Scenarios and Models Primer

Future Pathways to 2^{o}C-Compatible Oil Majors

Prepared by

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Key Findings

- Dozens of global energy models exist with over 1000 published scenarios. A general taxonomy of energy models includes their analytical approach (typically macroeconomic top-down or technology-rich bottom up); their solution methodology (i.e. the mathematical algorithm used to develop the projection); and their degree of foresight (i.e. whether the solution is developed with perfect foresight, like an idealized social planner, or with myopia of the future). Recent modelling efforts have developed hybrid analytical approaches which include both well-defined technology options and macroeconomic feedback loops.

- Oil and gas companies and industry associations publish scenario projections but are less forthcoming about how their models work. Inconsistency in time horizon, data fields, and even the units chosen (e.g. passenger-kms vs. new vehicle sales) obfuscate direct like-with-like comparison. Industry publications are narrative-driven rather than an exposition of modelled projections. Of the selected scenarios, few are explicitly two-degrees-warming compatible.

- Population and GDP growth are common macroeconomic drivers of energy demand. It is unclear for industry publications whether GDP growth prospects are entirely exogenous to projected energy demand, or whether climate damage in the given scenario has impacted GDP growth.

- Almost all lower-carbon scenarios show substantial improvements in energy efficiency combined with a rapid expansion of renewables displacing coal in primary energy supply.

- Most business-as-usual scenarios project that emissions will exceed the 2°C upper bound (where it is equally likely to exceed or not exceed 2°C warming) by 2020 to 2030. Shell is a clear outlier that anticipates this bound will be breached before 2020 in both its scenarios.

- Most selected scenarios project an inflection point in oil production in 2030. BP and Exxon are the only organisations that anticipate OPEC's share of production will fall through 2040; all other organisations project a rising share of OPEC production.

- A striking difference of opinions exists in the outlook for electric vehicles. Exxon and OPEC project fleet penetration of electric passenger vehicles to remain less than 5% in 2040, with less than 10% of new sales. Statoil has a more bullish outlook than even BNEF, which anticipates 35% of passenger vehicle sales in 2040 will be electric vehicles.

- The role of nuclear and CCS-equipped fossil fuel power is particularly uncertain. For high-coordination narratives like Shell Mountains and WEC Symphony, these low-carbon options feature heavily. For other transition scenarios, renewables dominate the electricity mix.

- Of the IOC comparator group (Chevron, Exxon, Total, Shell, and BP), Chevron is most exposed to upstream revenue sources. Exxon has the largest reserves base. Shell, with its recent acquisition of BG, is the most heavily gas-weighted.

Introduction

The global energy system is critical for enabling economic growth and development, international connectivity, and high living standards, but is incredibly complex. Understanding the global energy system is of utmost importance for energy and utility companies and their investors, governments and policy makers, and activists seeking to mitigate climate change. Many organisations, including academics, NGOs, and energy industry companies, periodically publish their best projections of the future energy system. They develop these projections based on economic models of the energy system and assumptions of future changes and development. These projections are relied upon by company managers, investors, policy makers, and civil society to inform decision making.

Understanding the projections of academics, NGOs, and companies requires a holistic view of the energy system and its many interacting parts. The development of an energy model requires assumptions about the relationships between the macroeconomy, technology development and deployment, efficiency gains, international trade and diplomacy, even consumer preferences. These models are parameterized according to different scenarios which give different views of the future. Given the importance of these model and scenarios to decision makers in all aspects of the energy transition, this document has been prepared to capture and compare the publications which form the evidence base. The taxonomy and universe of energy models is presented first followed by a comparison of selected scenarios and their assumptions. This document concludes with selected statistics of the international oil company comparator group which may be indicative of their role in or exposure to the transition to a low-carbon economy.

Models

Taxonomy of Energy Models

Integrated Assessment Models (IAMs) have been used in the past two decades to allow scientists and policy makers to explore the complex linkages between policy, the economy, and the environment (Dowlatabadi, H. 1995). They have come to prominence particularly in the analysis of climate change policy due to the wide ranging direct and secondary impacts of climate change policy on the energy system. IAMs are distinct from General Circulation Models (GCMs) which resolve complex thermodynamic and fluid dynamic equations in the planet's atmosphere to provide global projections of weather and climate. IAMs may sometimes include simplified versions of the former, and both are used to inform environmental policy making. A general taxonomy of IAMs is presented here to underpin the analysis of models and scenarios that follows.

The main taxonomical difference between IAMs is their analytical approach; their solution methodology; and their degree of foresight (Mai, T. et al. 2013).

Analytical Approach

The analytical approach of IAMs describes how the models conceive and analyse relationships in the energy-economy-climate system. The two general categories are top-down models and bottom-up models, however more recent modelling has bridged the two with the creation of hybrid models. In analytical approach, the best models seek to be technologically explicit, macroeconomically complete, and microeconomically realistic (Hourcade et al., 2006).

Top-down models characterize the macroeconomic relationships between the energy, climate, and economy system. Their strength is capturing the feedback relationships between energy technologies, the climate, and the economy. They rely, however, on extensive assumptions about these feedback relationships and economic elasticity. They generally fail to realistically capture relationships between technology, policy, and microeconomic actors.

Bottom-up models are generally more 'technology-rich', allowing extensive parameterization of the relationships between technology types and assumptions about changes in their engineering. These models are also better suited to capturing microeconomic phenomena such as oligopolistic market conditions and consumer behaviour. They are ill-suited to represent the feedback loops of the macroeconomy.

Emerging hybrid models attempt to bridge the strengths and weaknesses of top-down and bottom-up models. Such approaches include building extensive technical detail into top-down models or incorporating macroeconomic feedback considerations into bottom-up models. New hybrid models requiring new algorithms are being built from scratch to escape the limitations of the incumbents.

Solution Methodology

The solution methodology is the algorithmic infrastructure used to 'solve' a model for a given set of parameters. The solution methodology is closely related to the analytical approach: general equilibrium models more typical of top-down models; partial equilibrium are more typical of bottom-up models. Simulation, optimisation, and econometric solution methodologies are used for both top-down and bottom-up models. One model may combine multiple solution methodologies.

General equilibrium models are based on the fundamental work of Walras, L. (1874) and Arrow, K. & Debreu, G. (1954). These models consider the economy a system of closed and interrelated markets into which agents allocate their limited resources (e.g. labour and capital) in production which is transferable between sectors. A price vector for all markets is able to resolve the system of equations at each time step. For a complete development of the general equilibrium model, see Cardenete, M. A. et al. (2012).

Optimisation models seek to algorithmically optimise a prescribed objective function over the models' time horizon. Examples include welfare maximisation (i.e. the maximisation of a pre-defined utility curve), production surplus maximisation, or minimisation of infrastructure investment costs.

A partial equilibrium model considers one or several markets in isolation from the rest of the economy. Thus having a limited scope, these models more easily accommodate a multitude of technology options and their interrelated trade-offs. Economic and population growth and the activity of unrelated sectors of the economy are often taken as exogenous to these models.

Simulation models depart from computations of economic behaviour. Models are solved instead by quantitative relationships provided by the modeller. Their advantage is they require less calibration to produce meaningful results – the equations have built-in realism from describing observed relationships. Their disadvantage is their limitation from the same: the model's output is produced from equations tailored from historic data, not economic fundamentals.

Degree of Foresight

Models are also differentiated by their degree of foresight, which ranges from myopic to perfect.

Under perfect foresight, economic actors have full perfect information about the future. Optimisation models of this type act as a sort of optimal social planner and resolve all time periods simultaneously. These models are useful to provide a pareto-optimal counter-factual case to real decision making which is made with some degree of myopia. An example might solve the minimum energy investment subject to a known carbon emissions constraint through 2100.

Myopic (also called dynamic-recursive) models are solved time-step by time-step, allowing a more realistic treatment of decision-making under uncertainty. Information availability may be limited only to past solved time-steps or information regarding model constraints may be extended several time-steps into the future. An example might solve the minimum energy investment realistically deployed when a carbon emissions constraint is only known five years into the future.

Modelling critiques

Typical critiques of modelling efforts include the universal modelling of agents as ‘price takers’ (who have no strategic agency to manipulate prices in their favour); the use of varied discount rates for future utility and cash flows; technology uptake curves; failure to capture externalities; unrealistic foresight assumptions; and general ignorance of climate sensitivities, damage functions, and extreme events (see e.g. Wilkerson et al. 2014, Pindyck 2015).

Universe of Integrated Assessment Models

Dozens of energy-economy-climate integrated assessment models exist with over one thousand published scenarios. Extensive comparison studies of peer-reviewed IAMs were conducted as part of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Table 1 describes the IAMs which formed the evidence base for the IPCC's Fifth Assessment Report (AR5). In order to be accepted for the IPCC AR5, the models, their scenarios, and projections were required to have been peer reviewed.

Table 2 provides a more detailed look at the models and scenarios selected for further analysis in this document. These models and scenarios are widely referenced and cross-referenced and form the main literature base for global energy projections. They include publications from NGOs and governments, academic sources, and private industry projections.

Table 1 IAM literature base for IPCC (2014). Reproduced in part from IPCC (2014), Working Group III, Annex ii.10, 1309-10.

Model	Institution	Analytical Approach	Solution Methodology	Degree of Foresight	Regional Coverage
AIM-Enduse	National Institute for Env. Studies, Japan	BU	PE	Myopic	32
BET	Central Research Institute of Elec. Power Industry, Japan	TD	GE	Perfect	32
DNE21+	Research Institute of Innovative Technology for the Earth, Japan	BU	PE	Perfect	54
EC-IAM	Environment Canada, Canada	TD	GE, Opt - Welfare	Perfect	11
Ecofys	Ecofys, UK	BU	PE	Myopic	1
ENV-Linkages	OECD	TD	GE	Myopic	15
FARM	Öko-institut e.V., Germany	TD	GE	Myopic	15
GCAM	University of Maryland, USA	BU	Simulation	Myopic	14
GEM-E3	Joint Research Center, EU	TD	GE	Myopic	37
GRAPE	Institute for Applied Energy, Japan	TD	GE	Perfect	15
GTEM REF 32	Department of Agriculture, Fisheries, and Forests, Australia	TD	GE	Myopic	13
IEEJ	Institute of Energy Economics, Japan	TD	Econometric	Perfect	43
IGSM	MIT	BU	GE	Myopic	16
IMACLIM	Centre International de Recherche sur l'Environnemnt et le Developpemnet, France	BU	GE	Myopic	12
IMAGE	Netherlands Environmental Assessment Agency, Netherlands	BU	Simulation, PE	Myopic	26
iPETS	National Center for Atmospheric Research, US	TD	GE	Perfect	9
KEI-Linkages	Korea Environment Institute, South Korea	TD	GE	Myopic	13
MARIA23	Tokyo University of Science, Japan	TD	GE	Perfect	23
MERGE	Stanford University, US	TD	GE, Utility-max	Perfect	9
MERGE-ETL	Paul Sherrer Institut, Switzerland	TD	GE, Welfare-max	Perfect	9
MESSAGE	International Institute for Applied Systems Analysis, Austria	TD	GE, Costs-min	Perfect	11
MiniCAM-EMF	Pacific Northwest Laboratory, US	TD	PE	Perfect	14
Phoenix	Pennsylvania State University, US	TD	GE	Myopic	24
POLES	Enerdata, France	BU	PE, Econometric	Myopic	57
REMIND	Portdam Institute for Climate Impact Research, Germany	TD	GE, Welfare-max	Perfect	11
SGM	Pacific Northwest Laboratory, US	TD	GE	Myopic	8
TIAM-ECN	Energy Research Centre of the Netherlands, Netherlands	BU	PE, Econometric	Perfect	15
TIAM-World	KanORS, India	BU	PE, Econometric	Perfect	16
TIMES-VTT	VTT, Finland	BU	PE	Perfect	17
WITCH	Fondazione Eni Enrico Mattei, Italy	TD	GE, Surplus-max	Perfect	13
WorldScan2	Bureau for Economic Policy Analysis (CPB), Netherlands	TD	GE	Myopic	5

Table 2 Selected Integrated Assessment Models

Organisation	Publication	Model	Analytical Approach	Solution Methodology	Degree of Foresight	Publication Horizon	Key Scenarios
NGO/Government							
IEA	World Energy Outlook	WEM	Hybrid	Simulation	Myopic	2040	CPS; NPS; 450S; Low Oil Price; High Oil Price
	Energy Technology Pathways	ETP-TIMES	BU	Partial Eq.	Perfect	2050	2DS; 4DS; 6DS
WEC	World Energy Scenarios	GMM	BU	Partial Eq.	Perfect	2050	Jazz; Symphony
EIA	International Energy Outlook	WEPS+	TD	General Eq.	Perfect	2040	Reference; Low Oil Price; High Oil Price
OPEC	World Oil Outlook	OWEM	TD	General Eq.	Perfect	2040	Reference
IEEJ	Asia/World Energy Outlook	World Energy Outlook Model	TD	Econometric	Perfect	2040	Reference; Advanced Technology; Low Price
Academic							
MIT	Energy and Climate Outlook	IGSM-CAM	TD	General Eq.	Myopic	≥2050	Reference
IPCC	Fifth Assessment Report	Various (31 ea.)	Various	Various	Various	Various	Various (1,184 ea.)
Private Industry							
Shell	Energy Scenarios	Shell WEM	Unspecified			2060	Mountains; Oceans
BP	Energy Outlook	Unspecified				2035	Base Case; Low Growth; Faster transition; Strong Shale
Exxon	Outlook for Energy	Unspecified				2040	[none] (single projection)
Statoil	Energy Perspectives	Unspecified				2040	Reform; Renewal; Rivalry

Scenarios

Scenarios are developed within integrated assessment models as a set of parameters, assumptions, and constraints which give some plausible view of the future (Janssen, S. et al., 2009). In energy, economy, and climate modelling, scenarios often involve a combination of policy, technology, and social change which results in different states of the energy-economy-climate system. Since the Copenhagen Accord (2009), many scenarios have been developed to explore how global climate change might be limited to 2°C of warming, the target most generally agreed up as the 'safe' limit to warming.

Selected Scenarios

International Energy Agency (IEA)

The IEA was established in 1974 by the OECD to ensure the security and stability of world energy supply. The IEA advocates for affordable, secure, and clean energy and provides extensive information and analysis in collaboration with country governments and the energy industry. The IEA publishes the annual World Energy Outlook (WEO) which features three main scenarios, below, as well as minor scenarios like the low oil price scenario. The IEA also published the annual Energy Technology Pathways (ETP) which examines the development of new and alternative energy technologies. ETP scenarios correspond to various levels of global warming: 2°C warming scenario (2DS), 4°C warming scenario (4DS), and 6°C warming scenario (6DS).

Current Policy Scenario (CPS)

The conservative scenario of the WEO, the CPS projects energy markets based on existing and implemented policies only, providing the counter-factual case for new policies introduced in the NPS and 450S.

New Policy Scenario (NPS)

The NPS is the IEA's central scenario. The NPS includes expected and intended policies, even if the details of such policies are not yet determined. The NPS tempers the implementation of intended policies with realistic expectations of the government's ability to implement them. Such policies might include renewable, low-carbon, and efficiency energy programmes, the reform of energy subsidies, carbon pricing, and alternative fuels and vehicles.

450 Scenario (450S)

A scenario used to illustrate the policies necessary to achieve a peak atmospheric concentration of 450ppm CO2e, limiting long-term climate change to 2°C of warming with 50% likelihood. This scenario does not include active global climate change policy until 2020, but has interim decarbonisation in the meantime.

World Energy Council (WEC)

The WEC is a global network of energy leaders in intergovernmental, governmental, and private organisations. The WEC facilitates dialogue on pressing issues in the energy system. In 2013 the WEC published the results of a scenario-building exercise in *World Energy Scenarios*.

Jazz

Jazz is an energy scenario which emphasizes energy access and affordability. Jazz is characterised by higher GDP growth, freer trade, and technology competition. Energy investment decisions are driven by investors, markets, and consumers.

Symphony

Symphony is an energy scenario which emphasizes the environmental sustainability of the energy system. Symphony is characterized by lower GDP growth, coordinated government action on sustainability, and support for renewable energy systems. Energy investment decisions are driven by government policies and international carbon markets.

US Energy Information Administration (EIA)

The EIA is the statistics and analysis agency of the US Department of Energy (DoE). From time-to-time, the EIA publishes the International Energy Outlook, with projections of future energy supply and demand.

High Oil Price

The EIA high oil price scenario envisions a future where the oil price reaches US$150/bbl by 2020 and over US$200/bbl by 2040 (real US$2012). The oil price results in a different global supply and demand, fuel, and technology mix.

Reference

In the EIA Reference scenario, the oil price is approximately US$100/bbl in 2020 and US$140/bbl in 2040. The EIA calls their scenario projections policy-neutral – baselines against which policy and market changes may be analysed.

Low Oil Price

In the low oil price scenario, the EIA considers a future where the oil price stays near US$70/bbl through 2040.

Organisation of Petroleum Exporting Countries (OPEC)

OPEC is an inter-government organisation which coordinates the production and export of petroleum by 13 member countries. OPEC publishes the annual World Oil Outlook (WOO), which establishes a reference case (below) for world energy supply. Other scenarios of the WOO include higher and lower economic growth scenarios, and upside and downside oil supply scenarios.

Reference

OPEC's reference case includes projections of energy demand and supply, technology improvement, capital stock turnover, and the enactment of new policies limited to those being seriously discussed or considered at the time of publication.

Institute of Energy Economics Japan (IEEJ)

The IEEJ was founded by the Japanese Ministry of Trade and Industry in 1966. The IEEJ conducts research into energy issues with focus on those particularly pertinent for Japan. The annual Asia/World Energy Outlook provides a projection of world energy supply and demand with particular resolution for Asian countries. As well as the Reference and Advanced Technology scenarios, the IEEJ publishes a minor low price scenario.

Reference

The Reference scenario projects energy supply and demand based on past trends and the current direction of energy policy development.

Advanced Technology

In the Advanced Technology scenario, governments adopt policies which significantly increase the amount of advanced and low-carbon energy technology around the world.

Massachusetts Institute of Technology (MIT)

The MIT Joint Program on the Science and Policy of Global Change studies how to confront the economic, health, and social challenges of climate change. The Program publishes an Energy & Climate Outlook annually.

Central

The Central scenario of the Outlook is the Program's best projection of world energy demand and supply, technology improvements, and current and foreseeable climate change policy.

Royal Dutch Shell plc

Shell is an international oil company headquartered in The Hague, Netherlands and its primary listing is on the London Stock Exchange. Shell produces 3.0mboe/d and has a total enterprise value of US$224bn. Shell produces scenario projections periodically, the most recent being the New Lens Scenarios.

Oceans

In the Oceans scenario, the energy future is dictated largely by markets and public opinion. The transition to more sustainable energy carriers is delayed by inexpensive fossil fuels and public opposition to nuclear power.

Mountains

In the Mountains scenario, the government takes a more active role in shaping the energy future, including the transition to more sustainable and low-carbon energy carriers.

BP plc

BP is an international oil company headquartered in London, UK with its primary listing on the London Stock Exchange. BP produces 3.3mboe/d and has a total enterprise value of US$123bn. BP produces an annual Energy Outlook with one main base case scenario. Secondary scenarios include a low growth scenario, a faster transition scenario, and a shale gas and oil upside scenario.

Base Case

BP's Base Case scenario includes current trends of decoupling growth from carbon emissions, changing regional dynamics of energy supply, and changing energy sources and carriers, including LNG, shale oil and gas, and renewables.

Faster Transition

BP's Faster Transition scenario goes beyond INDC commitments at COP21 to consider a future where energy efficiency, renewables, and carbon pricing increase rapidly, significantly constraining oil demand growth.

Exxon Mobil Corp.

Exxon is an international oil company headquartered in Irving, Texas, US. Exxon produces 4.1mboe/d and has a total enterprise value of US$391bn. Exxon produces an annual Outlook for Energy.

Reference

The Outlook for Energy offers only a single, central scenario, representing Exxon's best projection of future energy supply and demand.

Statoil ASA

Statoil is a government sponsored enterprise formed in the 1970s to extract oil and gas resources in the Norwegian continental shelf. Statoil remains 67% owned by the Norwegian Ministry of Petroleum and Energy and is headquartered in Stavanger, Norway. The company produces 1.8mboe/d, and has a total enterprise value of US$65bn. Statoil produces the annual report Energy Perspectives with three main scenarios.

Rivalry

Statoil's Rivalry scenario paints a bleak picture of conflict and competition for energy supplies. This scenario is characterised by lower economic growth and the dominance of incumbent high-carbon energy carriers as countries seek energy security.

Reform

Reform is Statoil's central scenario. In Reform, countries continue to make policies which reduce energy intensity and transition from high-carbon to low-carbon energy carriers. The decarbonisation is insufficient to meet a 2°C warming limit, and climate change impacts economic growth by the end of the period.

Renewal

In the Renewal scenario, governments take strong action to enact an energy transition, leading to the rapid adoption of low- and no-carbon energy carries and substantial decreases in energy intensity. The projections of the Renewal scenario explicitly target and meet the GHG emissions constraints for a 2°C warming future.

Scenario Comparison

The following sections compare the assumptions and projections of the selected scenarios, where available. Data has been obtained from tables and figures in selected publications. When capturing data from figures, point-capture software has been used with a typical precision of three significant digits. Unit manipulations are not noted however other assumptions or calculations to enable like-with-like comparisons are. References for all scenario publications and model documentation is provided at the end of the document.

Exogenous Assumptions

Among the energy models, GPD and population growth are common exogenous assumptions. The well-known Kaya identity (Kaya, Y., 1990) (see equation 1) reveals how critical these assumptions are in the projection of overall emissions.

$$CO_2\ Emissions = Population * \frac{GDP}{Population} * \frac{Energy}{GDP} * \frac{CO_2}{Energy} \quad (1)$$

Figure 1 shows GDP growth assumptions for selected scenarios. The lowest growth scenarios, WEC's *Symphony* and Statoil's *Rivalry* have entirely different stimulae. In Statoil's *Rivalry*, conflict causes instability which ultimately constrains investment and growth. In WEC's *Symphony*, environmental constraints prevent rapid growth in pollution-intensive fuels. The most common growth outlook, 3.5%, is a figure taken from projections by the OECD, Worldbank, and the IMF (see IEA 2015b), and is weighted by greater growth in the near-term and reduced growth in the long-term. Few scenarios include the feedback loop of climate change damage to GDP growth.

Figure 1 GDP growth assumptions of selected scenarios

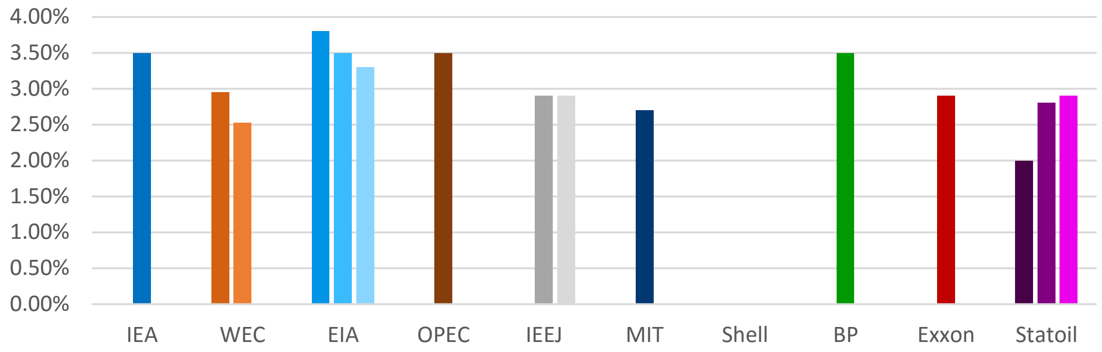
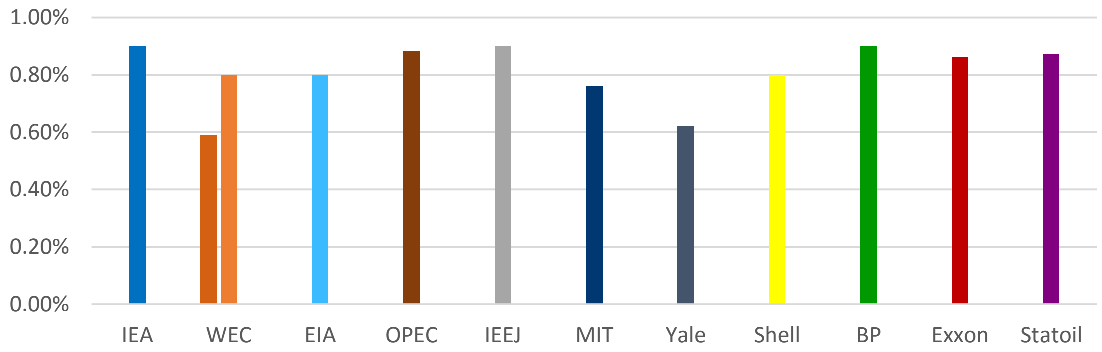


Figure 2 shows the population growth assumptions of selected scenarios. The most common assumption, 0.9%, is based on the United Nations Population Division Report (2014). This population growth puts the total global population at 9Bn people by 2040.

Figure 2 Population growth assumptions of selected scenarios

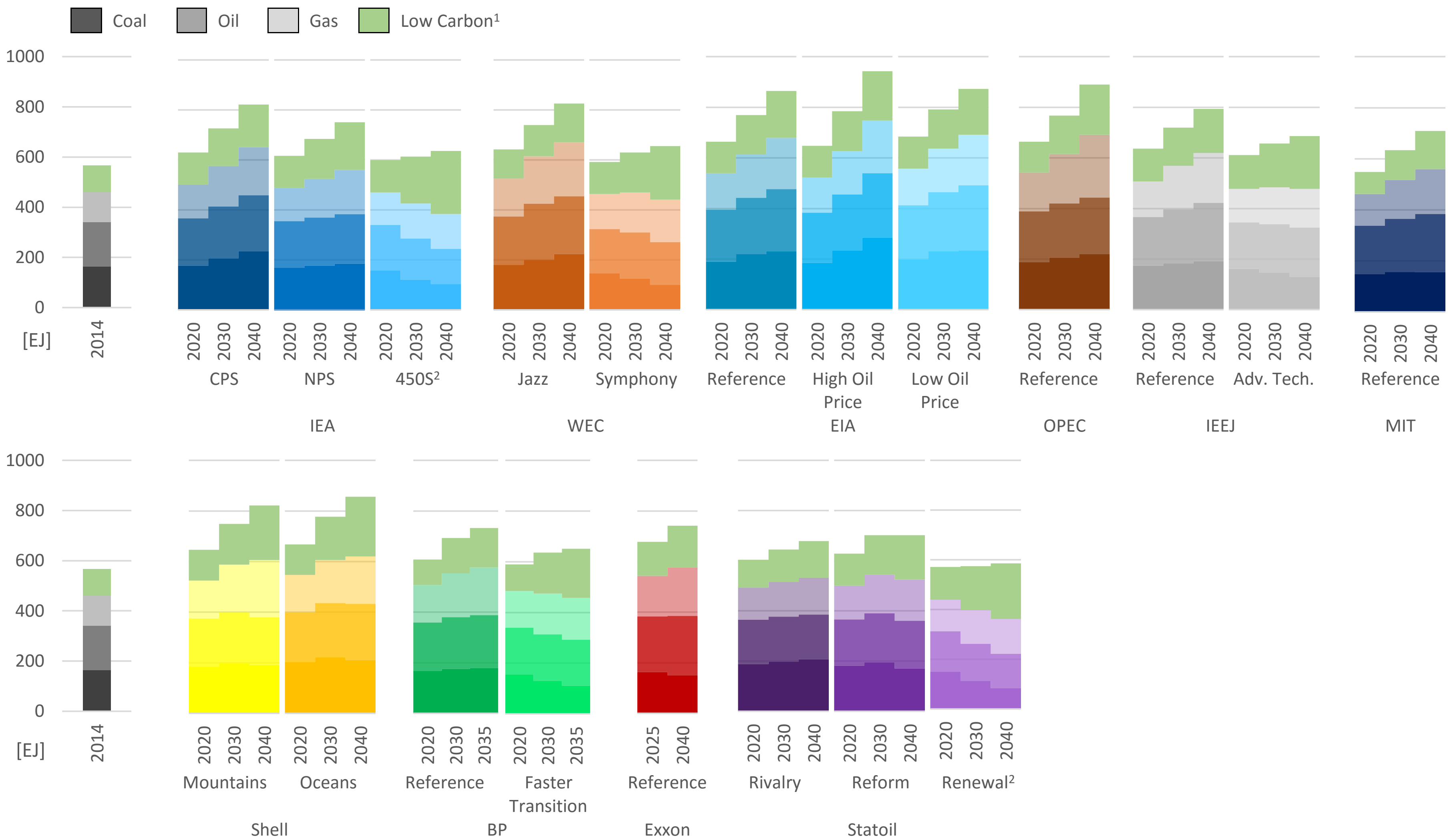


Primary Energy Supply

In most IAMs, final energy demand is typically projected from socioeconomic factors, technology adoption, population, and growth. Final energy demand. Technology adoption examines how energy carriers are transformed from primary supply energy sources to final energy demand. Supply prices, technology price curves, efficiency deployment, and regional trade capacity is used to calculate equilibrium prices which trace energy supply through transformation to energy demand.

Figure 3 shows the total primary energy demand (TPED) for selected scenarios. Common among low(er) carbon scenarios is the rapid displacement of coal as a primary energy source and the approximate doubling of renewable primary energy by 2040. These transition scenarios also show a substantial improvement in efficiency of energy use, with much lower total growth of total primary energy.

Figure 3 Total Primary Energy Demand (TPED) for selected scenarios



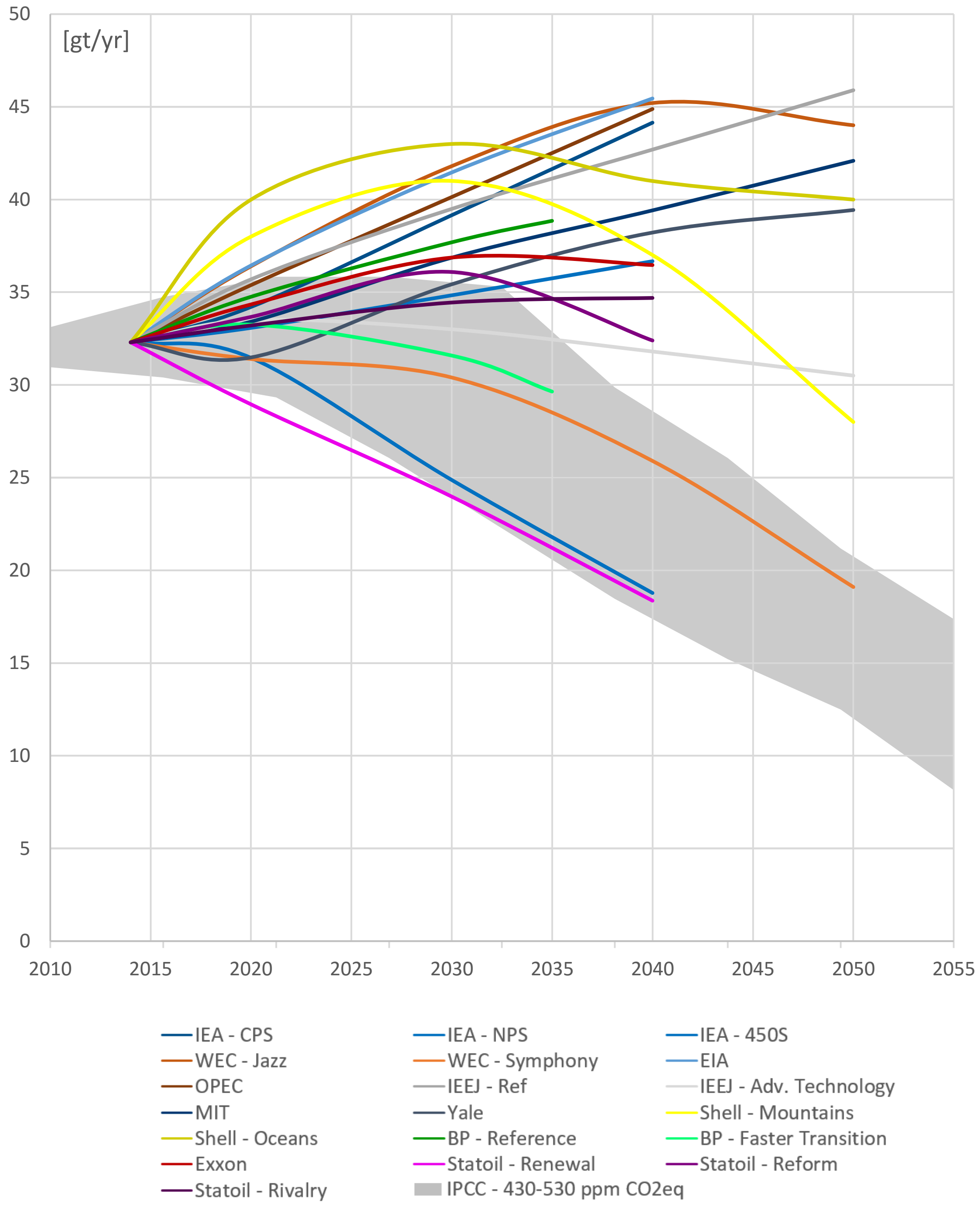
[1] Low carbon includes all renewables, nuclear, biofuels, and fossil-fired power equipped with CCS

[2] Scenarios explicitly compliant with a 2°C warming future

Greenhouse Gas Emissions

Figure 4 shows greenhouse gas emissions from energy and industry for selected scenarios and the IPCC AR5 range for keeping within 2°C warming. 530 ppm is about the limit where exceeding 2°C warming in 2100 is about as likely as not exceeding 2°C warming (see IPCC 2014, Summary for Policy Makers, Table SPM.1). Shell's scenarios project leaving the 2°C warming range most rapidly, with most other scenarios following from 2020 to 2030.

Figure 4 Energy and industry emissions for selected scenarios



Oil Production and OPEC Fraction

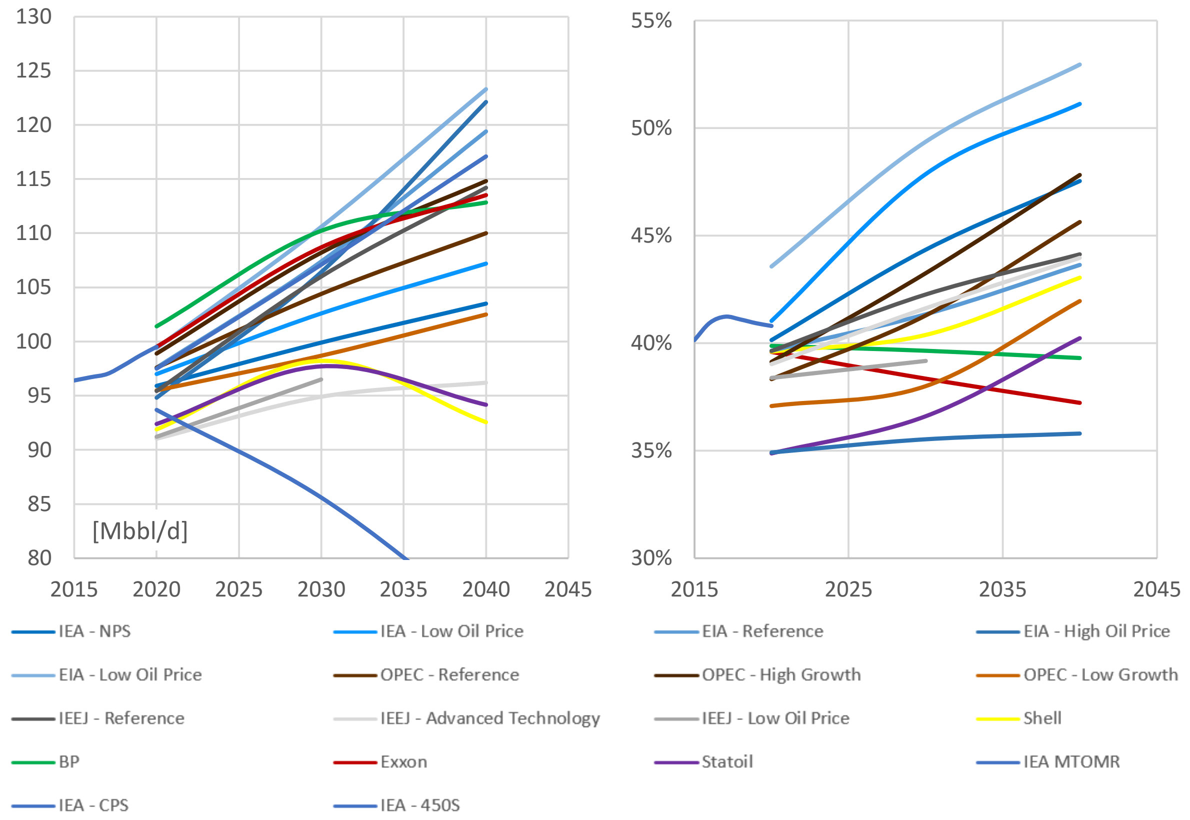
Projections for oil production give an indication of future demand for oil products, the primary product of an oil and gas major. Growth in production indicates a future with large markets for oil and a reliable revenue stream for IOCs in spite of price uncertainty. Declining production indicates a future of increased competition for the IOCs as they struggle for market share in a constricting environment.

Figure 5 shows world oil production for selected scenarios. For both the EIA and the IEA, the low oil price scenario leads to more oil production. Misalignment in 2020 projections is not only due to changes in the interim years (i.e. 2016 to 2020) but also variances in accounting of oil production, e.g. the inclusion of condensate products and natural gas liquids, and the self-consumption during refining and upgrading.

Figure 6 shows the fraction of oil production from OPEC member countries. Almost all scenarios project OPEC to increase their fraction of global oil production, especially the low oil price scenarios from the IEA and EIA. The only scenarios which anticipate a decrease in OPEC's fraction of production are BP and Exxon.

Figure 5 Oil production outlook for selected scenarios

Figure 6 Fraction of OPEC production



Biofuels

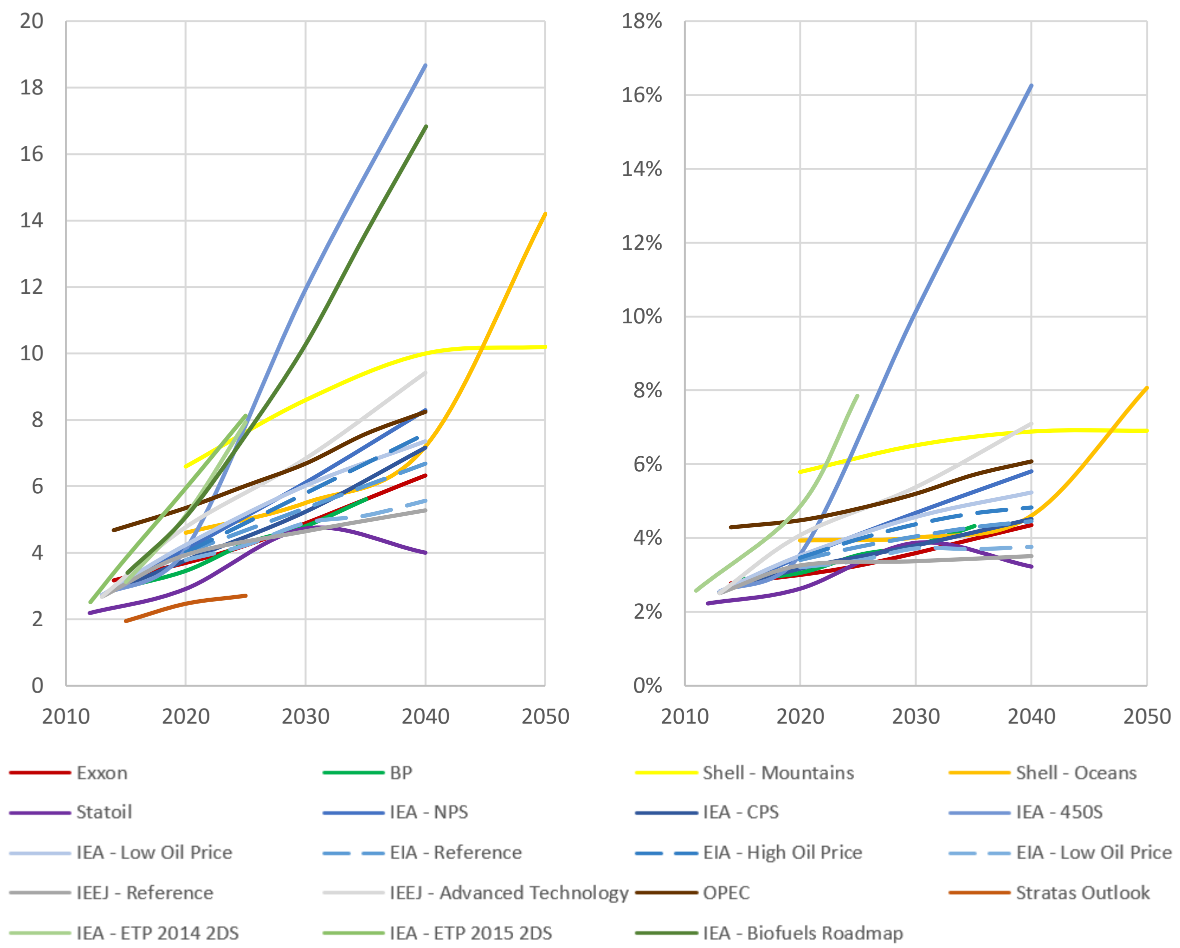
Approximately 44% of oil demand is currently for road transport (OPEC 2015). This demand may be disrupted by biofuel, hydrogen, natural gas, and electric vehicle alternatives. Biofuels offer an alternative to conventional fossil-derived fuel products. Policies which support the growth and development of biofuels expose oil producers to competition from substitute products, but also offer oil and gas companies an alternative technology path which may be more compatible with a low-carbon future. The growth and role of biofuels in selected scenarios and other projections are examined below.

Figure 7 shows the projected addition of biofuels in the global total primary energy supply. In Shell's *Mountains* scenario, early biofuel adoption is driven by policy. Shell's *Oceans* overtakes *Mountains* mid-century as high oil prices drive the development of liquid biofuel alternatives.

Figure 8 shows the projected proportion of biofuels in total transport fuels, which displaces oil products. The similarity between these figures indicates that most biofuels are used in transport applications.

Figure 7 Biofuel projections – TPES

Figure 8 Biofuel projections – portion of transport fuels



Electrification of Transport

The electrification of transport has significant potential to disrupt global oil demand. Figure 9 shows the penetration of electric vehicles in the passenger light duty vehicle stock for selected scenarios. For BNEF, Statoil, and the ETP 4DS, these penetration values were computed from annual sales in a simple stock depletion model based on the US Department of Transportation's Vehicle Survivability and Travel Mileage Schedules (2006), with the inherent assumptions that US vehicle survivability might be extrapolated to other countries and into the future.

Figure 9 Penetration of EVs into the passenger light duty vehicle stock

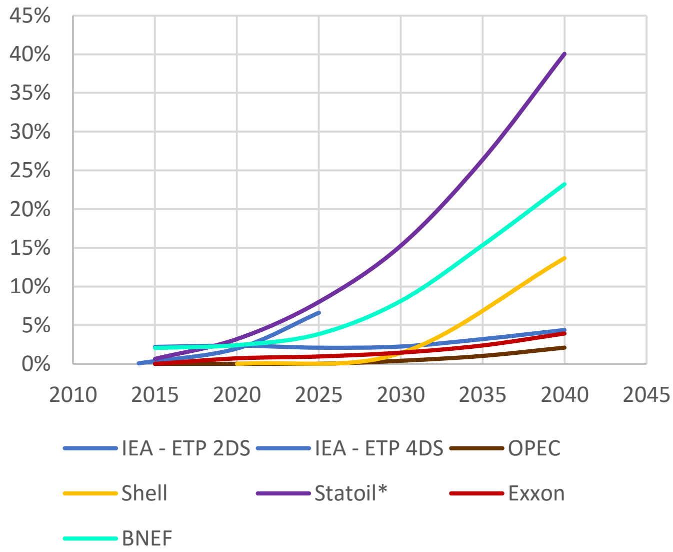


Table 3 Projected EV sales in 2040

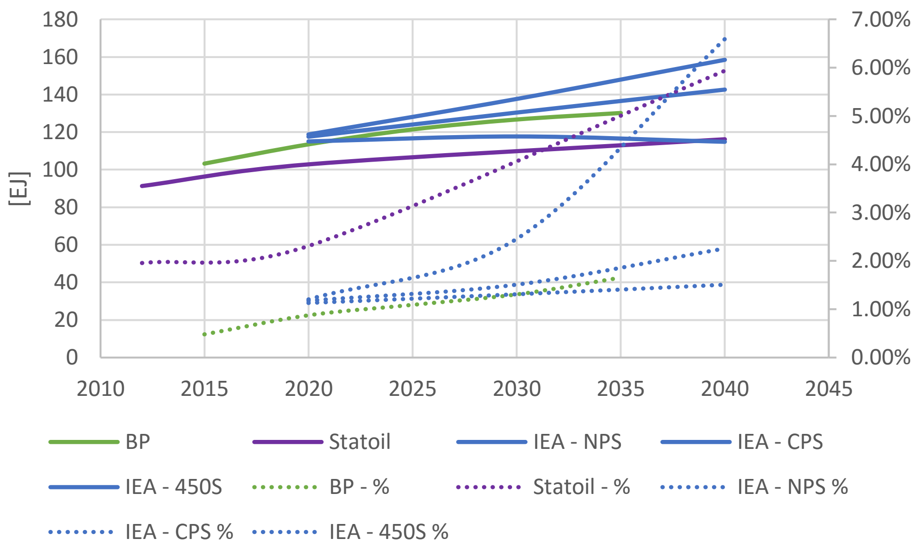
Sales % EVs in 2040	
ETP 4DS	6%
Exxon	<10%
BNEF	35%
Statoil*	62%

*North America, China, India, OECD Europe

Table 3 shows electric vehicle sales in 2040 as a percentage of all new vehicle sales. Statoil's projection is only for North America, China, India, and OECD Europe, but OPEC (2015) projects that two thirds of all new vehicle sales will be in these regions between 2014 and 2040.

Figure 10 captures more broadly the electrification of the entire transport sector where projections are available, both in absolute energy and as a portion of final energy demand for transport.

Figure 10 Electrification of transport final energy consumption

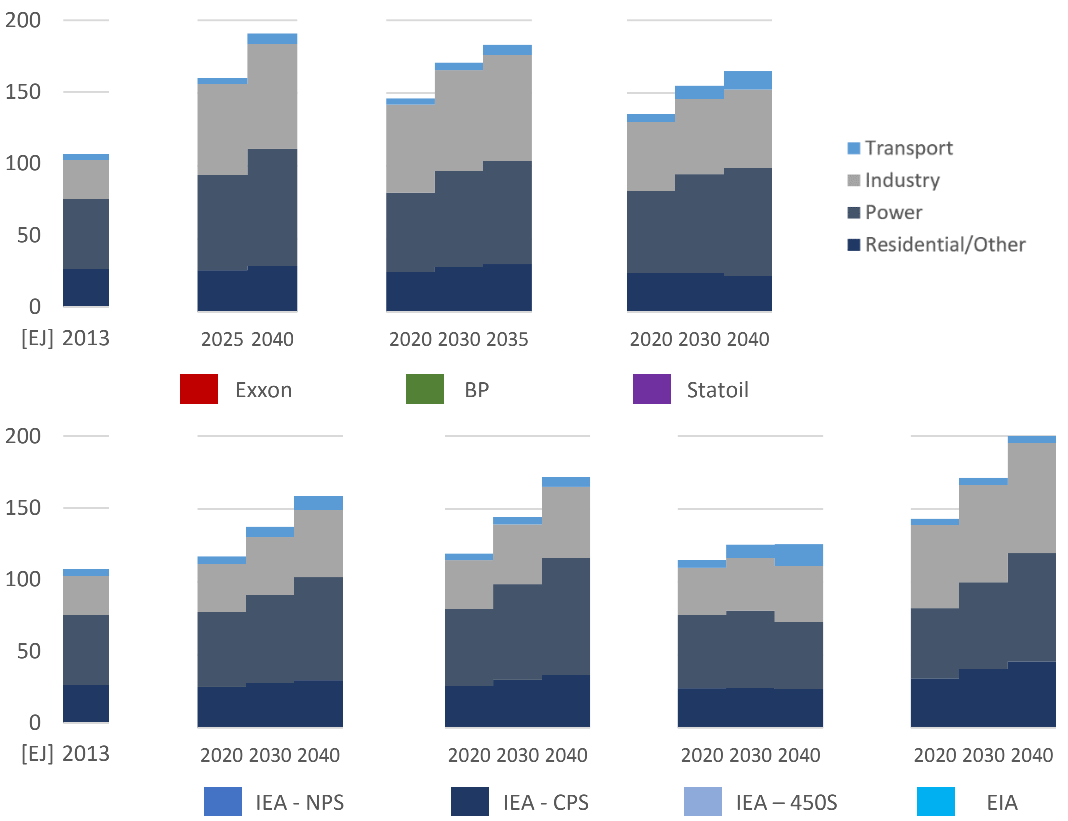


Natural Gas Outlook

While the outlook for oil demand is far from certain, even less is known about the outlook for natural gas. Natural gas has a wider diversity of end-uses and resources landscapes are continually changing, for example by the development of shale gas recovery and its use in countries other than the US. There is far from perfect arbitrage between natural gas end markets, leading to massive build-outs of LNG shipping and receiving capacity worldwide. Major exporters include Qatar, Malaysia, Australia, and Nigeria, shipping to major importers Japan, South Korea, China, and India. New export capacity is being built rapidly to meet demand, both from incumbent Australia and new entrants US and Russia, with global export capacity growing 41% between 2014 and 2020 (IGU 2015).

Sectoral-resolution breakdowns of natural gas demand are not widely published. Figure 11 shows breakdowns obtained from BP, Exxon, Statoil, the EIA, and the IEA.

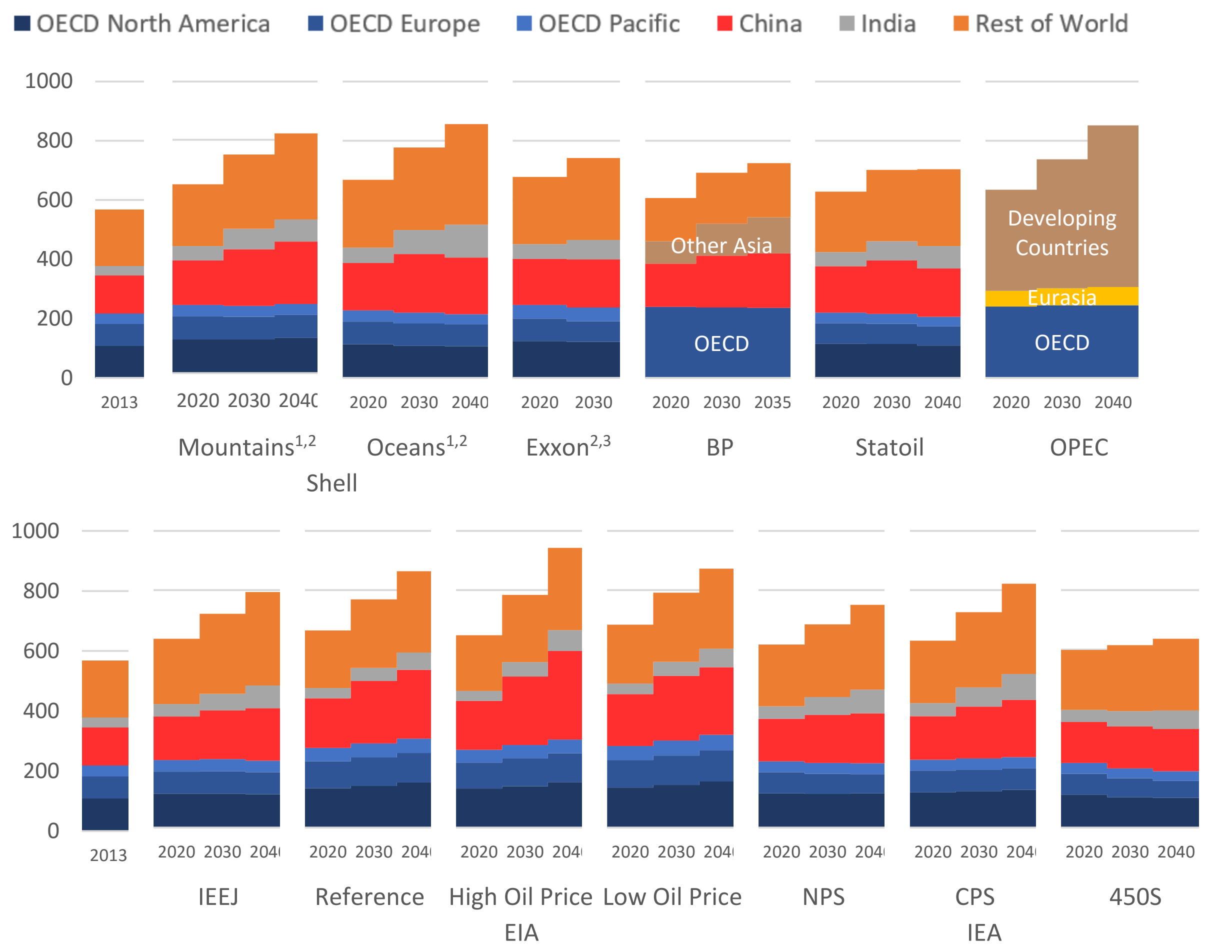
Figure 11 Natural gas outlook by sector for selected scenarios



Regional Outlook

The outlooks for energy growth for the selected scenarios all indicate that growth of total energy demand is expected to be driven by non-OECD countries. Exxon, BP, Statoil, and the IEA's NPS show more constrained projections of non-OECD demand growth. Where projections have been added or subtracted for individual countries, the country's projection has been assumed to be the IEA NPS', in proportions given in the IEA's *Key World Energy Statistics* (2015d). Figure 12 shows the primary energy demand outlook for selected scenarios.

Figure 12 Regional total primary energy demand outlook for selected scenarios

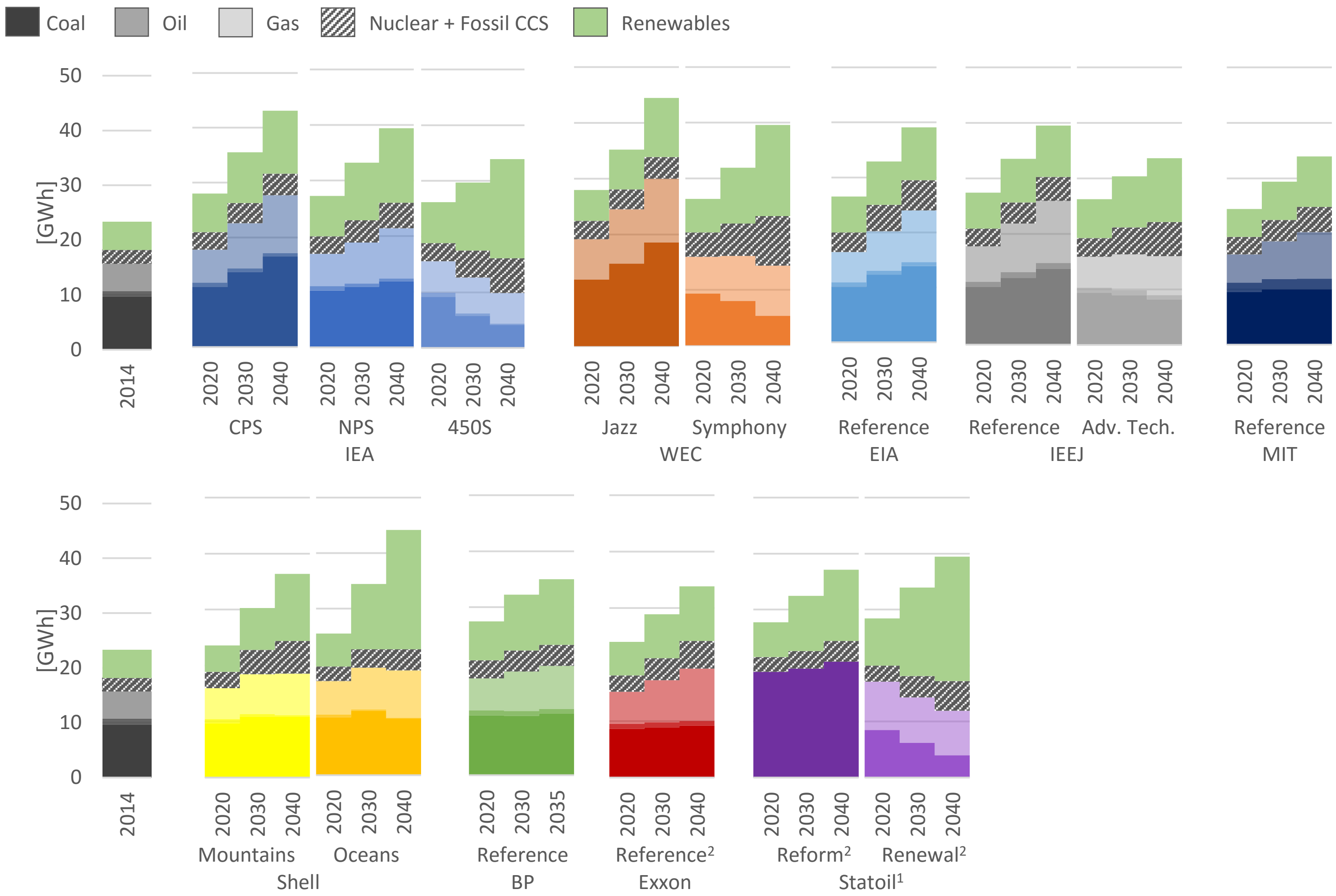


1: Projections for Mexico have been added to those for US and Canada to give OECD North America
2: Projections for Norway, Switzerland, and Turkey added to those for the EU to give OECD Europe
3: Projections for Chile subtracted from remaining OECD countries to give OECD Pacific

Electricity Markets and Future Generation Mix

Fundamental drivers of oil and gas demand, including the electrification of transport, the realisation of any carbon constraint, and the use of gas in generating electricity depend substantially on the future electricity generating mix. Figure 13 shows the future global electricity mix for selected scenarios. Substantial uncertainty exists in the future of coal-fired power. In certain scenarios, like WEC's *Jazz* and the IEA's *CPS*, coal-fired power grows through 2040 largely due to its price competitiveness with natural gas. For 2°C warming-constrained scenarios like the IEA's *450S* and Statoil's *Renewal*, coal-fired power diminishes rapidly. Another key source of uncertainty is the future of low-carbon non-renewable power, i.e. nuclear and coal- and gas-fired power equipped with CCS. Scenarios with a well-coordinated response to developing a low-carbon economy, such as WEC's *Symphony* and Shell's *Mountains* favour low-carbon non-renewable electricity more than other business-as-usual and low-carbon scenarios.

Figure 13 Future electricity generation mix for selected scenarios



[1] *Reform*: coal, oil, and gas power comingled; *Renewal*: oil and gas power comingled
[2] Projections linearly interpolated from 2040 projection

International Oil Company Comparison

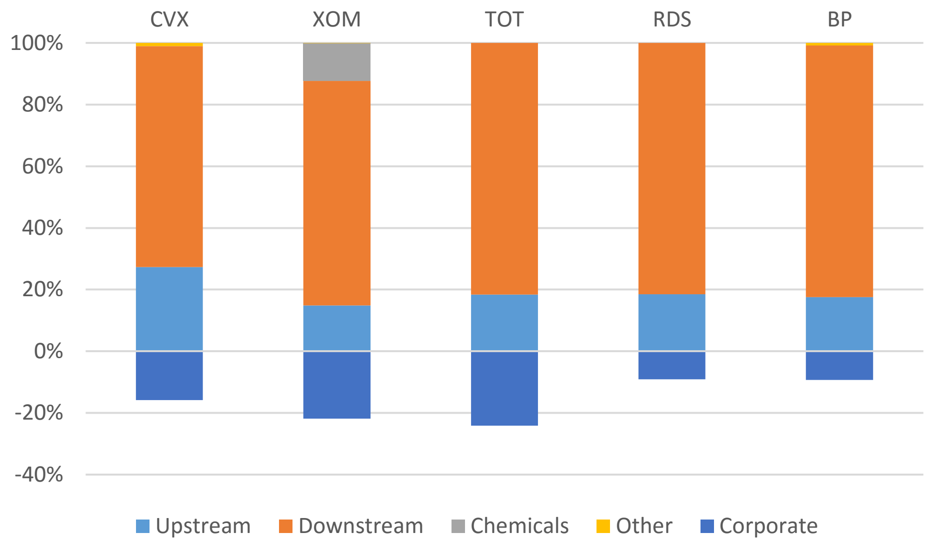
This section examines the business positioning of the international oil company (IOC) comparator group: Chevron (CVX), Exxon (XOM), Total (TOT), Shell (RDS), and BP.

IOC Revenue Comparison

The IOC comparator group is well-diversified through the oil and gas value chain. This diversification acts as a natural hedge against supply and demand of internal goods and services in the industry.

Figure 14 shows revenue sources for the IOC peer group. Chevron has the greatest exposure to upstream operations. Total and Exxon have the largest corporate expenses. Revenue from chemicals operations was only available for Exxon, for the other majors this revenue may be comingled with other downstream activities. All data was taken from Capital IQ (2016).

Figure 14 Revenue source breakdown for IOC peer group



IOC Reserves and Production Comparison

Reserves and production are fundamental to the valuation of an oil and gas company (see e.g. Kaiser & Yu 2012). Figure 15 through Figure 20 show reserves and production data for the IOC comparator group. All data comes from Capital IQ (2016).

Figure 15 and Figure 16 show the oil and gas reserves of the IOC peer group respectively. Exxon has by far the largest reserve base of the peer group. Shell, with its recent acquisition of BG, has added substantial gas reserves. This is best shown in Figure 17 which shows the ratio of gas to oil reserves. Shell is the most gas-weighted followed by Total, though none would be classified as gas companies, the threshold for which is 10,000 CF/BBL (Kaiser & Yu 2012).

Figure 18 and Figure 19 show reserves by total carbon and energy content respectively. Figure 18 also shows reserves as a proportion of the 2100 carbon budget. Combined, the reserves of the IOC peer group totals almost 3% of the 50% likelihood of 2°C warming carbon budget (GCP 2016).

Figure 20 shows the change in reserves to production (R/P) ratio since 2013. R/P ratios for all peer IOCs remain well over 10.

Figure 15 Oil reserves of IOC peer group

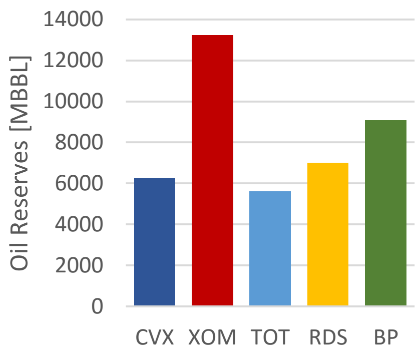


Figure 16 Gas reserves of IOC peer group

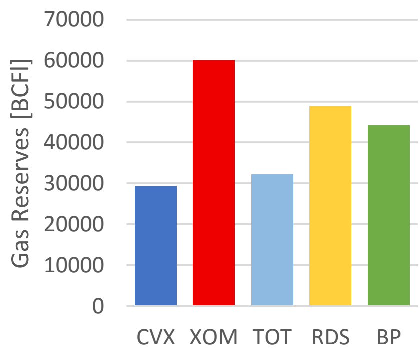


Figure 17 Reserves ratio of IOC peer group

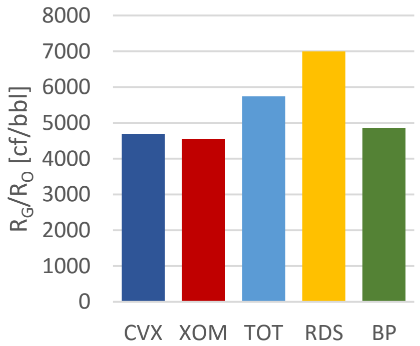


Figure 18 Reserves by carbon content and as a portion of the 2014-2100 2°C warming carbon budget

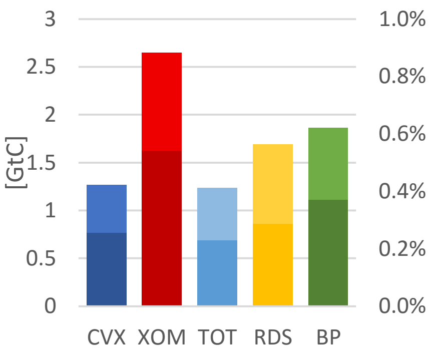


Figure 19 Reserves by energy content of IOC peer group

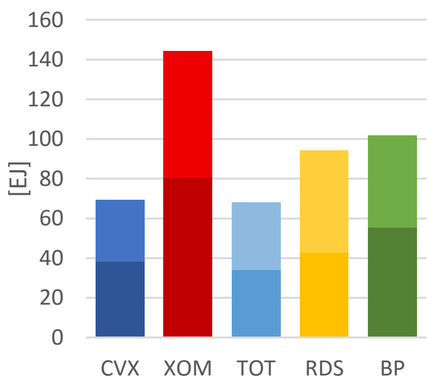
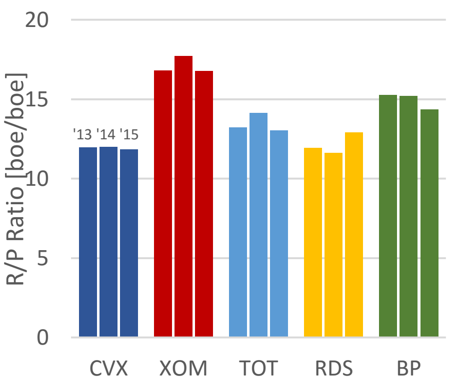


Figure 20 R/P ratio change 2013-15



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