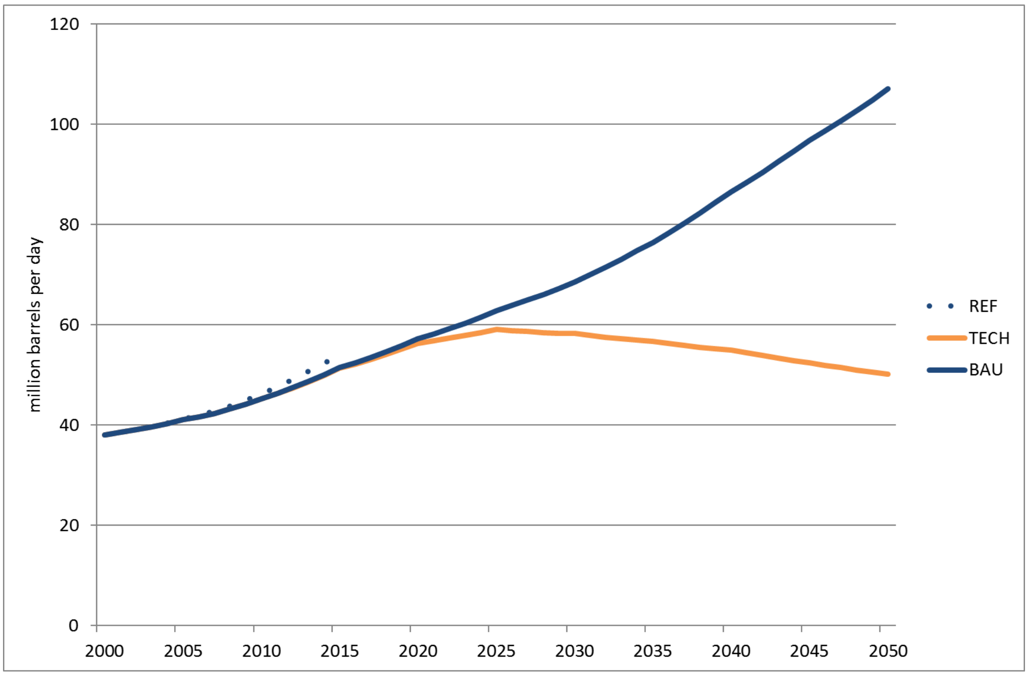
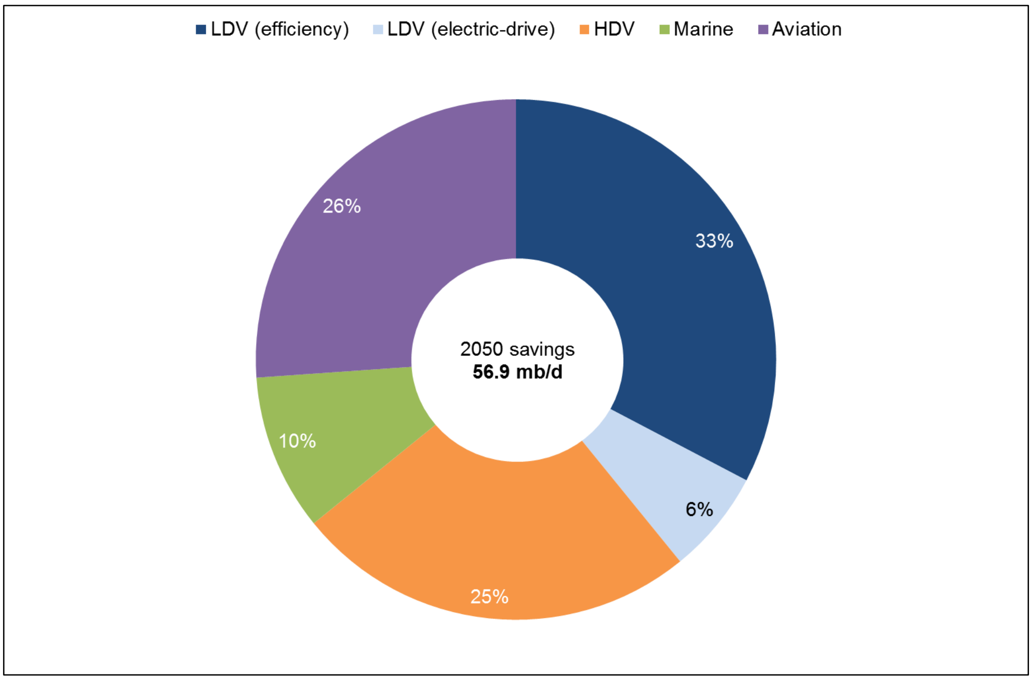


Figure 1.5 shows projected trends by mode from 2015 to 2050 under the BAU and TECH scenarios. Aviation is projected to be the fastest growing mode under both scenarios, whereas the on-road sector accounts for the majority of potential oil savings based on its dominant (but declining) share of transportation energy use. Figure 1.6 breaks down these potential oil savings in the TECH scenario compared to the BAU in 2050 by transportation mode.

Figure 1.6 Reduction in oil use from BAU to TECH in 2050 by mode



Improvements in LDV efficiency have the greatest potential for oil savings in 2050, followed by improved HDV, aviation, and marine efficiency. Electric-drive LDV technologies are an important contributor to long-term reductions in oil consumption, though it may take several decades for these vehicles to displace a substantial share of transportation oil demand.

1.3 Demand sensitivities

Rebound

The scenarios described above are deterministic and have been designed in such a way that oil demand is consistent with a specified level of low-carbon technology uptake. The TECH scenario, however, could be over-stating the true oil demand reduction subsequent to the adoption of the specified low-carbon transport policies for that scenario because the reduction in global oil demand drives a substantial reduction in the price of oil, which could lead to a rebound in oil demand. This could arise either from an increasing demand for transport services or from oil-using technologies become more competitive. This ‘rebound effect’ is not taken account of in the TECH scenario and, therefore, it is likely that the TECH scenario over-states the true reduction in oil demand that would be observed if the low-carbon transport policies associated with that scenario were adopted.

To take account of this rebound effect, we modelled a REBOUND scenario, in which the feedbacks from lower oil prices to oil demand are estimated based on the econometric energy demand equations in E3ME, which include oil prices as a short-run and long-run explanatory parameter. The estimated energy demand equations indicate a price elasticity of demand for petrol and diesel in the road transport sector of -0.7 in the long run i.e. a 1% decrease in price would lead to a -0.7% increase in demand. In TECH scenario, the crude oil price falls by 33% by 2050 relative to the baseline. However, when taxes and other costs are included this translates to around a 20% reduction in average petrol and diesel prices globally, relative to BAU. For aviation and marine the price decreases are greater because the tax component is lower. At the global level we find that by 2050, total oil demand in the REBOUND scenario is around 18% higher than in the TECH scenario.

If the specified energy-efficient transport policies were adopted globally, then the TECH scenario could be considered as a lower-bound estimate of the level of oil demand, while the REBOUND scenario reflects an upper bound oil demand estimate (since higher demand, would lead to higher prices, which would then serve to reduce demand). If we included further iterations between the E3ME energy demand equations and Pöyry's Cronos oil price model, then we would end up with oil demand somewhere in-between the TECH and REBOUND scenario outcomes.

Ambitious biofuels

Building on the assumptions in the TECH scenario, the Ambitious biofuels (BIO) scenario assumes strengthening of existing policies in the US, EU, and Brazil, and introduction of new policies in the rest of the world that promote the production of second-generation biofuels from waste and energy crop feedstocks for use in on-road vehicles. The fuel volumes assumed in the BIO scenario are in addition to the volumes of first- and second- generation biofuels that are forecast according to current region-specific biofuel blends for gasoline and diesel-equivalent fuels. Table 1.3 indicates the additional biofuels volumes assumed for 2030 and 2050, for the US, EU, and rest of world (RoW) (in million tonnes of oil-equivalent).

Table 1.3 Additional biofuels volumes assumed in BIO scenario (mtoe)

Region	2030	2050
US	3.2	39
EU	2.6	22.9
RoW	0.8	39

Assumed potential biofuel volumes for 2030 are based on the methodology developed for a 2015 study that evaluated potential low-carbon fuel deployment in the Pacific Coast region of North America.[26] In a medium case, that study estimated that US cellulosic fuel production could reach 135 petajoules (PJ) by 2030, or 3.2 million tonnes of oil-equivalent (Mtoe). This study assumes that Europe (given a slower start in initial plant deployment) could achieve 80% of the US production level, giving 108 PJ, or 2.6 Mtoe in 2030. Countries in the RoW are assumed to deliver the equivalent of 25% of the US volume, or an additional 0.8 Mtoe in 2030.

For 2050, the potential for additional biofuel volumes in Europe is assumed to be 22.9 Mtoe, equivalent to just over 60% of the technical potential estimated

[26] Malins, C., Lutsey, N., Galarza, S., Shao, Z., Searle, S., Chudziak, C., van den Berg, M., (2015). Potential low carbon fuel supply to the Pacific region of North America. International Council on Clean Transportation. Washington, D.C.

for sustainable biofuel production from wastes and residues in Europe.[27] The technical potential was adjusted downward to account for economic viability of collection and under-collection for non-economic reasons, as well as future competition among economic sectors for biomass resources. The assumed 2050 volume is equivalent to roughly 10% of projected 2030 transport energy demand in Europe.

The 2050 potential for the US is based on a study by UCS that estimated 677 million tons of potential dry biomass availability, of which 400 million tons were energy crops. This estimate already controls for collection cost. This study assumed that additional biofuels could be produced from 277 million tons of dry biomass, as well as 200 million tons of new energy crops. It then assumed half of this biomass might be available for liquid fuels, with the other half used for heat and power. Assuming the same average conversion efficiency as a 2014 study of potential biofuel production in Europe,[28] these values translate to 39 Mtoe in the US in 2050. For the rest of the world, the BIO scenario assumes as much again as is achievable in the US (39 Mtoe).

Technology stretch

While the TECH and BIO scenario include aggressive assumptions for the deployment of efficient/electric-drive technologies and biofuels, respectively, the STRETCH scenario allows for the possibility that new technologies may become available by 2050 that were not accounted for in either of the preceding scenarios. The STRETCH scenario models the impact of reducing energy demand for all fuel types, modes, and regions by 10% in 2050 compared to the BIO scenario. It does not consider any additional policies that would reduce the growth in transportation activity or shift passenger and freight activity to less energy-intensive modes. Such policies could potentially reduce fossil fuel demand below the levels considered in this analysis, which intentionally focuses on technology impacts.

Figure 1.7 indicates total projected transportation oil demand in all five modelled scenarios. Notably, the TECH scenario encompasses 88% of potential oil demand reductions in 2050 compared to the BAU. These reductions from the TECH scenario are achievable based on the policies identified to promote the efficiency of new LDVs, HDVs, aircraft, and marine vessels; catalyze a long-term shift to electric-drive LDVs; apply market-based measures to aircraft; and improve operational efficiency of marine vessels.

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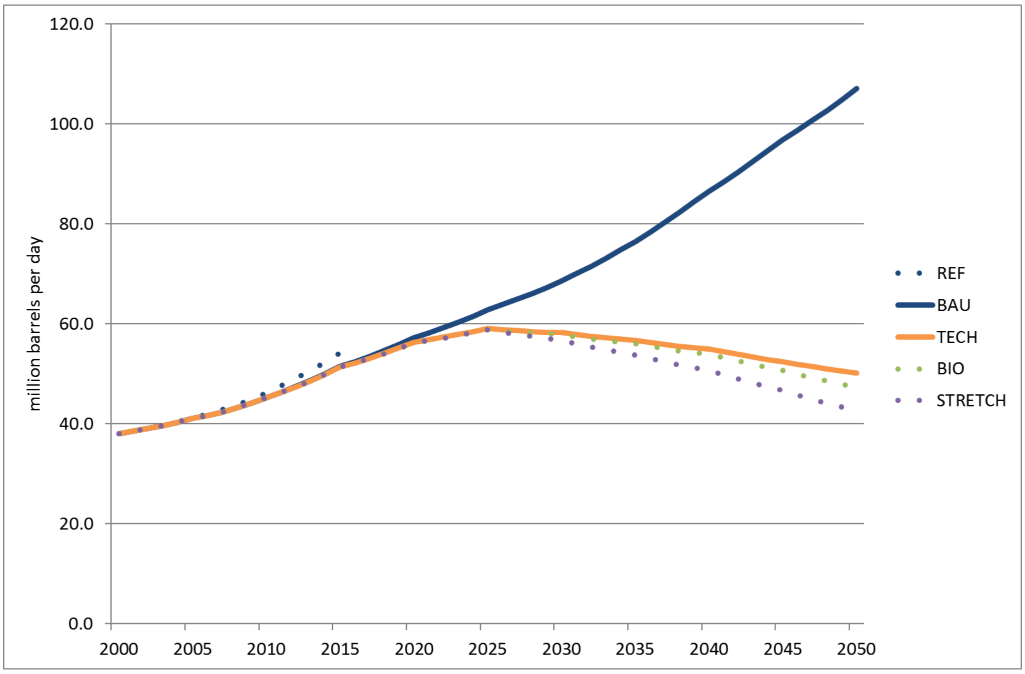
[27] Harrison, P., Malins, C., Searle, S., Baral, A., Turley, D., Hopwood, L. (2014). Wasted: Europe's untapped resource. International Council on Clean Transportation. February. Retrieved from http://www.theicct.org/wasted-europes-untapped-resource-report

[28] ibid.

Figure 1.7 Transportation oil demand by scenario



2 Impact on crude oil production and prices

2.1 Introduction to oil market modelling

In this section, we examine the impact of changes in oil demand on oil prices using Pöyry's economic model of the global crude oil market, Cronos. The oil price in the model is determined by the break-even cost of the most expensive new oil non-OPEC capacity investment that is needed to meet oil demand in each future year. The model contains assumptions for the evolution of OPEC supply, non-OPEC production costs, US shale oil production and depletion of existing capacity. It can be characterised as a long-run economic fundamentals model.

This approach is not designed to capture the impact of events that are not foreseen by the market and may cause significant short-term variations in price. Examples of such events include the oil crises of the 1970s, the Gulf war in 1990 and the US shale oil boom and behaviour from OPEC that is being currently experienced. The low price elasticity of both crude oil supply and demand mean that the oil price varies sharply in response to such events. It should be borne in mind that unforeseen events (which are often geo-political in nature) will continue to occur and the oil price will continue to be volatile.

We believe that our approach looking at the long-run economic fundamentals is a robust way of analysing the policy implications of low carbon transport policy on oil prices.

2.2 Oil supply modelling approach

Global oil market model

The purpose of the model is to project the price trends in the future oil market based on the assumptions for the long-run marginal ('breakeven cost') of incremental investment in new crude oil production capacity.

Inputs and assumptions

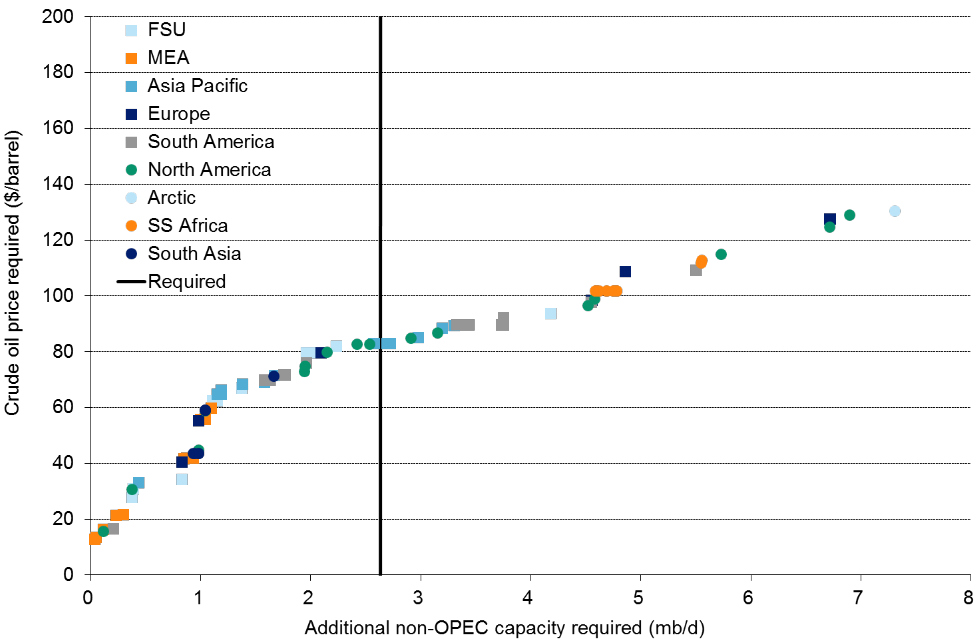
In this instance, demand was provided by the ICCT in different scenarios, while we used our Pöyry supply curve for the production sources. This supply curve evolves over time and contains our assumptions for global oil reserves, new development rates, production costs and tax regime data.

We assume that OPEC producers continue to behave strategically rather tht compete on price with other players in the market based on their production fundamentals. We assume that the cartel will aim to defend its market share over the modelled period in all scenarios.

Derivation of oil supply curve

The supply curve contains one offshore and onshore source per country, as well as unconventional sources such as shale oil in the U.S. and Canadian oil sands. For all sources we take different assumptions for reserve availability, production costs and tax regimes. These sources are stacked up based on their final 'breakeven cost' assumption to determine the marginal source. The resulting incremental supply curve for 2030 is presented in Figure 2.1.

Figure 2.1 Example Pöyry global incremental oil supply curve (2030, TECH scenario)



The oil prices presented in this study represent the long-run market fundamentals

As demand for oil increases the 'Required incremental oil' line moves to the right, requiring incrementally more expensive oil supply sources to meet demand. The higher cost of this marginal unit sets the long-term market price for crude oil. The price reported in this analysis, therefore, reflects the long-run marginal cost of oil production. In reality, there is likely to continue to be volatility around this long-run price that cannot be modelled.

2.3 Oil prices and production: key messages

We have used the approach described above to model the price of oil and to estimate the production of crude oil in key regions in ICCT's global transport demand scenarios. The results for price and production estimates are provided in Sections 2.4 and 2.5. The key messages of this modelling exercise are:

Reducing oil demand by 8mb/d in 2030 and 33mb/d in 2040 could reduce oil prices by $8/barrel and $27/barrel, respectively. This reduction would lead to an annual average reduction in global oil expenditure of $330 billion between 2020 and 2030, based on total crude oil consumption.

This difference may be as high as $37/barrel in 2040 if the incremental reserves required in a high demand scenario are more difficult to access. When taking a more conservative assumption for non-OPEC source availability, more expensive sources are required both in the TECH and the BAU scenario. The reduction potential for 2030 in this case increases to 15% and to 29% in 2040.

We expect oil prices will recover from their level in late 2015 to $80/barrel by 2020. The oil market in 2015 has an excess of 2 million barrels per day of supply over demand due to rapid increases in US production and OPEC's strategic response to maintain their market share. Oil demand will continue to grow to 2020 and existing production will continue to decline. This will lead to a return of a situation where investment in new non-OPEC production capacity is required. We expect that this will require a price of $80/barrel in 2020 to stimulate this investment. By way of comparison the US EIA forecast oil prices of $79/barrel in its 2015 Annual Energy Outlook.

As prices return to $80/barrel in the 2020s, U.S. shale oil will return to production growth. US shale oil production growth has been more resilient than expected in response to lower prices. However, the second half of 2015 has seen a reversal of production growth and a fall in production is expected in 2016. We expect 75% of shale resources to be economical to produce at >$80/barrel and therefore show an increase in U.S. production until 2025 in all scenarios.

Reduced oil demand will lead to lower production from deepwater and Arctic sources. Given the very high cost of ultra-deepwater and Arctic sources, these would only be available at prices significantly above $100/barrel. While in the BAU scenario, some of these sources are being developed in the 2040s, they do not play a role in the TECH scenario.

If OPEC pursued a more aggressive strategy, prices could reduce by another 1.5-4% compared to the TECH scenario from the late 2030s. Performing a sensitivity on the TECH scenario with OPEC pursuing a production-increasing (revenue-optimising) strategy led to price decreases from $82.7/barrel to $81.5/barrel in 2030, and from $83.5/barrel to $81.0/barrel in 2040. OPEC market share increased from 40% to 44% in 2040 and to 48% in 2050.

Even if demand were to recover due to the lower price situation, the loop effect on prices would be small and still considerably lower than in a high demand world. We have examined the potential impact of lower prices in the TECH scenario on oil demand and hence prices. In this case, demand between 2025 and 2035 is 2.9% higher on average than in the TECH scenario, while prices are up 1.0%.

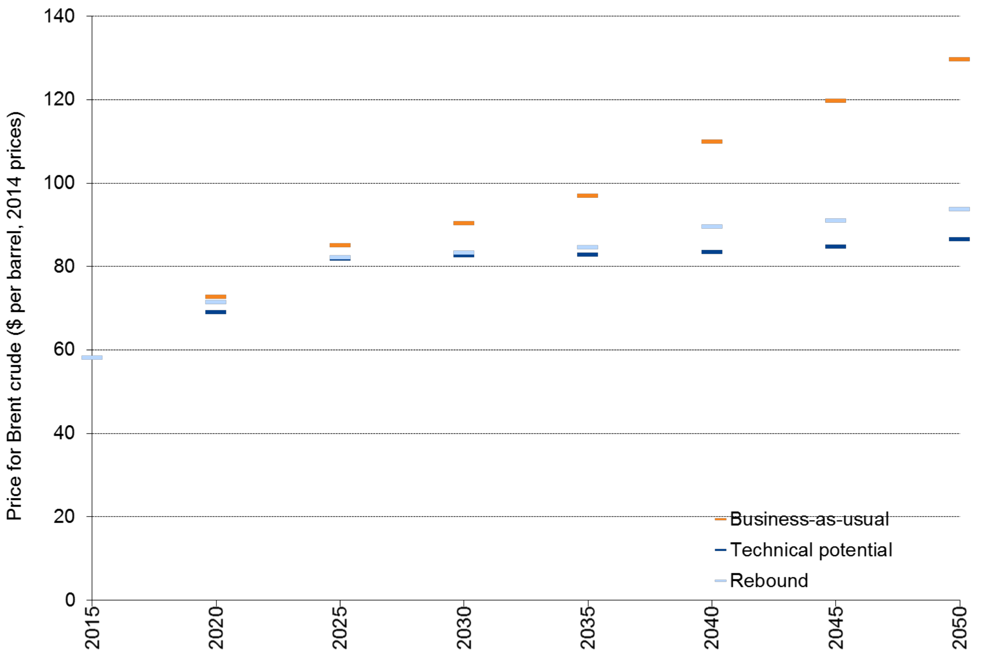
2.4 Crude oil price projections

Figure 2.2 shows the projections for Brent crude oil prices in the base scenarios and sensitivities. After 2020, prices rise to $80/barrel in all scenarios, as the current situation of over-supply is resolved. Following this initial period, prices remain at levels between $80/barrel and $85/barrel in the TECH scenario. BIO and STRETCH scenarios, not shown on the chart, are similar in shape and level to the TECH scenario, with a small additional decrease in both scenarios (1% and 1.5%, respectively). While oil fields continue to deplete at a growing rate, demand is in decline from 2025 and can be met without tapping into any higher-priced resource. In these scenarios, most high-cost sources, such as Arctic projects stay undeveloped for the modelled period.

In the BAU scenario, accelerated demand growth leads to continued increases in oil prices, especially after many of the U.S. shale resources are assumed to be fully exploited from the early 2030s. In this scenario, prices rise to >$100/barrel in 2036, and reach $130/barrel in 2050.

In the rebound case, the trajectory of prices is similar to that in the TECH scenario. Between 2024 and 2032, the difference between the two cases is less than 1%. Only after that, does the price increase somewhat in the rebound case, as demand grows again and more expensive sources need to be developed.

Figure 2.2 Oil price projections by scenario



2.5 Crude oil production projections

As mentioned above, we model OPEC as one source, the production of which is based on an assumption. In this study, we have assumed that OPEC retains its market share (~40% of global demand) in all scenarios and sensitivities, unless otherwise stated. The resulting OPEC production assumptions are presented in Figure 2.3.

For the TECH scenario, we have looked at an OPEC response sensitivity, whereby OPEC has perfect foresight and optimises its revenues over the period between 2030 and 2050. The strategy we have determined to be optimal for OPEC in this case is to further increase production from 30 mbpd in 2030 to 33 mbpd in 2050. While this decreases the price by another 7% in 2050 compared to the TECH scenario, this is more than compensated for by the 8% increase in market share.

Figure 2.3 OPEC crude production assumptions by scenario

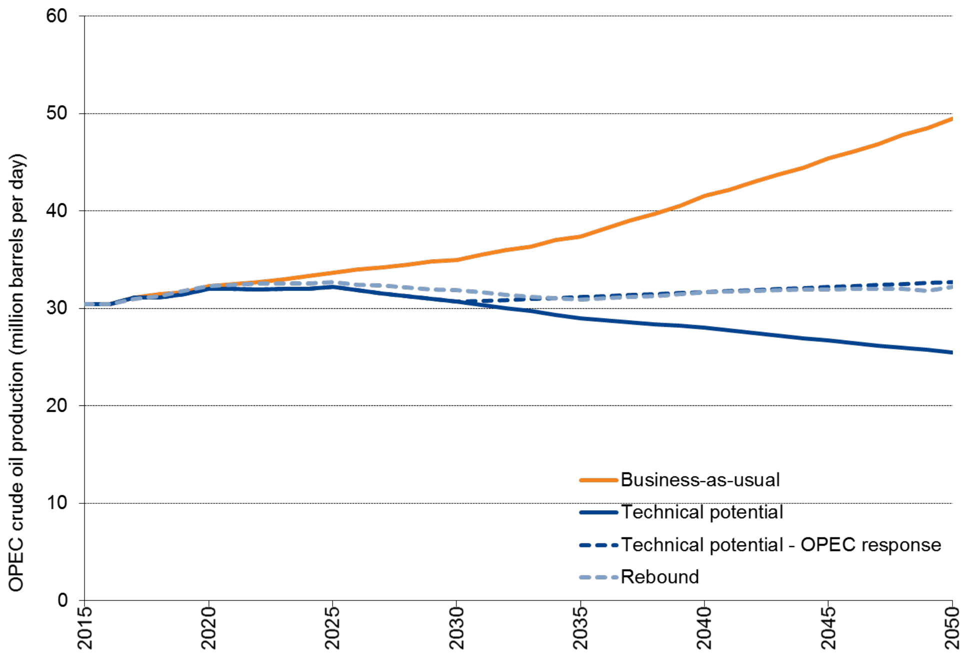
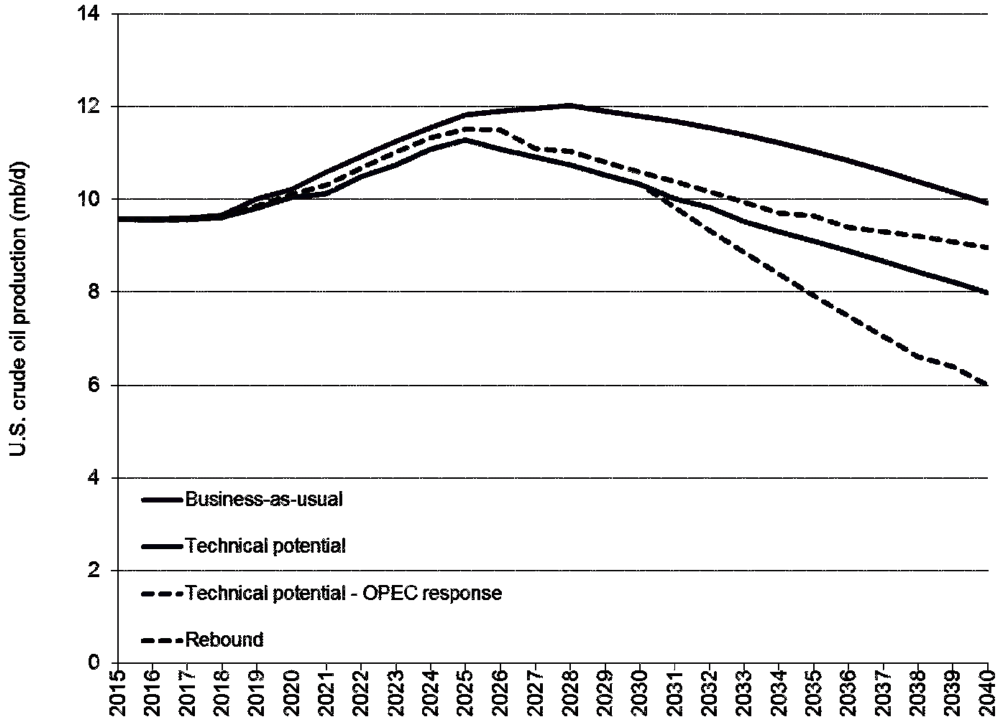


Figure 2.4 presents the results for U.S. crude oil production. U.S. oil production is expected to remain at ~9.5mb/d in the short-term as prices are low. As prices return to >$80/barrel, shale oil production increases again and U.S. production is projected to peak at 11.3mb/d in 2025 in the TECH case. After this date, more and more lower-cost shale oil sources are expected to be mostly depleted and more expensive sources are not economical at around $80/barrel. Therefore, U.S. production decreases from 2025, reaching 6.5mb/d in 2050 in the TECH scenario. In the BAU scenario, even more shale sources are being produced due to higher demand.

Figure 2.4 U.S. crude production projections by scenario



3 Macroeconomic impacts

3.1 Introduction

The final part of the analysis involves modelling the wider macroeconomic effects of the oil market changes described in the previous chapter of this report. Specifically, we assess the macroeconomic effects in the US of a reduction in the price of oil and a reduction in oil production consequent to the change in oil demand in the TECH scenario.

Section 3.2 describes our macroeconomic modelling approach and the key energy-economy feedbacks that are captured in the modelling framework. In Section 3.3 we present the results from the macroeconomic modelling of the oil market scenarios.

3.2 Macroeconomic modelling approach

Macroeconomic modelling using E3ME

The E3ME model was used to assess the macroeconomic effects of changes to oil prices and oil production under the future TECH scenario, where efficiency improvements in transport technologies drive a reduction in global oil demand. E3ME is a macro-econometric model of the global economy and uses a series of empirically-estimated sectoral and region-specific equations to estimate how households and industry respond to key drivers (such as changes in oil prices) and how this behavioural response affects the wider economy. E3ME incorporates an input-output framework to capture industry supply chain inter-dependencies at a high level of sectoral detail. It takes account of each sector’s dependence on oil as an input to the production process, so that we are able to assess the effects of oil price changes on different sectors in different regions.

E3ME is particularly well-suited to the macroeconomic analysis of oil market changes because it includes a detailed representation of feedbacks between energy markets and the economy. Changes to transport fuel demand directly affect economic transactions, which are represented as input-output coefficients in the model’s economic accounting framework. The effects of oil prices on other sectoral prices are also calculated within the model, based on the observed composition of each sector’s intermediate inputs to production. Prices are one of the key explanatory variables in the equations that determine impacts on consumption, imports and exports. The interaction between product prices and wages is also an important feature of the model.

Economic feedbacks modelled in E3ME

For this part of the analysis, E3ME was applied to estimate the economic impacts of the deterministic oil market scenarios. In the scenarios modelled, there are two key inputs that drive the macroeconomic results and determine the scale of the economic impact in each region:

- oil prices (which, by 2050, are 40% lower in the TECH scenario than in the BAU, due to the reduction in demand for oil)
- oil production (which, in the TECH scenario is 11% lower than in the BAU in the EU, by 2050, due to a reduction in global demand for oil)

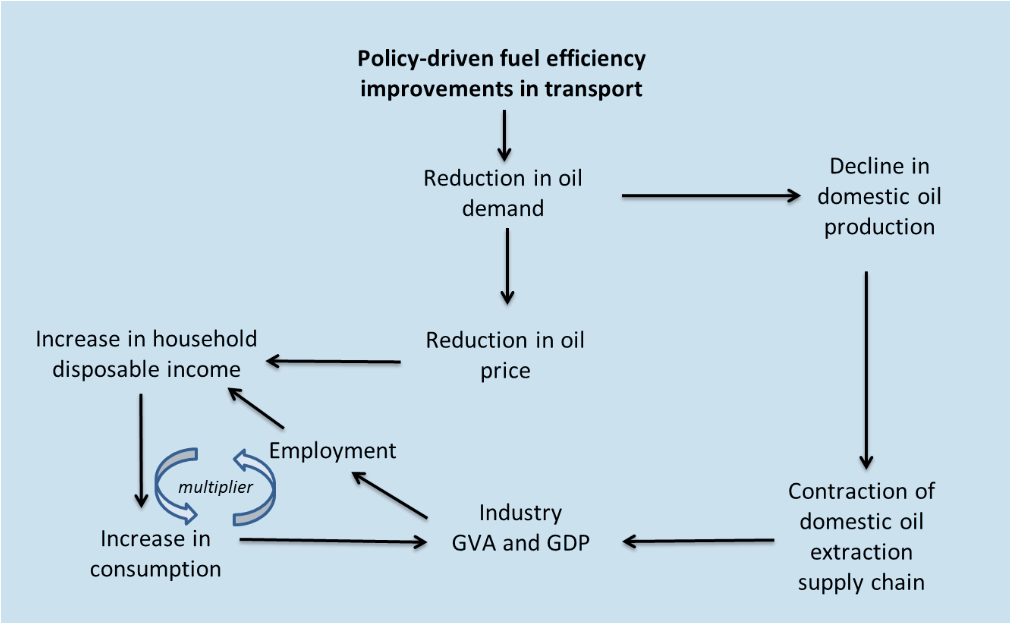
This analysis isolates the impact of changes in oil prices and production

In order to allow for a meaningful comparison of results, we do not model the impact of the reduction in oil demand or the cost of the low-carbon transport technologies in the TECH scenario. The purpose of this macroeconomic analysis is to isolate the impact of the changes in oil price and oil production, as a result of the lower oil demand implied by the TECH scenario.

When interpreting the results, it should be noted that, because the transport efficiency improvements in the TECH scenario drive a reduction in oil demand, the economic impact of the oil price change in this scenario is lower than if the same change in oil prices came about in a future with BAU oil demand. Transport in the TECH scenario is more efficient and uses less oil, so the wider economy is less affected by a change in the oil price.

Figure 3.1 shows the macroeconomic flows associated with the oil market changes that are depicted in the TECH scenario. The sections below describe these macroeconomic flows, focussing on the expected impact on consumers, industry and the oil extraction sector.

Figure 3.1: Economic impacts of low-carbon transport policy in the TECH scenario



Impact on consumers

The reduction in oil demand in the TECH scenario drives a 40% reduction in global oil prices relative to the BAU scenario by 2050 which is passed onto consumers as reductions in the prices for motor fuel. The extent to which these cost savings are passed on to consumers varies between countries depending on:

- The supply chain for motor fuels: in some countries, transport, distribution and retail costs account for a large proportion of the petroleum industry’s intermediate costs, which dampens the effect of an oil price change on final fuel prices.

- The rates of tax and fuel duty included in the retail price of motor fuel: in countries with high rates of fuel duty, the relative impact of an oil price change on final fuel prices will also be lower.

Facing lower fuel prices, consumers will be better off in real terms, due to a reduction in inflationary pressures meaning that as real disposable incomes increase, consumers are able to spend more on other goods and services. In the EU, it is likely that these goods and services will have a larger share of their supply chain located domestically, compared to that for motor fuel, leading to increases in output and GDP.

As shown in Figure 3.1, there are also multiplier effects, as the increase in industry output drives an increase in employment and further increases in real incomes, real consumption and GDP.

Impact on industry

Although transport (and road transport in particular) accounts for the majority of consumption of oil and petroleum products, industry also uses large quantities of oil for non-transport purposes.

All companies will benefit from lower transport costs, but the reduction in oil prices could bring additional benefits for companies in industrial sectors that consume oil in other ways, by lowering their costs of production. This includes, for example, companies in the chemicals and plastics sectors, which use oil for non-energy purposes as a raw material input to production.

Any savings in production costs could be retained as profit, or alternatively could be passed on as cost savings to consumers. The extent to which companies lower the prices of goods depends on the market structure and degree of competition in their sector. However, as the oil price changes are global, it is expected that, in globally-competitive markets, most of the cost savings will be passed on to consumers, at least in the long run.

Impact on the oil extraction sector

The overall impact on the oil extraction sector comprises real output effects (due to the reduction in oil production) and price effects (following the lower global oil price).

The reduction in oil production will lead to a reduction in employment in the oil extraction and petroleum refining industries. Furthermore, the contraction of the oil supply industries will lead to a reduction in demand for products from higher-tier suppliers and a reduction in investment. Following the reduction in demand for their products, there is also likely to be a reduction in employment in the industries that are in the oil extraction supply chain. The reduction in demand, production and employment, could lead to further negative induced effects.

Furthermore, facing lower revenues due to the reduction in oil price, oil extraction companies will make lower profits and, as a result, could reduce wage rates for employees or make efficiency savings by reducing employment and/or reducing demand for products from higher-tier suppliers. In the latter case, it is noted that these effects are likely to be small as this sector is not labour-intensive and has a relatively short supply chain. The reduction in revenues and profits for large oil companies will affect shareholder dividends and could also affect future investment in the oil extraction industry.

Net economic impacts

The net economic impact is predominantly driven by consumption and trade effects. In oil-importing countries, consumers will benefit from lower prices that will lead to an increase in real disposable income. This in turn will boost consumption and GDP.

Conversely, in oil-exporting counties, the reduction in the value of domestic production and exports of oil could lead to lower GDP. The reduction in revenue and profits in the oil extraction sector could lead to reductions in investment (though it is noted that the macroeconomic effects of lower oil industry profits are not explicitly modelled in E3ME). There will also be real effects, as the reduction in oil production will drive a reduction in demand for labour and intermediate goods/services used by the oil industries. The largest oil exporters are highly reliant on oil revenues to support government budgets, so rates of public consumption will come under pressure if there is a sustained fall in oil prices.

There are a number of factors that determine the extent of the impacts of the lower oil price and lower oil production in the TECH scenario. These include:

- **The oil intensity of economy:** countries that are more heavily dependent on oil will benefit more from a reduction in the price of oil.
- **The size of the domestic oil extraction sector and its supply chain:** a loss of production will impact on employment and the oil sector's supply chain.
- **Fuel tax rates:** higher fuel taxes imply a smaller percentage change in motor fuel prices for a given percentage change in the price of oil and so it is expected that the economic impacts of oil price changes will be lower in countries with higher fuel tax rates.

3.3 Macroeconomic modelling results – key messages

Although the macroeconomic modelling of the change in oil price and oil production was undertaken at the global level, the focus of this section of the report is the key messages from the macroeconomic modelling for the US.

The TECH and REBOUND scenarios represent the upper and lower bound of energy demand and oil prices under the low-carbon transport policy scenario. Results in this section are therefore presented as a range between those two scenarios.

Economic impact on the US

The US benefits from the oil market effects associated with the global transition to more efficient modes of transport. However, the impacts and economic flows following lower oil prices in the US economy are somewhat different to those reported in a separate study for the EU.

Effects of lower oil production

In the context of the economic impacts of the TECH scenario, the most important difference between the EU and the US economies is the difference in domestic oil production. Whilst the EU has relatively low domestic oil reserves and is heavily dependent on imported oil, oil production in the US is much higher. By 2050, oil production in the US in the BAU scenario is expected to still be around 8.9mb/d (after peaking in around 2030 at 12 mbpd), compared to 0.7mb/d in the EU. This is, in part, due to recent increases in proven US shale oil reserves. However, the fall in global oil demand in the TECH scenario leads to lower levels of US oil extraction.

By 2050, there is a 2.4mb/d reduction in US oil production in the TECH scenario relative to the BAU, which leads to a 0.2% reduction in US GDP.

Prices

In the US, the reduction in crude oil prices drives an overall 0.4-0.5% reduction in the consumer price level by 2030, and a 1.2-1.3% reduction in prices by 2050. The US has a more oil-intensive economy than the EU and fuel duty is substantially lower. As a result, despite the same reduction in the crude oil import price, US consumers benefit relatively more than EU consumers following the lower oil price.

Real incomes and consumption

The lower oil prices in the TECH scenario drive a 0.4-0.5% increase in real incomes in 2030 and a 1.3-1.4% increase in real incomes by 2050. The magnitude of the impact of lower oil prices on consumer prices is greater in the US than that in the EU and so the effect on real incomes in the US is also greater.

Consumption in the US increases by around 1.0% by 2050, as a result of lower prices and increases in real household incomes. Some of the increases in household income are used by US households to increase savings rates, but there is still a 1% increase in consumption.

GDP and employment

The net impact on GDP as a result of the lower oil prices and production in the TECH scenario is 0.4-0.5% in 2050, which is similar in scale to the GDP impact in the EU. The GDP impact associated with the lower oil prices in the US is 0.1-0.2% by 2030 and 0.6-0.7% by 2050. However, the US is a large producer of oil and the positive GDP effects associated with lower prices for consumers and industry are reduced somewhat by the negative effects of a reduction in oil production (which leads to a -0.2% impact on GDP by 2050).

The net impact on employment following the oil price and oil production changes in the TECH scenario reaches 0.1% (172,000 jobs) by 2050. The oil extraction sector has a low labour intensity, so the negative impact on employment in the US oil extraction sector and its supply chain is small, equivalent to a reduction of around 15,000 jobs by 2050).

Appendices

Appendix B References and Acronyms

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List of acronyms

BAU – Business-As-Usual Scenario (this study)

BEV – Battery electric vehicle

BIO – Aggressive Biofuels Scenario (this study)

CO_2 – carbon dioxide

EEDI – Energy Efficiency Design Index

ETS – Emission Trading Scheme

EU – European Union (including 28 member countries)

FCEV – Hydrogen fuel cell electric vehicle

gCO_2/km – grams of carbon dioxide per kilometer

GHG – greenhouse gas

HDT – Heavy-duty truck

HDV – Heavy-duty vehicle

HHDT – Heavy heavy-duty truck (Class 7 & 8 vehicles in the US)

ICAO – International Civil Aviation Organization

ICCT – International Council on Clean Transportation

IMO – International Maritime Organization

LCV – Light Commercial Vehicle

LDV – Light-duty vehicle

mbpd – Million barrels of oil per day

Mtoe – Million tonnes of oil-equivalent (energy unit)

NRC – National Research Council

PC – Passenger Car

PEV – Plug-in electric vehicle (includes BEV and PHEV)

PHEV – Plug-in hybrid electric vehicle

PJ – Petajoule

REF – Reference Scenario (this study)

RoW – Rest of World

TECH – Technology Potential Scenario (this study)

UCS – Union of Concerned Scientists

US – United States of America

ZEV – Zero Emission Vehicle

Appendix C ICCT Modelling Approach

Introduction

Transportation oil demand scenarios were evaluated using the ICCT's Global Transportation Roadmap model (hereafter referred to as the Roadmap model). The following discussion of the Roadmap modeling approach is adapted from Appendix II of an earlier ICCT study.[29] The Roadmap model draws upon the best available data for global and national transportation activity, emissions, energy use, and policies, to quantify the potential of current and future transportation sector policies to reduce energy consumption and emissions. The model was developed to provide insights on questions most critical to government regulators, policymakers, and other stakeholders, including:

- What is the current growth rate in energy use, greenhouse gas (GHG) emissions, and local air pollutant emissions from the transportation sector by mode and by region?
- What are the energy and emission benefits of past, existing, and future transportation policies?
- How do countries and regions compare in terms of vehicle efficiency, emission rates, and mode shares?

The Roadmap model has been reviewed by transportation modeling experts to ensure the validity and adequacy of calculation methods and algorithms, and a version of the model is publicly available on the ICCT website, along with the model documentation.[30] The model is updated regularly, and its outputs are validated against the results of other major national and international transportation emissions and energy models.[31]

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[29] Chambliss, S., Miller, J., Façanha, C., Minjares, R., & Blumberg, K. (2013). The Impact of Stringent Fuel and Vehicle Standards on Premature Mortality and Emissions. International Council on Clean Transportation. Retrieved from http://theicct.org/global-health-roadmap

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[31] Mishra, G.S., Fulton, L., Yeh, S., Kyle, P., McCollum, D.L., Miller, J., Cazzola, P. (2014). Summary of International Transport Energy Modeling Workshop. ITS, UC Davis, CA, USA (19 October 2014). Available at origin.library.constantcontact.com/down...396/iTEM%2BMeeting%2BSummar_10192014.pdf

Model Scope

For the transportation oil demand scenarios, future activity growth rates for each transportation mode and region were extracted from the IEA's 4-degree scenario in the 2014 ETP report.[32] These growth rates were applied to the estimates of historical transportation activity derived from the best available national and international models and data sources.

By relying on exogenous input parameters related to policies for vehicle efficiency, electric-drive technologies, in-use aviation and marine efficiency, and low-carbon fuels, the model estimates corresponding well-to-wheel (WTW) emissions to 2050. The following points characterize the scope of the Roadmap model:

POLLUTANTS Selected GHGs (CO_2, CH_4, and N_2O) and local air pollutants (NOx, exhaust PM2.5, HC, CO, black carbon, and SO_2). WTW emissions of GHGs and local air pollutants include the fuel lifecycle, comprising the refining, processing, distribution, and combustion of fuels. The Roadmap does not assess lifecycle emissions from vehicle manufacturing, distribution, or end-of-life (i.e., disposal or recycling), nor does it examine the transportation infrastructure lifecycle.

MODES Light-duty vehicles (LDVs), buses, motorcycles, three-wheelers, heavy-duty trucks (HDTs, subdivided into light, medium, and heavy HDTs), passenger and freight locomotives, passenger aircraft, and freight marine vessels.

COUNTRIES The model focuses on the ten countries/regions with the greatest annual new-vehicle sales: the United States, the EU-28 (the 28 member states of the European Union), China, India, Japan, Brazil, Canada, South Korea, Mexico, Australia, and Russia. The model also analyzes five broader regions: other countries in Latin America (excluding Brazil and Mexico), non-EU Europe, other countries in the Asia-Pacific (excluding China, India, Japan, South Korea, and Australia), Africa, and the Middle East.

TIME HORIZON 2000 to 2050, in five-year increments. Annual results were calculated using linear interpolation of five-year results.

FUEL TYPES Gasoline, ethanol (grain, sugarcane, and cellulosic), diesel (conventional and low-sulfur), biodiesel (oil-based and ligno-cellulosic), compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen, electricity, jet fuel, and residual fuel.

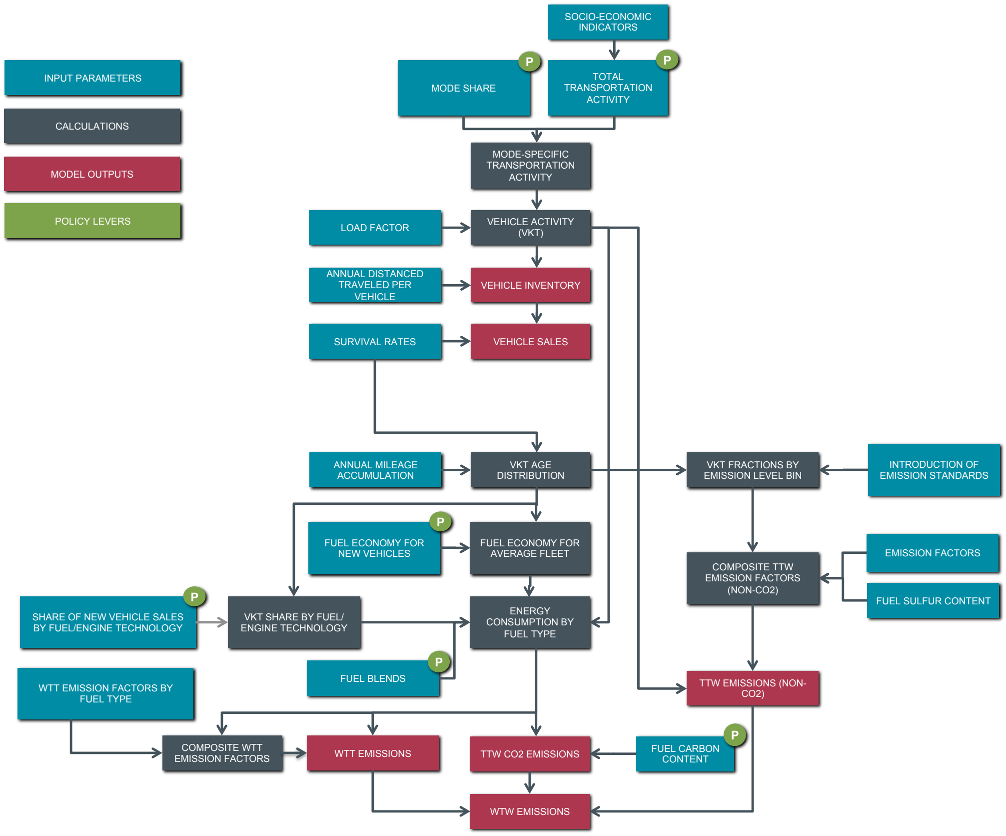
VEHICLE TECHNOLOGIES Conventional, hybrid, plug-in hybrid (PHEV), battery electric (BEV), and fuel cell vehicles (FCEV).

On-Road Calculation Methods

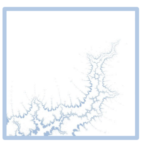
Figure C.1 illustrates the methodology used by the Roadmap model for on-road emissions calculations. This analysis reports energy use by fuel type in units of million barrels of oil-equivalent per day (based on energy content of fuels).

[32] OECD/IEA (2014). Energy Technology Perspectives 2014. Available from http://www.iea.org/etp/etp2014/

Figure C.1: On-road Calculation Methods



Historical land-based transportation activity (passenger-km and ton-km) and mode shares are taken from multiple data sources. Load factors (passengers/vehicle or tons/vehicle) are used to convert transportation activity into vehicle activity (VKT). The breakdown of vehicle activity by technology type is determined from vehicle sales and a turnover algorithm. The turnover algorithm utilizes survival curves developed using a Weibull distribution reliability function to estimate average vehicle retirement age for a given region and mode. Vehicle stock and sales are calculated as model outputs and can be used to validate and calibrate the model. Fuel consumption is the product of vehicle activity and fleet-average fuel efficiency, which is estimated using new-fleet efficiency and a turnover algorithm. Due to a lack of globally consistent forecasts for congestion and roadway capacity, the model considers neither rebound effects from increased fuel efficiency nor decreased activity as a result of traffic congestion (though these effects may cancel out to some degree); however, the model does include assumptions to convert test-cycle vehicle efficiency to in-use efficiency. The breakdown of fuel consumption by type is determined from fuel blends. TTW emissions of CO2 are calculated as the product of fuel consumption (by type) and carbon content of fuels, while TTW emissions of local air pollutants are calculated as the product of TTW emission factors and either vehicle activity (for on-road modes) or transportation activity (for rail and aviation). Average TTW emission factors are based on new vehicle emission standards and a turnover algorithm. Well-to-tank (WTT) emissions of all pollutants are calculated as the product of fuel consumption (by type) and WTT emission factors. Emissions from marine vessels are estimated directly from IMO projections.



Emission factors for CO2 and SO2 are based on the carbon and sulfur content of fuel, respectively. Emission factors for all other pollutants are based on a weighted average of emission rates from vehicles in each emission standard category.

External Review and Validation

The ICCT has collaborated closely with government agencies in the countries/regions highlighted in the Roadmap model to ensure that the model includes the most representative and credible publicly available data. The ICCT also collaborated extensively with the International Energy Agency (IEA) on data collection and emissions modeling. Many updates were done to the Roadmap model using the IEA's Mobility Model (MoMo) for areas where the Roadmap model lacked data. The input parameters and model outputs from the Roadmap model were compared against numerous global and national transportation data sources and emissions inventory models, and the results of such comparisons are available together with the Roadmap model documentation.[33]

[33] Burton, A., Shao, Z., Miller, J., & Façanha, C. (2013). Comparative analysis of activity and emissions. International Council on Clean Transportation. Retrieved from http://www.theicct.org/global-transportation-roadmap-model

Appendix D Pöyry Modelling Approach

Pöyry oil market modelling – conceptual overview

The oil market modelling exercise within this study – examining the effect of demand changes on the global price of crude oil – was carried out using Pöyry's oil market model, Cronos. This model relies mostly on publicly available data for reserve estimates, availability assumptions and production cost expectations, to produce projections for future crude oil prices.

As an economic fundamentals model, it focuses on long-term equilibrium between supply and demand. Therefore, its outputs should be used to examine long-term trends in global oil prices, rather than short-term volatility. It is continuously used as part of Pöyry's quarterly update of energy price projections in Europe, and it has been used in the past to answer questions such as:

- Given a certain OPEC strategy, what are the expectations for global oil prices in the medium- to long-term?
- What would the impacts of lower than expected availability of shale oil be to global oil prices and production in other countries?
- What are the impacts of higher production costs in certain regions on global oil prices?
- How much of a certain source can be expected to be developed by a certain point in time?

The model projections are based on a number of variables:

OPEC supply

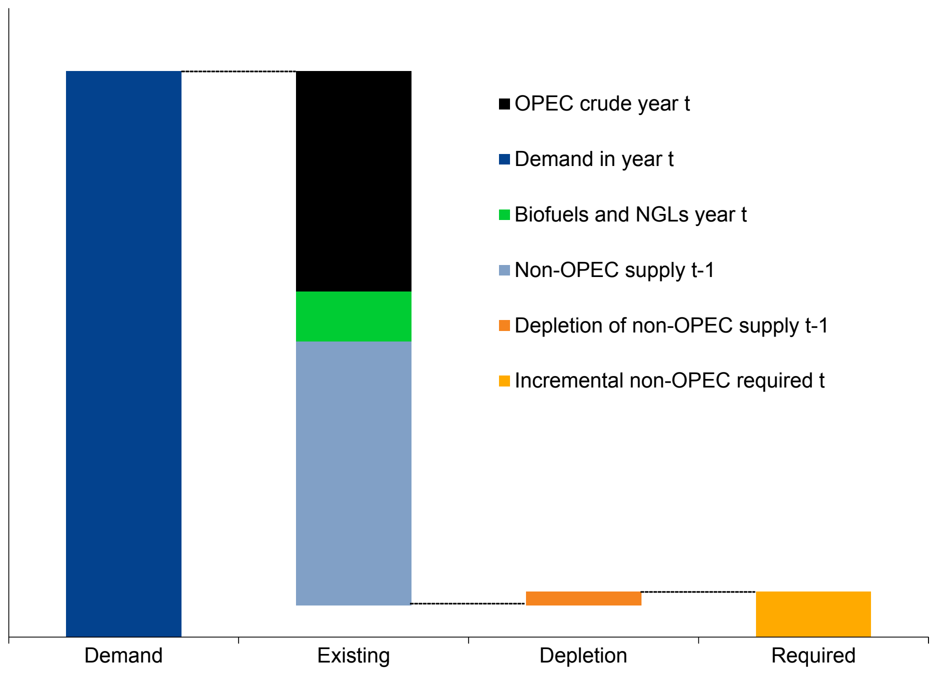
We determine OPEC behaviour by observing the current and historic performance of the cartel. Our assumption for OPEC behaviour going forward is that the cartel is aiming to hold its market share of around 40%.

Non-crude sources

For biofuels, NGLs and other non-crude sources, we take an assumption based on our internal experience. NGLs are assumed to grow by around 12% until 2030. In the BIO scenario, the assumption for biofuels production is higher, to meet demand as specified by the ICCT.

The OPEC and non-crude sources are net off demand in each year; the remainder of demand is then matched with the supply curve.

Figure D.2: Determination of incremental supply requirement



Supply curve

To create a global non-OPEC crude oil supply curve, we assemble global oil reserve, production costs and tax regime data from a number of publicly available sources, such as USGS, IEA and EIA. Based on historical information, we take assumptions on how much new oil capacity will be available to be developed in every country per year.

Based on this stack of sources available, the model determines the marginal new source needed to be developed in any given year. The break-even price of that marginal source then sets the price for that year.

The supply stack differentiates between onshore and offshore sources for each country. Additionally, unconventional and high price sources, such as shale oil in the U.S., oil sands in Canada and Arctic oil are added separately.

Model validation

As Cronos is being used to provide key inputs for Pöyry's quarterly modelling update, we take steps to ensure constant validation of the inputs and outputs. The model's input assumptions are being taken from widely accepted sources, and the model itself is being reviewed by industry experts on a semi-annual basis.

Oil market modelling – scenarios and sensitivities

Demand scenarios

The main purpose of this study is to examine the impact of implementing technology-forcing policies on oil demand in global transport and subsequently the global price of oil.

The ICCT has modelled this transport demand in a range of scenario and sensitivities. To isolate this effect, we have kept the global non-transport demand constant at 2014 levels (around 38mb/d). The final global liquid fuels demand as used in this study are shown in Figure XXX6 below. In all scenarios, demand increases from around 94mb/d in 2015 to around 100mb/d in 2020. From then until 2025, demand growth slows somewhat in the TECH scenario, and then declines to 91mb/d in 2050. In the BAU scenario, demand growth continues strong and actually increases after 2025. In 2050, total oil demand in the BAU scenario is projected to reach 150mb/d.

Figure D.3 provides an overview of the scenarios in context.

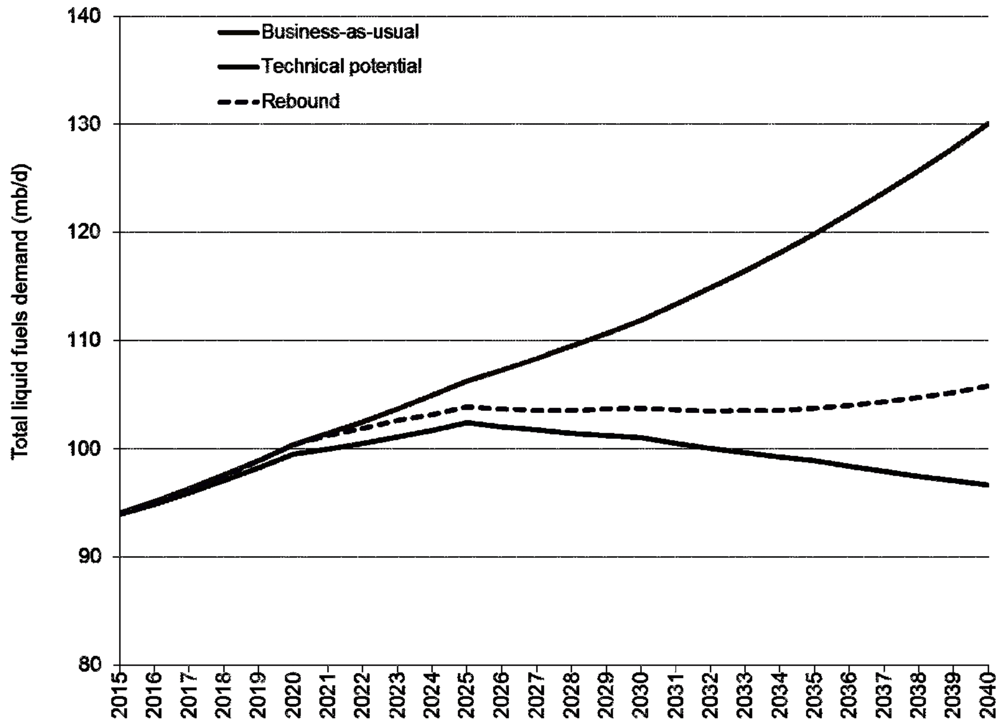


Figure D.3: Total demand assumptions by scenario

BAU

- Strong demand growth (1.4% p.a.)
- No autonomous efficiency changes
- OPEC reacts by increasing its output, holding market share constant

TECH

- Strengthened policies improve efficiency
- Lower demand, 0.9% growth p.a. before 2025
- From 2025, demand is falling (-0.5% per year)
- OPEC defends market share, restricts supply
- In OPEC sensitivity, cartel increases production to capture higher market share

BIO

- Strengthened policies improve efficiency and second-generation biofuels
- This leads to slower demand growth (0.9% p.a. before 2025)
- OPEC decreases output after 2025 to defend market share

STRETCH

- Sensitivity analysis models effect of reducing energy demand for all fuel types by 10% by 2050 compared to the BIO scenario
- Demand growth after 2025 is even lower (falling at a rate of -0.7% p.a.)
- OPEC holds market share constant

Figure D.4: EU crude production projections by scenario

OPEC response

The base assumption for OPEC behaviour in this study is the cartel following a strategy of defending its 2015 market share (~40%). At the time of this study, this appeared to be the most likely course of action of OPEC going forward. It is worth noting that in 2015, OPEC members were unable to agree on a quota, which could lead to even higher OPEC production in the short- to medium-term. In the long-term, however, it is in the countries' interests to collaborate, and we assume that this occurs.

However, assuming OPEC can control its output within a certain range, there could be strategies that improved the group's revenue over time. Therefore, we have looked at a case where OPEC seeks to optimise its revenue over the period from 2030 to 2050. Of all the possible strategies for OPEC to employ (10mb/d production decrease in 2050 compared to 2030 up to 10mb/d increase over the same period, in 1mb/d increments), the increase by 2mb/d case appeared to be the optimal solution[34].

This resulted in a 3% reduction in prices compared to the TECH scenario in 2040, and a 7% drop in 2050.

Resource availability sensitivity

One of the central assumptions to be taken when constructing annual supply curves is the rate at which newly developed sources can be made available to the market. We have examined the sensitivity of the results to changes in this assumption.

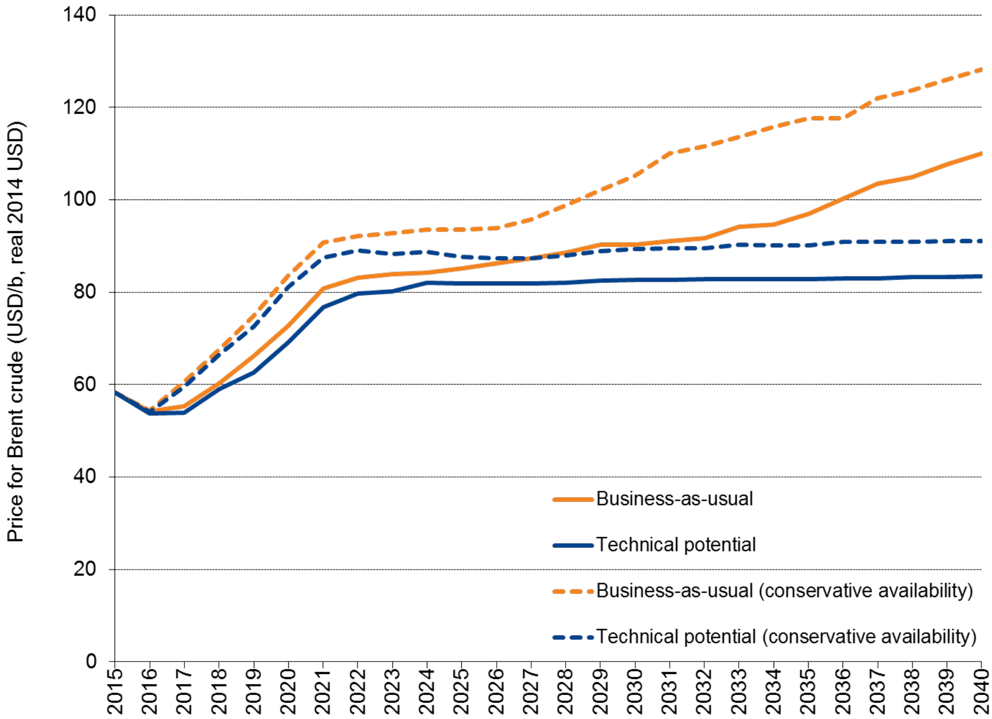
Figure D.5 shows price projections for the BAU and TECH scenarios both for the base availability case and for the conservative availability case. Notably, in both cases, the price increase in the short-term is quicker and more pronounced. However, after the price reaches around \$90/barrel in the TECH scenario, it settles – just as it does in the base availability case – and stays

[34] Optimum determined as revenues between 2030 and 2050 discounted to PV using a 3.5% social discount rate.

between $88/barrel and $95/barrel over the rest of the modelled period. In the BAU, prices continue to rise earlier, and reach 10%-20% higher levels than with the base assumption.

The relative differences between the two cases, i.e. the reduction in oil prices caused by the demand reduction, is similar to that in the base assumption case.

Figure D.5: Oil price projections in base scenarios and conservative resource availability sensitivities



Reference scenario and modelling historical prices

ICCT modelled a counterfactual case for 2000 to 2014 (REF), examining oil demand had the policy decisions enforced in that period not been taken. Demand is slightly higher in the REF scenario than in reality.

As our model is a long-term economic model, it would not capture all short-term price variations. It is, however, able to recreate the underlying fundamental trend of oil prices in that period. To create price projections for the REF scenario, we have therefore:

(1) modelled oil prices between 2000 and 2014 based on actual demand and OPEC production

(2) recorded the error term between or 'fundamentals based' price results and actual prices; and

(3) applied this error term to the price projections resulting from modelling prices based on the REF demand.

Figure D.6 shows the REF modelled prices compared to outturn prices. As demand diverges only slightly from the actual demand (0.2% higher than historical in 2005, 3% in 2014), prices are also very close (1.2% higher in 2005, 8% in 2014). However, it is worth noting that as demand growth is somewhat higher in the REF scenario, some more expensive sources would probably have had to be developed between 2010 and 2015, leading to an un-proportionally higher price increase compared to the moderate demand increase.

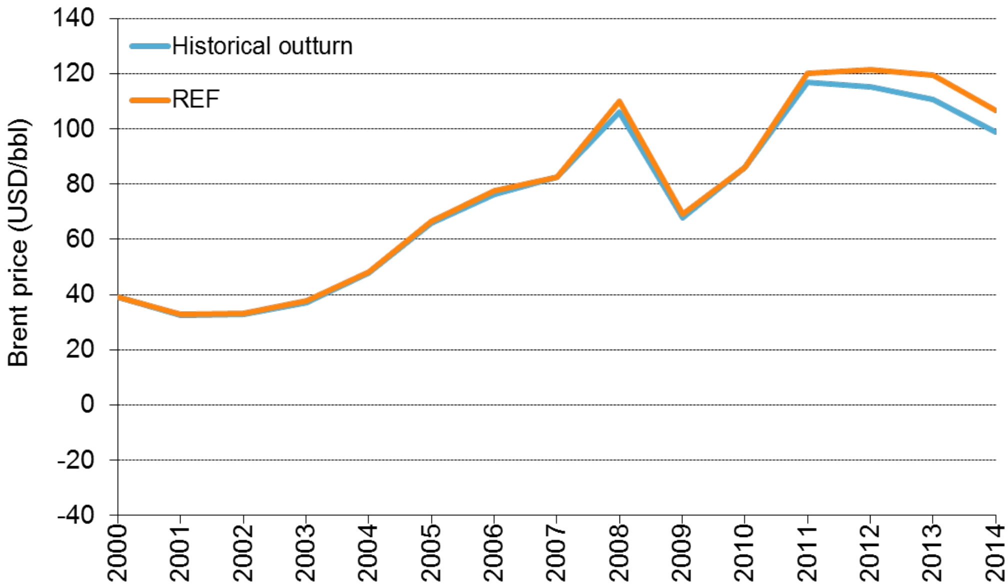


Figure D.6: REF scenario results and outturn prices

Price setting in Pöyry's oil market model

Incremental demand

To generate a projection for the price of Brent in any year, we match supply and demand in that year to determine the marginal source, which sets the price in that year. As a first step, we determine incremental net demand[35] needed to be met from newly developed non-OPEC sources. This consists of the net demand growth over the previous year and depletion from existing resources. Demand growth is based on ICCT's scenarios and depletion rate is assumed at around 5% until 2030.

Global oil reserves and availability

The next step is to construct a supply curve for newly developed non-OPEC sources. First, we create a list of resources, one onshore and one offshore per country, based on the U.S. Geological Survey's World Petroleum Assessment[36], which provides estimates for undeveloped oil reserves. In the most recent update, the mean estimate for total global reserves in this assessment is around 700 billion barrels of oil, around 20 times the global annual consumption in 2014 (this does not include unconventional sources such as shale oil or tar sands). We then take assumptions for how quickly

[35] Net demand is total demand less refinery gains, OPEC production, and NGL and biofuels production.

[36] U.S. Geological Survey 2012 World Assessment of Undiscovered Oil and Gas Resources. Retrieved from: http://pubs.usgs.gov/dds/dds-069/dds-069-ff/

these reserves could be made available to the market if they are economical to produce. So while from an economic standpoint, cheaper sources would produce as much of their reserve as possible, this assumption serves as a limit on how much can be explored, developed and produced in a single year. We recognise that the modelling is highly sensitive to this assumption, which is why we have carried out a sensitivity with a more conservative estimate for availability.

Production cost and tax regimes

In order to create a merit order of these sources, we match every source with assumptions for development and production costs, and tax regime data. The majority of this is based on publicly available data from sources such as the IEA, EIA or Reuters. The cost of developing a particular source is constant over time, we do not assume any production cost increases in real terms. The resulting supply curve implies that over the longer term, 50% of the new conventional sources are assumed to be available for less than $90/barrel, and 65% for less than $100/barrel.

Appendix E Macroeconomic Modelling Using E3ME

Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global edition is a new version of E3ME which expands the model's geographical coverage from 33 European countries to 59 global regions. This is the most comprehensive model version of E3ME to date and it includes all the features of the previous E3MG model.

Recent Applications

Recent applications of E3ME include:

- an assessment of the economic and labour market effects of the EU's Energy Roadmap 2050
- contribution to the EU's Impact Assessment of its 2030 environmental targets
- evaluations of the economic impact of removing fossil fuel subsidies
- an assessment of the potential for green jobs in Europe
- an economic evaluation for the EU Impact Assessment of the Energy Efficiency Directive

This model description provides a short summary of the E3ME model. For further details, the reader is referred to the full model manual available online from www.e3me.com.

E3ME's basic structure and data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2012 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

The main dimensions of the model

The main dimensions of E3ME are:

- 59 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 69 industry sectors, based on standard international classifications
- 43 categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the six greenhouse gases monitored under the Kyoto protocol

The countries and sectors covered by the model are listed at the end of this document.

Standard outputs from the model

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing a broad range of economic indicators. In addition there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO2 emissions by sector and by fuel
- other air-borne emissions
- material demands (Europe only at present)

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2050.

E3ME as an E3 model

The E3 interactions

Figure E.1 shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO_2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

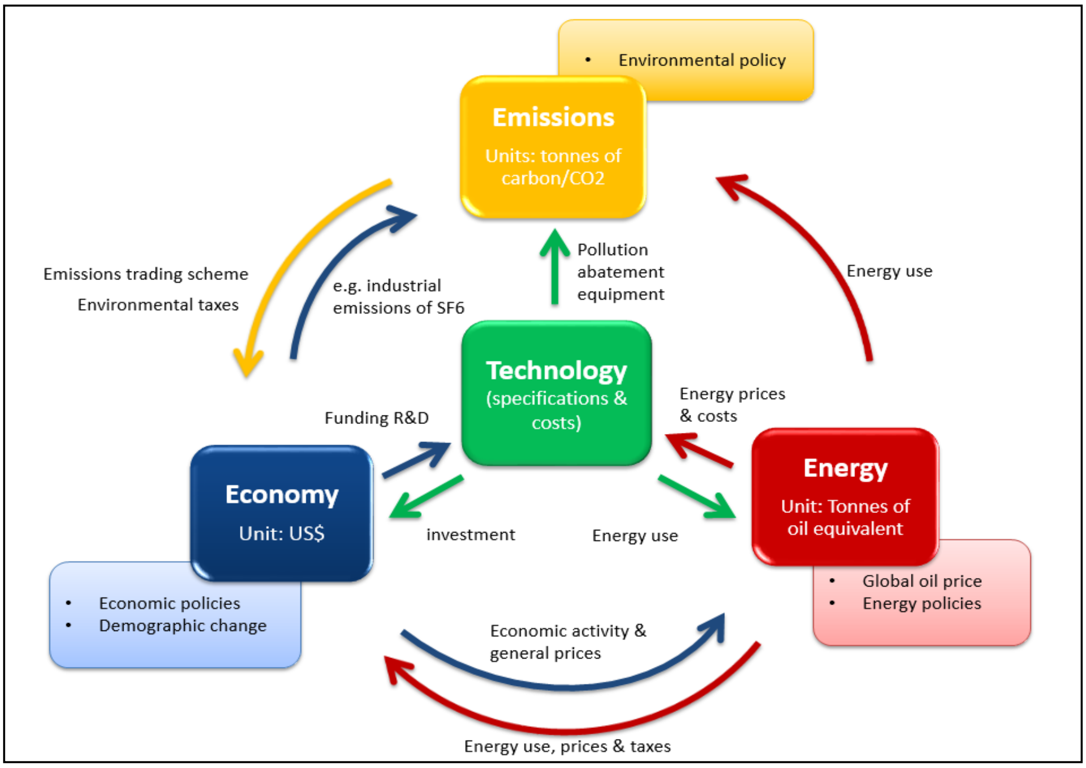
The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

The role of technology

Technological progress plays an important role in the E3ME model, affecting all three Es: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model[37].

[37] See Mercure, J-F (2012), 'FTT:Power A global model of the power sector with induced technological change and natural resource depletion', Energy Policy, 48, 799–811.

Figure E.1: Linkages between energy, the economy, the environment and technology in E3ME



Treatment of international trade

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demand
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

The labour market

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment. This is typically a key variable of interest for policy makers.

Comparison with CGE models and econometric specification

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches. In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[38], which are included as standard in the model's results.

Key strengths of E3ME

In summary the key strengths of E3ME are:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies
- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

Table E.1: Sector classifications in E3ME

[38] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. Barker, T., Dagoumas, A. and Rubin, J. (2008) 'The macroeconomic rebound effect and the world economy', Energy Efficiency.

	Regions	Industries (Europe)	Fuel Users
1	Belgium	Crops, animals, etc	Power use and transformation
2	Denmark	Forestry & logging	Own use and transformation
3	Germany	Fishing	Iron and steel
4	Greece	Coal	Non-ferrous metals
5	Spain	Oil and Gas	Chemicals
6	France	Other mining	Non-metallic minerals
7	Ireland	Food, drink & tobacco	Ore-extraction (non-energy)
8	Italy	Textiles & leather	Food, drink and tobacco
9	Luxembourg	Wood & wood prods	Textiles, clothing & footwear
10	Netherlands	Paper & paper prods	Paper and pulp
11	Austria	Printing & reproduction	Engineering etc
12	Portugal	Coke & ref petroleum	Other industry
13	Finland	Other chemicals	Construction
14	Sweden	Pharmaceuticals	Rail transport
15	UK	Rubber & plastic products	Road transport
16	Czech Rep.	Non-metallic mineral prods	Air transport
17	Estonia	Basic metals	Other transport services
18	Cyprus	Fabricated metal prods	Households
19	Latvia	Computers etc	Agriculture, forestry, etc
20	Lithuania	Electrical equipment	Fishing
21	Hungary	Other machinery/equipment	Other final use
22	Malta	Motor vehicles	Non-energy use
23	Poland	Other transport equip	
24	Slovenia	Furniture; other manufacture	
25	Slovakia	Machinery repair/installation	
26	Bulgaria	Electricity	
27	Romania	Gas, steam & air cond.	
28	Norway	Water, treatment & supply	
29	Switzerland	Sewerage & waste	
30	Iceland	Construction	
31	Croatia	Wholesale & retail MV	
32	Turkey	Wholesale excl MV	
33	Macedonia	Retail excl MV	
34	USA	Land transport, pipelines	
35	Japan	Water transport	
36	Canada	Air transport	
37	Australia	Warehousing	
38	New Zealand	Postal & courier activities	
39	Russian Fed.	Accommodation & food serv	
40	Rest of Annex I	Publishing activities	
41	China	Motion pic, video, television	
42	India	Telecommunications	
43	Mexico	Computer programming etc.	

44	Brazil	Financial services	
45	Argentina	Insurance	
46	Colombia	Aux to financial services	
47	Rest Latin Am.	Real estate	
48	Korea	Imputed rents	
49	Taiwan	Legal, account, consult	
50	Rest ASEAN	Architectural & engineering	
51	OPEC	R&D	
52	Indonesia	Advertising	
53	Rest of world	Other professional	
54		Rental & leasing	
55		Employment activities	
56		Travel agency	
57		Security & investigation, etc	
58		Public admin & defence	
59		Education	
60		Human health activities	
61		Residential care	
62		Creative, arts, recreational	
63		Sports activities	
64		Membership orgs	
65		Repair comp. & pers. goods	
66		Other personal serv.	
67		Hholds as employers	
68		Extraterritorial orgs	
69		Unallocated/Dwellings	
Source(s): Cambridge Econometrics.			

Appendix F Detailed macroeconomic results

US Results

Table F.1: Economic impact of lower oil price in the TECH scenario

	2030	2050
	% change relative to BAU oil price scenario	
GDP	0.15%	0.68%
Employment	0.02%	0.09%
Consumer prices	-0.45%	-1.33%
Real income	0.46%	1.40%
Consumption	0.24%	1.05%
Exports	-0.35%	-0.32%
Imports	-0.05%	0.53%

Source: E3ME.

Table F.2: Economic impact of lower oil price in the REBOUND scenario

	2030	2050
	% change relative to BAU oil price scenario	
GDP	0.10%	0.60%
Employment	0.01%	0.08%
Consumer prices	-0.37%	-1.24%
Real income	0.37%	1.31%
Consumption	0.17%	0.94%
Exports	-0.33%	-0.52%
Imports	-0.07%	0.38%

Source: E3ME.

Table F.3: Economic impact of lower oil price in the REBOUND scenario

	2030	2050
	% change relative to BAU oil price scenario	
GDP	-0.09%	-0.18%
Employment	-0.01%	0.01%
Consumer prices	0.01%	-0.34%
Real income	-0.11%	-0.12%
Consumption	-0.05%	-0.13%
Exports	-0.11%	-0.36%
Imports	-0.26%	-0.70%

Source: E3ME.