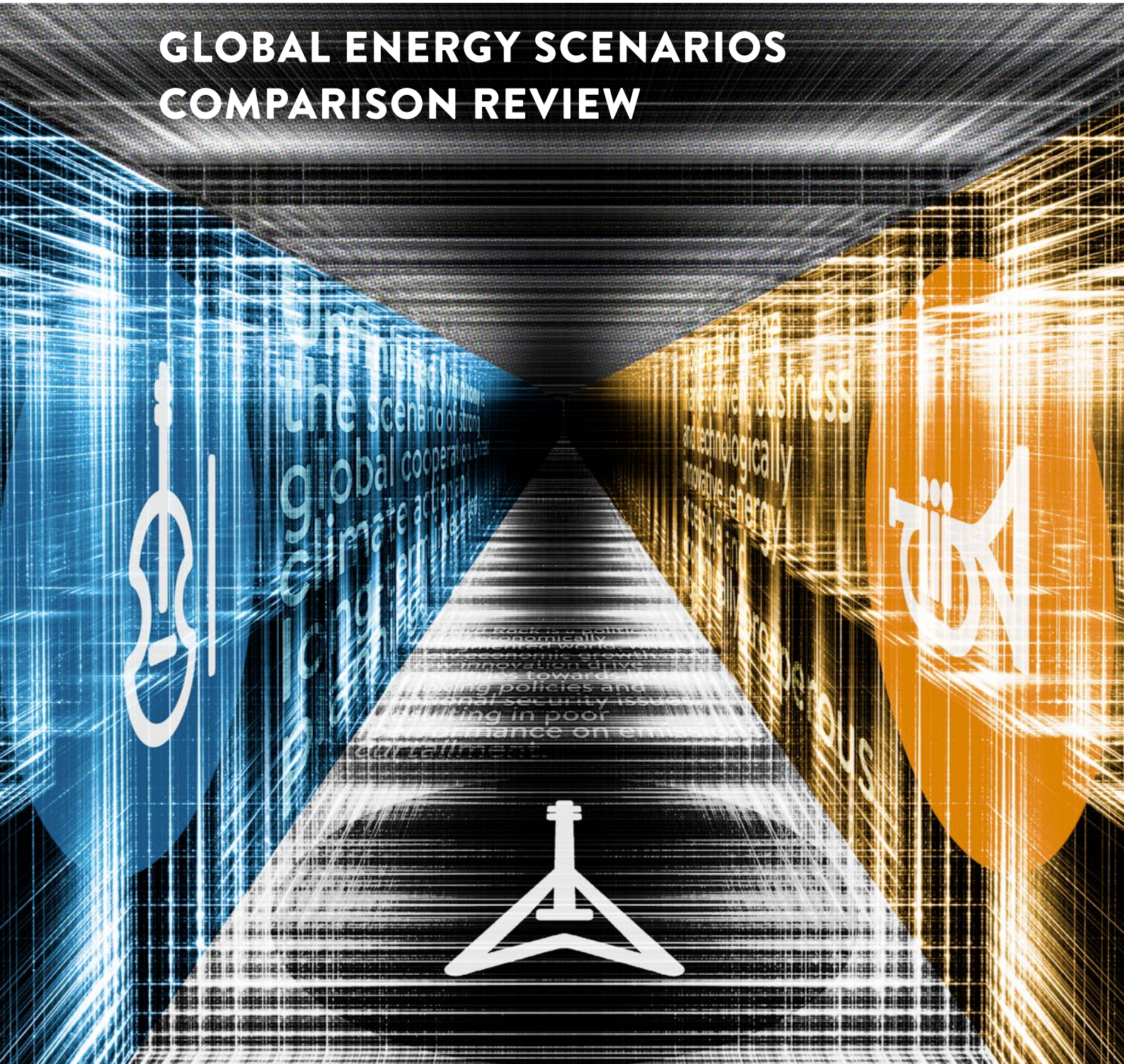
WORLD ENERGY COUNCIL

World Energy Insights Brief | 2019

TECHNICAL ANNEX



ABOUT THE WORLD ENERGY COUNCIL

The World Energy Council is the principal impartial network of energy leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all.

Formed in 1923, the Council is the UN-accredited global energy body, representing the entire energy spectrum, with over 3,000 member organisations in over 90 countries, drawn from governments, private and state corporations, academia, NGOs and energy stakeholders. We inform global, regional and national energy strategies by hosting high-level events including the World Energy Congress, publishing authoritative studies and working through our extensive member network to facilitate the world's energy policy dialogue.

Further details at www.worldenergy.org and @WECouncil

Published by the World Energy Council 2019

World Energy Council
Registered in England and Wales
No. 4184478

VAT Reg. No. GB 123 3802 48

Registered Office
62–64 Cornhill
London
EC3V 3NH
United Kingdom

TABLE OF CONTENTS

BACKGROUND AND OBJECTIVES

In anticipation of the **24th World Energy Congress**, which will convene over 6,000 energy leaders in Abu Dhabi in September 2019, the World Energy Council (the Council) is refreshing its **global energy foresight and updating its global scenarios narratives.** The focus is on an 'innovation twist to 2040' and the use of scenarios to explore and navigate new exponential growth opportunities for accelerating successful energy transition in an era of epic and disruptive innovation.

As a part of the refresh, the Council has conducted **a comparison study of global energy scenarios** in order to test the continued plausibility, relevance and challenge of its own existing scenario set, the **World Energy Scenarios 2016** (WES2016). Launched at the 23rd World Energy Congress in Istanbul in 2016, the WES2016 explore three alternative, plausible decarbonisation pathways to 2060 and their implications for achieving a 2°C limit.

By comparing the methods, narratives and assumptions associated with a benchmarkable set of global energy futures initiatives and studies, the Council seeks to provide our members with **clearer understanding and new insights on energy transition while preparing them to better engage with leadership dialogues which pivot on visions of a new energy future,** including those aimed at achieving internationally agreed commitments e.g. UNFCC Paris Agreement, UN 2030 Agenda for Sustainable Development, as well as those promoted by national governments, energy firms, and new energy start-ups. The review also provides an opportunity to reflect on the challenges and obstacles for utilising global energy scenarios to drive impact, and the challenges in bridging agile and flexible qualitative storytelling with long term, quantitative energy modelling.

Part one
Global Scenarios Comparison Review

GLOBAL ENERGY SCENARIOS COMPARISON REVIEW

GLOBAL ENERGY SCENARIO PRACTICES EMERGED IN THE 1970S

Scenario planning emerged as a process of strategic conversation in energy companies in the 1960s, as an alternative to bottom-up cash flow planning and energy price forecasting. The oil shocks of the 1970s and gluts during the 1980s having made clear that long-range forecasting alone was an insufficient approach to mitigating uncertainty, in recent decades there has been a proliferation of global energy scenarios published by energy firvms, international organisations and government agencies. Use of the term 'scenarios', however, covers many different methods, obscuring the comparison of studies.

DIVERSITY WITHIN GLOBAL ENERGY SCENARIOS METHODS

While all energy futures thinking is purposeful, users, uses and methods are varied. The terms 'scenario', 'forecast', 'outlook' and 'visions' do not mean the same thing. In Table 1, below, we distinguish three main approaches in global energy futures thinking which commonly use the term 'scenario'.

Plausible scenarios	Outlooks	Normative scenarios
• Plausible pathways of alternative future contexts that **might happen** whether or not we want them	• Data rich projections - **the future we expect/assume** on a business-as-usual projection of current trends	• Technically possible and **preferable future towards a target**
• **Qualitative based**, **narrative-led**, supported with **illustrative numbers**	• **Quantitative led**	• Focus on achieving a **specific goal** aligned to a global vision agenda
• Explicit about **societal and political elements** in addition to techno-economic elements	• Focus on **techno-economical elements**	• **Values and identity based approach**
• Provide a **clear and enabling pre-decision framework** for leaders to engage with uncertainty	• Provide a **sensitivity analysis & enable cost-benefit analysis** for decision makers to compliment the baseline projection with new policies	• Generated by starting from a clear **objective/target** and back-casting to identify the pathway for making progress (i.e. road mapping)
		

Table 1 – Three Global Energy 'Scenarios' Approaches

Criteria used to select a benchmarkable set of global energy 'scenarios':

- Geographical focus: **global sets of scenarios** with no specific regional focus
- Minimum time horizon: **no earlier than 2030**
- Quantification and illustrative numbers: no limitation to models used
- Release date: recent reports published no earlier than 2013
- Scope: representing the whole energy system

This resulted in a peer group of 12 sets, as listed in Figure B

Organisation/report	Plausible scenarios	Outlooks	Normative scenarios
World Energy Council (2016) World Energy Scenarios to 2060	• Modern Jazz (MJ) • Unfinished Symphony (US) • Hard Rock (HR)		
Shell (2013) New Lens Scenarios to 2100, Mountain, Ocean, Sky	• Mountain (M) • Ocean (O)		• Sky (S)
Statoil (2017) Energy Perspectives to 2050	• Reform (Rf) • Rivalry (Rv)		• Renewal (Rn)
EIA (2017) International Energy Outlook to 2040		• Reference	
IEA (2017) World Energy Outlook to 2040		• Current policies (CP) • New policies (NP)	• Sustainable Development (SD)
IEEJ (2017) Outlook to 2050	• Advanced Technology (AT)	• Reference	
BP (2018) Energy Outlook to 2040		• Evolving Transition (ET)	
CEPSA (2017) Energy Outlook 2030		• Reference	
Exxon (2018) Outlook for Energy: A View to 2040		• Reference	
Enerdata (2018) Global Energy Scenarios to 2040	• Ener Brown	• Ener Blue	• Ener Green
IRENA (2018) Perspective for Energy Transition			• 66% chance <2°C (662)
DNV GL (2018) Energy Transition Outlook		• Reference	
IPCC (2018) Global Warming of 1.5°C			• P1, P2, P3, P4

Figure B – Peer Group For Comparison Review

OVERVIEW OF KEY ASSUMPTIONS

The Council's set of WES2016, outlined in Figure C below, explore new and different energy futures unfolding in the context of a next era of productivity, prosperity and progress – **The Grand Transition** is underway. Three plausible, alternative decarbonisation pathways to 2060 are described and quantified - none of which achieve the goal of the 2°C safe-limit, but all of which can be used to support a better quality of global strategic dialogue on the links between energy transition, prosperity and climate change.

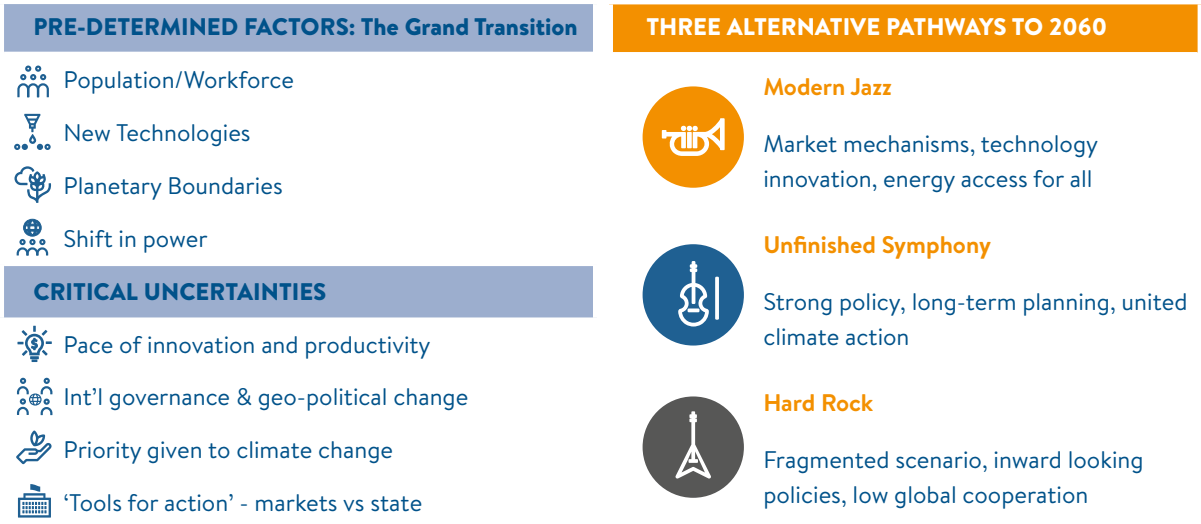
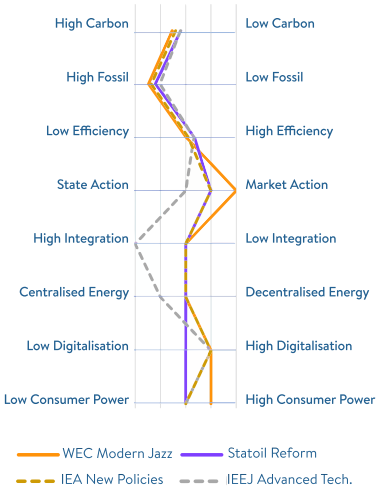


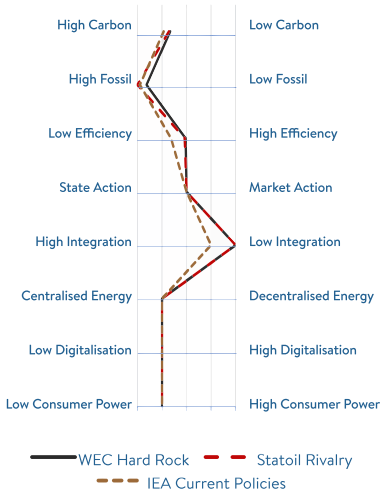
Figure C – Key Assumptions In The World Energy Scenarios Produced By The Council In 2016

WES2016 IN A NUTSHELL

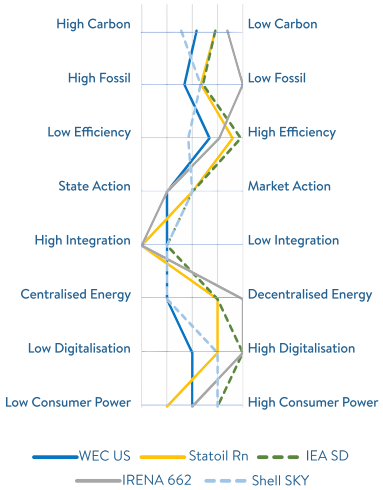
Modern Jazz is the market-driven, business and technologically innovative, energy accessible and economically prosperous world. If compared to IPCC, Modern Jazz logic can be mapped on more than one narrative of IPCC socioeconomic pathways: Fossil-Fueled-Development (SSP4: hard mitigation – easy adaptation), Middle-of-the-Road (SSP2: Medium in both) and Inequality (SSP3: easy mitigation – hard adaptation). Modern Jazz also exhibits similar profiles with Statoil Reform and IEEJ Advanced Technology. Similarly, IEA's New Policies outlook, which integrates new climate policies reflecting national commitments to the UNFCC Paris Agreement, is similar in profile to Modern Jazz.



Hard Rock is a politically and economically fragmented world, where low economic growth and low innovation drive countries towards inward looking policies and national security issues, resulting in poor performance on emissions curtailment. Hard Rock shares a similar profile with Statoil Rivalry and IPCC SSP3 Regional Rivalry: low levels of energy mix diversification and international cooperation, limited role of digitalisation, decentralisation and consumer power. Hard Rock is also similar to the IEA Current Policy outlook, which may imply that without coordinated policy action the world might experience a double whammy of low growth and high carbon emissions.



Unfinished Symphony is the scenario of strong global cooperation, united climate action and long-term integrated planning. This is the WES2016 scenario that comes closest to normative pathways such as Shell Sky, Statoil Renewal and IRENA Roadmap. Conceptually it is not distant from IEA Sustainable Development or IPCC Sustainable Development (SSP1), although they each have a broader focus on sustainability, including not only policy and economic cooperation, but also human development, healthy consumption and land-use management. Whilst there are some similarities between the profiles of the Council's Unfinished Symphony and normative scenarios, the latter reflect more varied assumptions for emissions reduction, share of fossil fuels in energy mix, increasing efficiency, regional integration, decentralisation & digitalisation in achieving a high growth-low emissions pathway.



WHERE DO THE COUNCIL'S SCENARIOS STAND?

Our comparison with the peer group finds that WES2016 inputs **include a more diverse set of drivers but quantified outputs are consistent with other plausible scenarios.** The logic of the Council's three archetype scenarios pivot on the futures frame of the energy-information-geopolitics nexus and explore the challenges of managing decarbonisation in combination with digitisation and decentralisation. **Modern Jazz** and **Unfinished Symphony** assume a digitally-disrupted market-driven world can boost the economy and reduce emissions and contemplate different ways of reforming regulations and reorganizing energy systems to achieve this. The best outcome in decarbonisation is achieved through strong international cooperation on policy and integrated planning to foster a smart and circular economy (Unfinished Symphony, rather than global digital innovation per se in Modern Jazz). **Hard Rock** envisages the pace of digital productivity and rising global environmental risks in an era of low growth might trigger political fragmentation and inward-looking policies which reduce the effectiveness of global cooperation. It raises a question: can a new era of regional and local innovation be successful in managing global energy transitions in an era of climate change impacts?

Most of the reviewed outlooks (IEEJ, CEPSA, BP, EIA, Ener-data, Exxon) strictly focus on the technical features of the energy system and integrate data about population and economic growth, environmental policies and technology advance. Conversely, WES2016 examine how the broader context of **society, politics and international governance can completely reshape the developments of the energy system.** This broader horizon is shared with other reviewed foresights: Shell, Statoil, IEA, IRENA, DNV GL, IPCC.

The figure in the preceding page plots the above discussed areas of alignment and critical uncertainties amongst the reviewed scenarios.

OVERVIEW OF KEY NUMBERS

Assumptions of **total energy demand** vary significantly among scenarios: demand tends to be higher in outlooks and generally lower, but with higher variance in normative scenarios. The WES2016 demand assumptions are generally lower than other plausible scenarios.

Electricity generation growth is almost an inescapable future. The growth in electricity generation is similar between plausible scenarios, outlooks and normative scenarios. Acceleration in the pace of electrification includes end-use.

There is a **more diverse energy mix** across all reviewed scenarios by 2040 (Figure E). They reflect an increasing role of renewables in the future. However, across plausible scenarios and outlooks, the overall fossil fuel share tends not to get lower than 70% (from today's 80%). Unfinished Symphony and DNV GL show patterns more akin to normative scenarios rather than outlooks.

Renewables gains are mainly at the expense of coal. Specifically, there is no doubt that solar and wind are going to grow in the future. Normative scenarios consistently prescribe a higher uptake compared to outlooks. Outlooks differ quite a lot from each other: the extent of growth of solar and wind is still an open question.

Normative scenarios indicate a significant reduction of **coal** while there is a great variety of its share in plausible scenarios and outlooks.

While there is uncertainty on the future of coal, the aggregate share of oil and gas does not seem to lose ground compared to today's consumption. Most of the plausible scenarios and outlooks predict a steep **growth of gas**, compensating for the decrease in oil.

Even as most outlooks predict a steep growth of gas, normative scenarios show a relatively early peak in gas use – before 2040. The peak varies across plausible scenarios and, in some cases, natural gas is assumed to become the energy system's backbone.

Oil demand is steady in outlooks and plausible scenarios and its share of energy mix is lower and more varied across normative scenarios. **Demand for nuclear power is assumed to increase** in all global scenarios sets

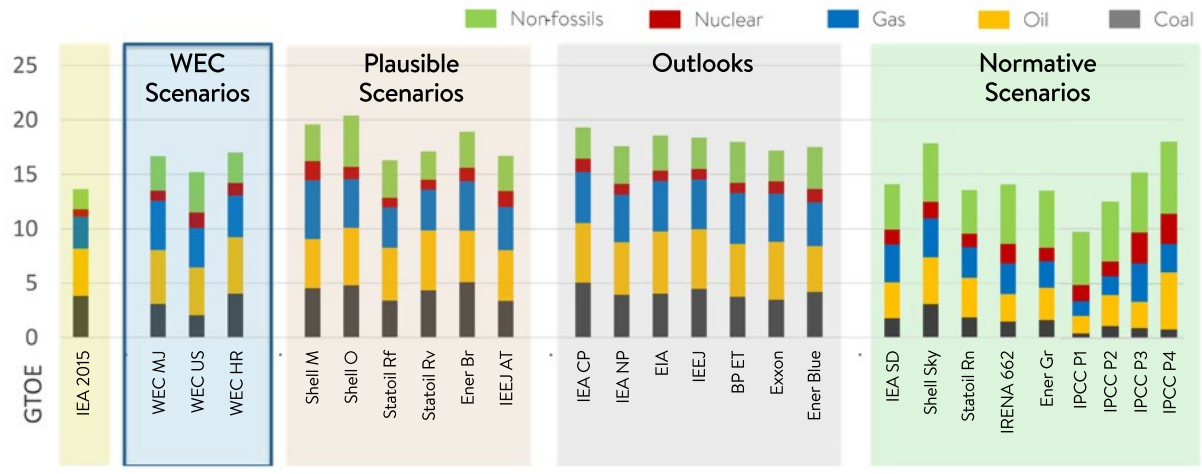


Figure E: Energy mix by 2040 (In GTOE)

HOW DO NORMATIVE SCENARIOS ACHIEVE LOW EMISSIONS AND HIGH GROWTH?

In this study we compared the following normative scenarios: Shell Sky, Statoil Renewal, IEA Sustainable Development, Enerdata: Energreen, IRENA 66% chance <2C, IPCC 1.5C.

Looking at the **primary energy mix** in the normative scenarios, some common elements can be identified: renewables grow fast from 15% to 30-40%, nuclear grows but sets at around a 10% share, gas oscillates around today's 20%, oil declines up to a 30% compared to today, coal share is reduced to half or a third of today.

Emissions strategies all share three main pillars: **(1) reducing energy demand by increasing efficiency, (2) electrification of end use, and (3) decarbonisation of electricity generation.**

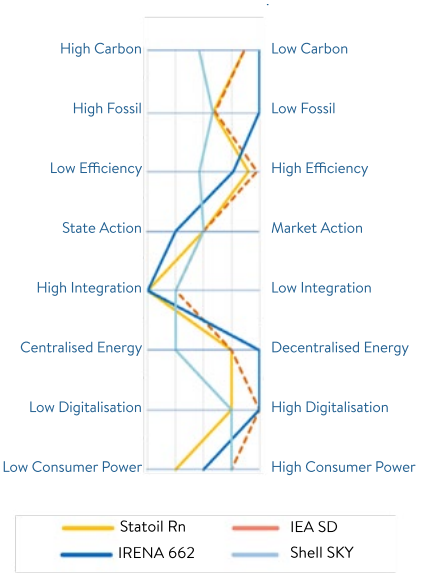


Figure F - Normative scenarios comparison

There are also several other similarities across normative scenarios:

- Strong attention to investments and increasing efficiency and decarbonisation not only of production side but also on user end side (especially transport).
- Despite high reliance on renewables in all normative scenarios, fossil fuels still play an important role (especially gas).
- Nuclear continues to play a major role in most of normative scenarios lowering global emissions, as well as ensuring security of baseload supply and stable production costs.
- High levels of digitalisation, though not as a silver bullet; all low-carbon technologies play a role (like CCUS in IRENA and Shell Sky).
- Role of governments in a combination of market interventions and state mandates, carried out with international coordination & regional integration.
- Pull for electrification from consumers varies across normative scenarios.
- System-wide rather than sectoral approaches:
    - Wide-spread of EVs for transport; higher efficiency standards and renovation rates in buildings, compatibly with distributed renewables
    - Industry switch to electricity, hydrogen and CCS
    - Increased reliability in the power sector due to better market design, smart grid integration, demand-side management and cost-effective storage
    - Integrated policy innovation – not only energy

MAJOR SIMILARITIES ACROSS SCENARIOS

- **All energy futures in this comparative study direct attention to the need for coordinated action and policies on global climate change**, specifically the climate targets and national contributions proposed in the lead up to the **UNFCCC Paris Agreement** negotiations. Progress beyond the Paris Agreement is achieved in some scenarios, but no WES2016 scenario meets the 2°C safe limit.

- **Rapid growth of renewables continues to be the key assumption in the shifting energy mix.** However **fossil fuels remain an important part of the energy mix** across the majority of plausible scenarios, outlooks and normative scenarios.

- The **continued diversification of energy mix is notable in all**, with increasing attention to **artificial/synthetic energy carriers and fuels**, notably a role for **liquid hydrogen** (H_2), produced from electricity, rather than alternative heat or chemical pathways.

- To successfully pursue a flourishing low carbon economy, scenarios also note the crucial need to **avoid political distrust, protectionism and conflict; consumers behaviours/choices and distributed/decentralised electricity production** also play important roles.

- Normative scenarios describe a world where both economic growth and low emissions are achieved thanks to the impact of **accelerating digitalisation in reducing energy demand, a strong role for governments, regional integration, global cooperation and a shift to a high level of investment in energy/clean energy infrastructures.**

- Across all normative and some plausible scenarios, **energy efficiency, electrification and higher deployment of renewable technologies** are essential elements in the transition towards a global low-or-zero carbon emissions energy future.

- **International cooperation and regional integration** are seen as crucial to accelerating decarbonisation across regions and markets.

WHAT NEW DEVELOPMENTS ARE MISSING?

- **Demographic diversity:** There is consistency in the slowing of global population growth rates assumed across different sets of global energy scenarios. Yet there is **no consideration of regional demographic diversity** (e.g. rapid ageing and/or rapid urbanisation, local depopulation) or the implications of shifting social norms. Will ageing societies and digitally enabled youth use more or less energy than previous generations?

- **Environmental feedback loops:** Given the increasing evidence of water stress, extreme weather impacts, land use competition, and air pollution crisis (emerging economy cities), when and how will the **broader sustainability and climate adaptation** investment agendas start to feature in global energy scenarios? There is a focus on the pace and costs of decarbonisation in a majority of scenarios, but the implications of the **wider sustainability agenda, e.g. increasing global water stress, is not considered** – with the exception of assumptions about energy access and air pollution in the IEA Sustainable Development outlook.

- **Digging deeper into the whole systems costs of accelerating renewables uptake and digitalisation:** Assumptions about the links between energy transition and digital productivity are linear and positive – accelerating digitalisation supports the rapid uptake of renewables and further cost declines. Yet the marginal costs of renewable supply are not the whole story (non-energy resource insecurities e.g. EROI on mining/recycling of Li batteries, whole system reliability/resiliency costs. There is no attention to **cyber security risks, interface complexity (kit/bit/chit/tokens) or demand-side disruptions of digitally empowered consumers and on demand services, which are not all about energy.**

- **Innovation is not just about technology:** Business model innovation is emerging in all parts of the energy sector – including utilities, and oil and gas companies. New economic models are also emerging which direct policy attention to sector coupling opportunities and challenges e.g. circular economy, regenerative prosperity. Will the energy transition be **economically rational or driven predominantly by political ideology** (as in WES2016 Hard Rock) and if the former, will alternative economic models emerge and shape a new era of energy regionalism with different energy pathways?

- **New demand driven energy paradigms:** A high rate of penetration of EVs is assumed in most of scenarios and assume a gamechanger in battery technology. Even as the electrification of end uses, including mobility, heating and cooling, accelerates, will assumptions about the **expanding and increasingly active role of consumers** (i.e. as prosumers, smarter, data empowered choices) see energy marginalised and commodified in the rise of energy-plus services? How will issues of **inequality and quality, as well as basic access** shape global energy transition pathways? The Shell Sky scenario makes explicit the need for global demand of 100 GJ/per capita as a better lives/livelihood' threshold.

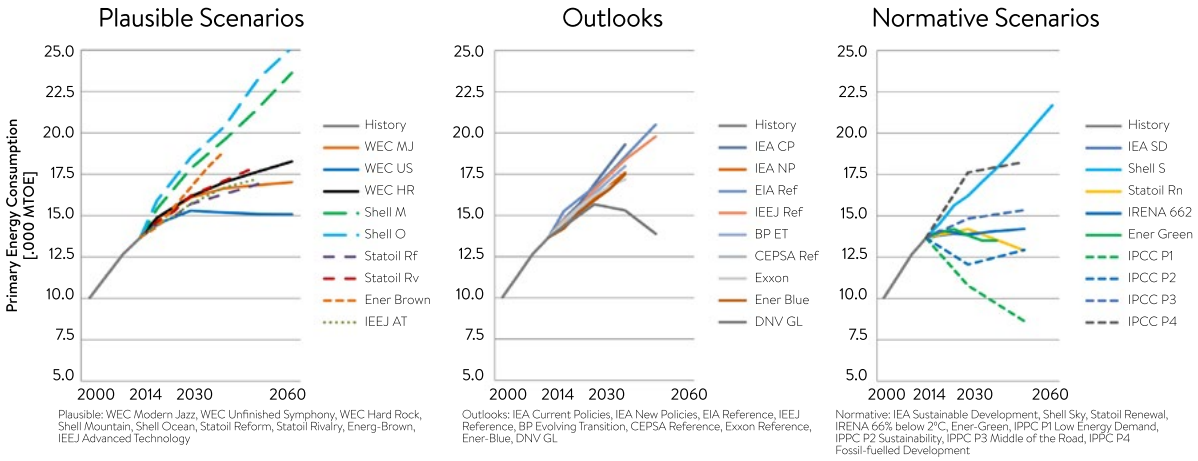
- **New energy geopolitics, which do not pivot on oil:** A new era of energy abundance is emerging, shaped by new and more diverse sources of natural gas and LNG and cheaper renewables. Storage is a gamechanger and alternative storage pathways are available. Will the new geopolitics of energy deepen? What is being traded, where and how is also expected to shift in a next era of productivity – **new trade patterns** and implications for manufacturing and freight transport are yet to be included.

- **Role of financial innovation in closing investment gaps:** Successful energy transition can be accelerated by the inclusion of social, environmental and whole system costs, which are difficult to calculate and not currently reflected in discussions about the price of carbon. Despite green finance and momentum towards investment in new energy start-ups, big gaps in energy infrastructure investment remain and the next financial crisis is expected. How might **new developments in the global financial system** constrain or accelerate successful global energy transition? Will the rise of a new hydrogen economy bring opportunities to repurpose existing infrastructures or increase the risk of stranded infrastructures?

Part two
Detailed Numbers Comparison

DETAILED NUMBERS COMPARISON

PRIMARY ENERGY DEMAND



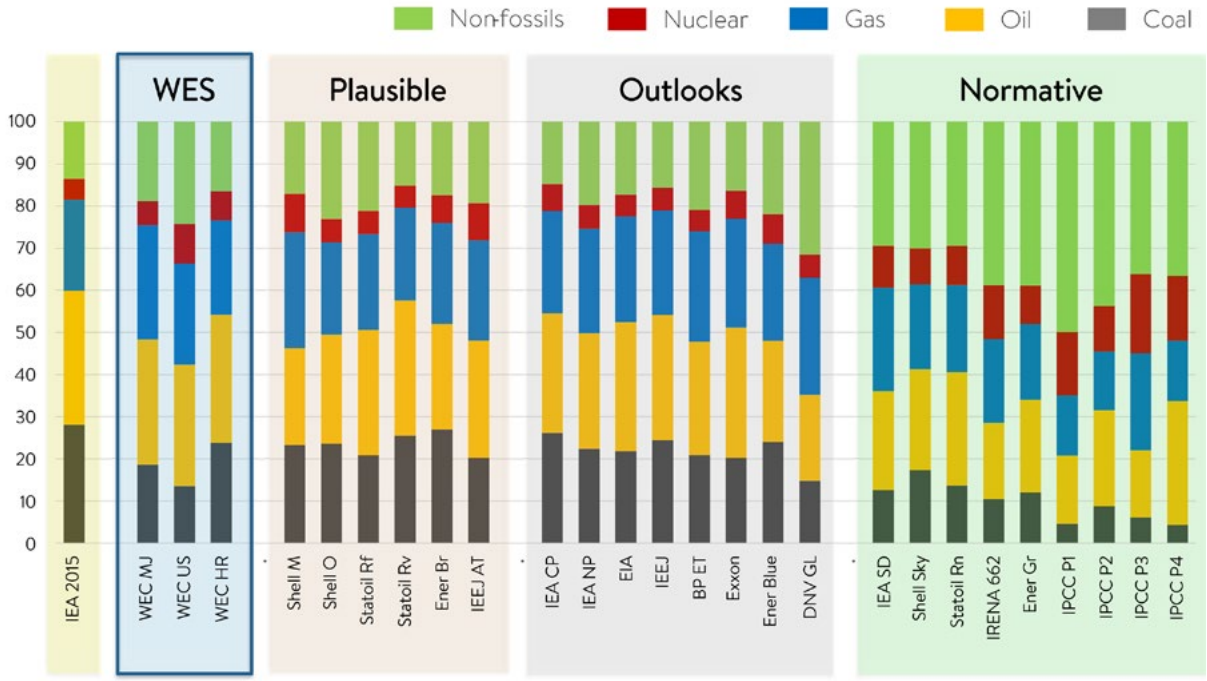
- There is convergence among **outlooks** on the future of **primary energy demand, that is growing** to around 20 Gtoe/year by 2050. DNV GL projection clearly stands out the rest of outlooks, distancing itself from 2030 where demand peaks and heads toward 2°C trajectories. The difference is mainly due to the assumed lower population growth (reckoning rising urbanisation and female education) and rapid efficiency gains (enabled by electrification).

- There is **higher variety in plausible scenarios**, ranging from 15 to 23 Gtoe/year. In this plausibility space the Council's scenarios are on the lower side, envisaging a peak before 2030 due to new efficient technologies and stricter policies. On the upper end of the plausible spectrum there are Shell scenarios, where population and prosperity growth drive up energy consumption. Those scenarios characterised by political fragmentation and inward-looking policies, like Council's Hard Rock or Statoil Rivalry.

- Across the **normative scenarios**, 2°C pathways, like IRENA and IEA Sustainable Development, exhibit a **demand relatively stable on today's levels** (ca. 14 Gtoe/year). Shell Sky energy consumption stands and is closer to the baseline projection. In other words, Shell scenarios do not compromise on energy access even under climate targets, as they aim at ensuring living standards of 100 GJ/pers. per capita primary energy (approximately double that of India and a third of USA today). This is to contrast against the outlooks and normative averages of 80 GJ/pers. and 65 GJ/pers. respectively (by 2040).

- IPCC's models explore possible 1.5°C-pathways under a broad set of assumption, so energy demand in the four archetypes reported in the summary for policy makers span from the low-energy-demand scenario (LED) at around 9 Gtoe/year, to a high fossil-fueled Development (FFD) of 18 Gtoe/year. This means that a world within 1.5°C warming (with limited overshoot) is **technically feasible even under a business-as-usual energy demand increase**. However, the massive deployment of renewables, nuclear and bioenergy with carbon capture and storage (BECCS) entailed in that scenario can pose serious social and institutional challenges. Generally, the comparison highlights that realistic projections of today's trends foresee an energy demand that is higher than what climate targets would prescribe. This is true also under plausible optimistic assumptions on efficiency and population: action is required to avoid climate change.

ENERGY MIX BY 2040 (%)



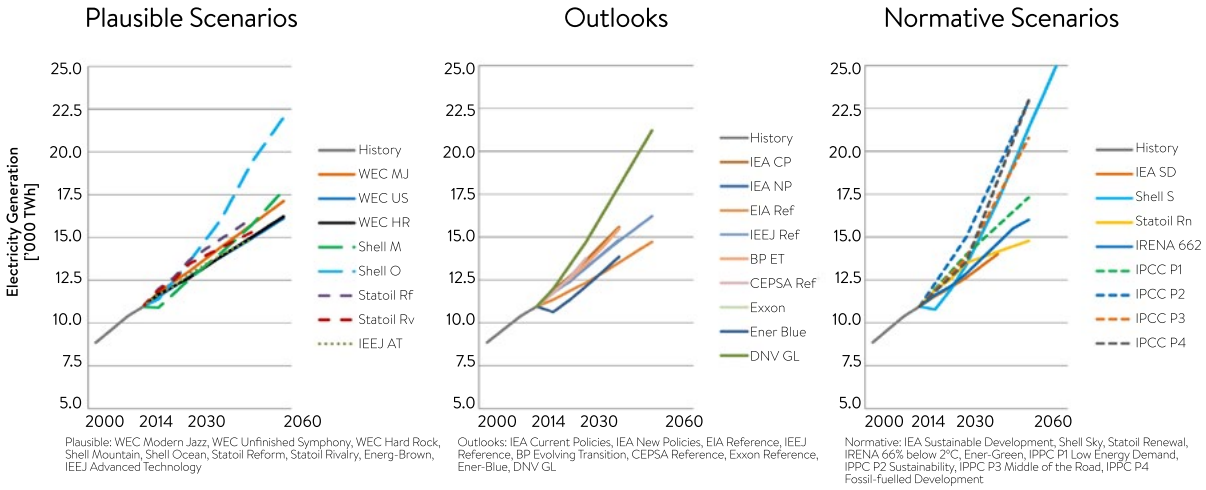
- All reviewed scenarios see an **increasing role of renewables in the future.** However, **across the probable and plausible scenarios**, the overall **fossil fuel share tends not to get lower than 70%** (from today 80%). Here again, Unfinished Symphony and DNV GL show patterns more akin to normative scenarios rather than outlooks.

- The renewable gains are mainly at the expense of coal. While there is uncertainty on the future of coal, the aggregate share of oil and gas does not seem to lose ground compared to today's consumption. Most of the plausible scenarios and outlooks predict a steep growth of natural gas, that compensates the decrease in oil.

- Looking at the primary energy mix in the normative scenarios some common elements can be identified across the 2 °C-pathways: renewables growing fast from 15% to 30-40%; nuclear growing but setting at around a 10% share; gas oscillating around today's 20%; oil declining up to a 30% reduction compared to today and coal sharing reduced to half or a third of today.

- IPCC 1.5°C scenarios require an even **stronger deployment of non-fossil energy**. We can identify on one hand a Low Energy Demand scenario, where the lower pressure on the demand allow for higher shares of RE and nuclear (jointly around 65% by 2040). On the other hand, there are slightly more carbonised scenarios (52-55% non-fossil by 2040). In the Sustainable Development pathway carbon phaseout is slower but there is a marked use of renewables. In the Middle of the Road trajectory there are less renewables and coal, but gas and nuclear become the main pillars of the energy strategy. The last IPCC archetype is the fossil-fuelled development, which despite showing a low coal and declining oil consumption in the 2040 snapshot, has heavily relied on fossils until 2030. So, to meet climate ambitions, this scenario severely cuts fossils toward 2050, switching to renewable and carbon negative sources, and increasing the role of non-energy and especially land use.

ELECTRICITY DEMAND



Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- Electricity generation growth is an **inescapable future**. There is a high convergence between the most of plausible scenario and outlooks, with an electricity demand expected to **double by 2060**.

- The growth is driven by **growing urban lifestyles and rising incomes**, the bulk of the increase in indoor lifestyles, especially in warm countries where electricity is the efficient way to provide needed cooling. Also, the electrification agenda is consistent with the **policy push for efficiency and clean energy**.

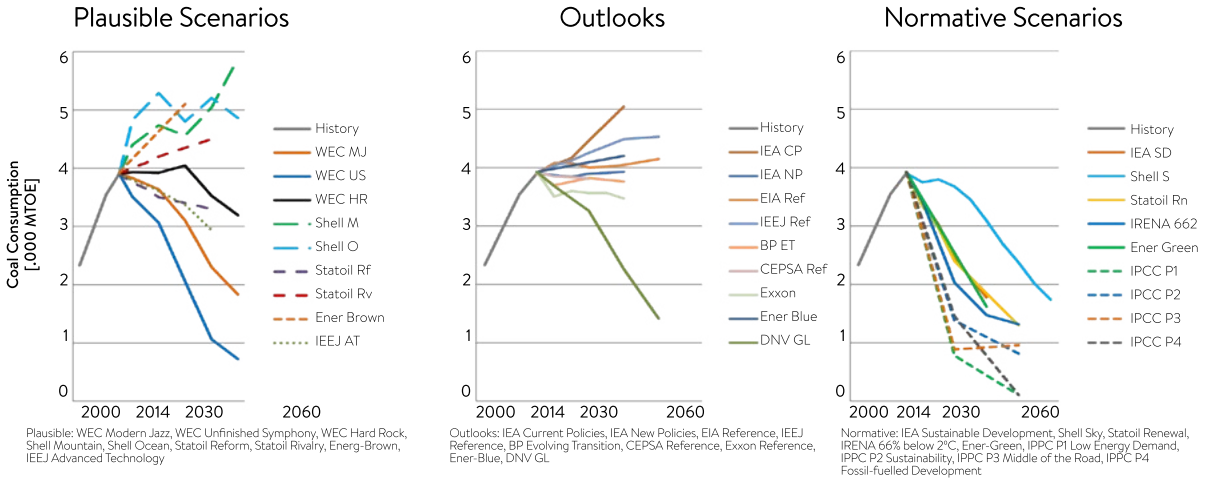
- There is a second category of scenarios that predict a much quicker growth in electricity demand (almost threefold expansion from today): Shell Ocean and Sky, DNV GL and most of IPPC 1.5° C. In these scenarios there is **higher progress in transport and industry electrification**. In Shell Sky autonomous driving and 3D printing accelerate electric vehicles penetration and electricity makes its way into the light industry as well. For DNV GL, falling costs will enable to reach half of global car sales to be EV by 2033 and penetration in the municipality bus sector as well. For IPCC electrification of end-use, is one of the cornerstones of the 1.5°C strategy, electricity reaching up to 70% of final consumption.

- On the supply side, the tremendous increase in decarbonised electricity requires **great attention on intermittency and grid reliability**. This will usually need policy support new market design, regional grid integration, demand-side management and cost-effective storage (such as Hydrogen in Shell Sky). Utility scale electricity/generation will compete head to head with distributed one, further driving down costs.

- Given the substantial load needed to charge EVs, transport electrification may have important implications on electricity networks, providing additional flexibility and reshaping business models to incorporate all households' energy supply. According to DNV GL, **electrification, digitalisation and multi-scale generation trends are prompting new business players, like oil majors and tech-giants** (e.g. Google and Amazon) to seek business opportunities in the electricity utility sector.

FOSSIL FUELS

Coal



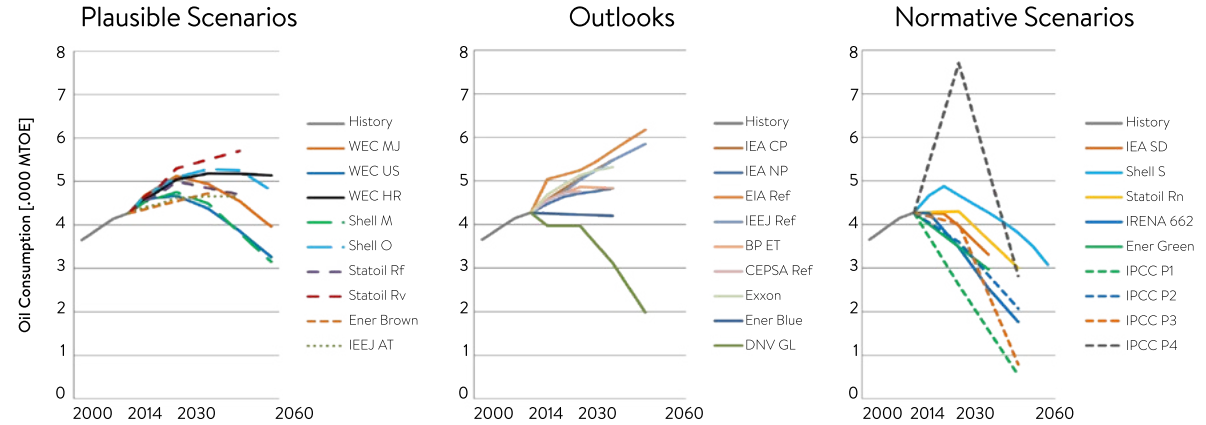
Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- In the WES2016, coal tends to decline, immediately in Unfinished Symphony, and after 2040 in Hard Rock. Coal is quite an **open question, mostly dependent on China** (which accounts for 60% of current consumption). Outlooks and plausible scenarios vary significantly, presenting both growth and decline projections. However, there is a **clear difference between the relatively stable trend of coal consumption in the outlooks and the rapid reduction imposed by normative scenarios.** In WES2016's Unfinished Symphony and DNV GL coal's strong and rapid decline is driven by **international agreements on policy targets** and by regionally-dependent losses of competitiveness. In DNV GL particularly, power generation from coal is significantly decreased by the growth of solar and wind

Oil



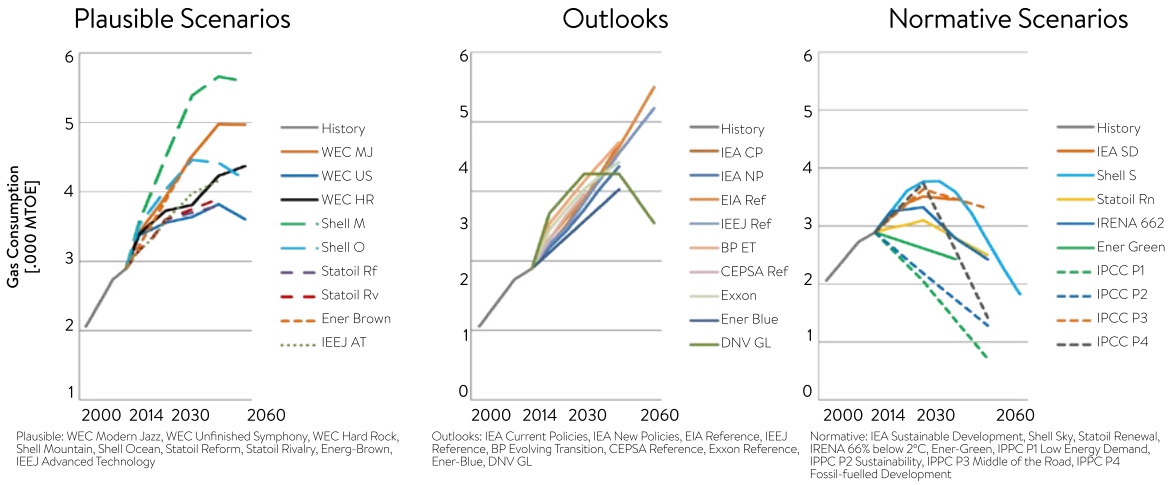
Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- Many outlooks expect consumption growth compatible with historical trends. While some outlooks and most of plausible scenarios foresee a **slowdown, stagnation and eventual decline of oil**, even if they differ on the projection of the height and time of peaks (Council's Modern Jazz and Unfinished Symphony for example expect a peak by 2030). Generally, the decline of oil (as for the coal) will be **resisted for employment reasons, but will be generated by emissions targets and competing fuels in transport:** increasing electricity for road segments, and biofuels in aviation. Given these warnings of peaks in demand rather than supply, policy makers, investors and other actors should be seriously wary of stranded assets and resources. In DNV GL, oil decreases significantly because of the **shift towards electrification of the transport sector**

Natural Gas



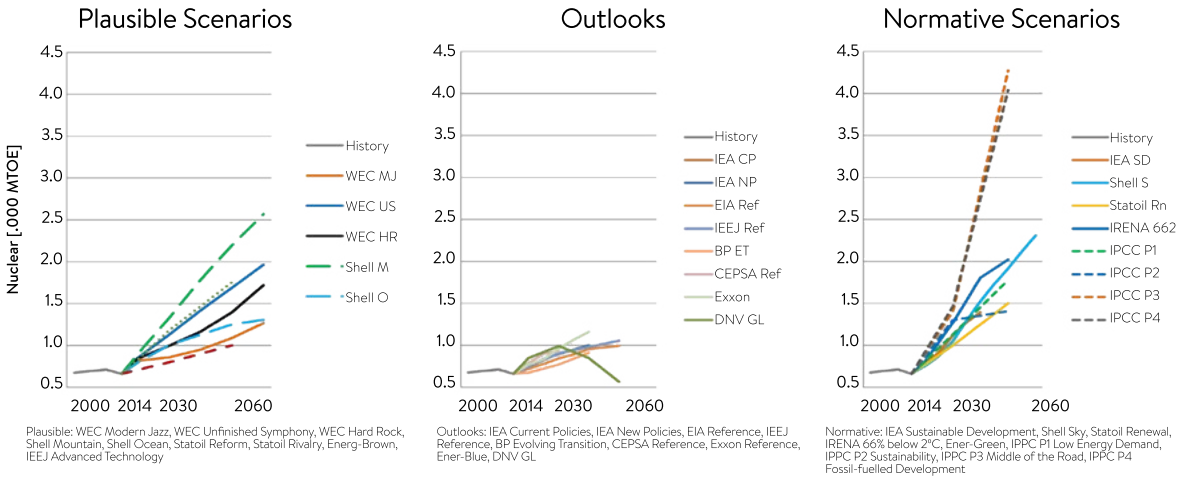
Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- In line with some views of gas as the bridge to renewable energy sources, natural gas is generally **projected to grow in the near term in almost all scenarios except some normative ones (EnerGreen IPCC).** Modern Jazz is the most gas-intensive of WES2016 and follows the outlooks trend. The development of gas will be closely **connected to the power sector** where it both complements (to meet peak loads) or competes directly with renewables. There is **more uncertainty over the medium to long term future of gas.** For example, in the Shell Mountain scenario gas is the main energy backbone (doubling supply by 2050 as compared with today), whereas in DNV GL outlook and other normative scenarios it peaks as early as 2040. In the context of an increasingly climate committed world, the future of gas relies on CCS technologies to make it cleaner. For instance, a prolonged relevance of gas is observed in the IEA Sustainable Development and IPCC Middle of the Road pathways.

NUCLEAR



Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

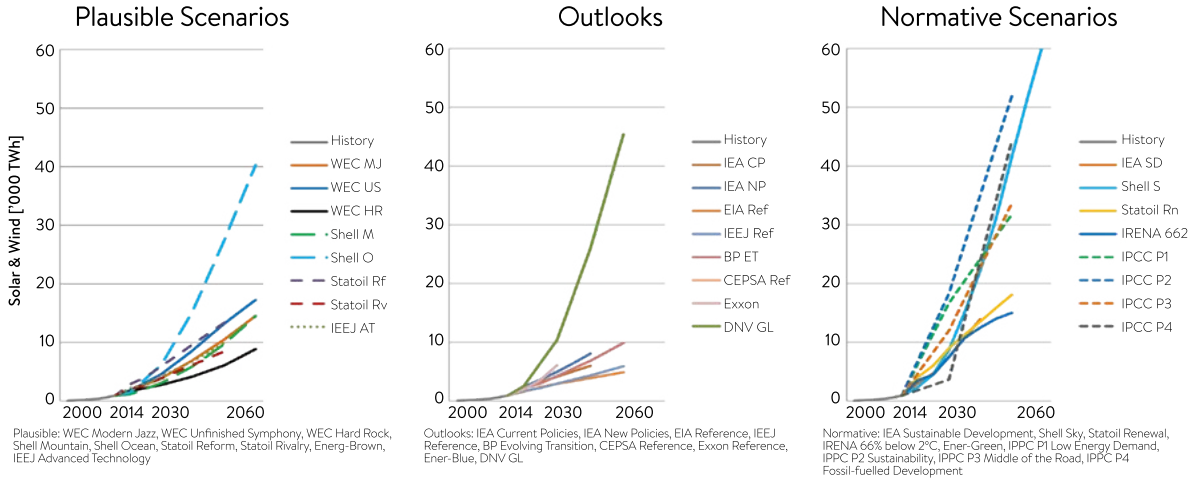
Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- The future of nuclear is **uncertain.** Outlooks project a growth higher than the historical trend but limited to no more than 1 Gtoe/year by 2050. This figure can be higher (up to double) for top-down driven scenarios like Shell Mountain and Council's Unfinished Symphony or normative ones. DNV GL stands clearly apart in predicting a decrease in generation after 2030. This is because it accounts for the **limited social acceptance** of nuclear given risks associated with potential disasters, nuclear waste and decommissioning. Moreover, it will **compete against fast-to-market renewable** options whose learning curves are showing much more promising signals

- At the other extreme there are the carbon intensive IPCC archetypes (Middle of the Road and Fossil Fuelled Development) where the almost **six-fold increase of nuclear energy by 2050** is part of an all-out decarbonisation strategy starting in 2030 to quickly adjust against the carbon budget. This deployment will not be in competition with renewables but will serve to balance intermittency with a stable base load and reduce the network operation costs. Those IPCC scenarios seem to be incredibly optimistic on the deployment of nuclear whereas in other scenarios it is severely constrained by the limited social acceptability. This highlights the risks of a delay in fossil consumption cuts that rely on a successful future nuclear scale up

SOLAR AND WIND



Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- There is no doubt that **solar and wind are going to grow in the future**, but we are now in the early stage of an exponential surge and small changes in signals today can shift predictions by considerable of unpredictable orders of magnitudes

- Reviewed scenarios can be grouped in three main ranges: in **outlooks and some plausible scenarios** there is an up-to **10-fold expansion** approximately by 2050, in other plausible (including WES2016) and some normative scenarios (IEA SD, IRENA, Statoil Renewal) this growth can be reasonably higher (around 15- to 20-fold) and lastly there is the staggering 40- to 50-fold rise in Shell Ocean and Sky, DNV GL and IPCC 1.5°C pathways. In all scenarios, photovoltaics (PVs) represent the biggest share of this increase, especially for Shell scenarios that emphasise their role as the n° 1 source by 2070 (like oil today)

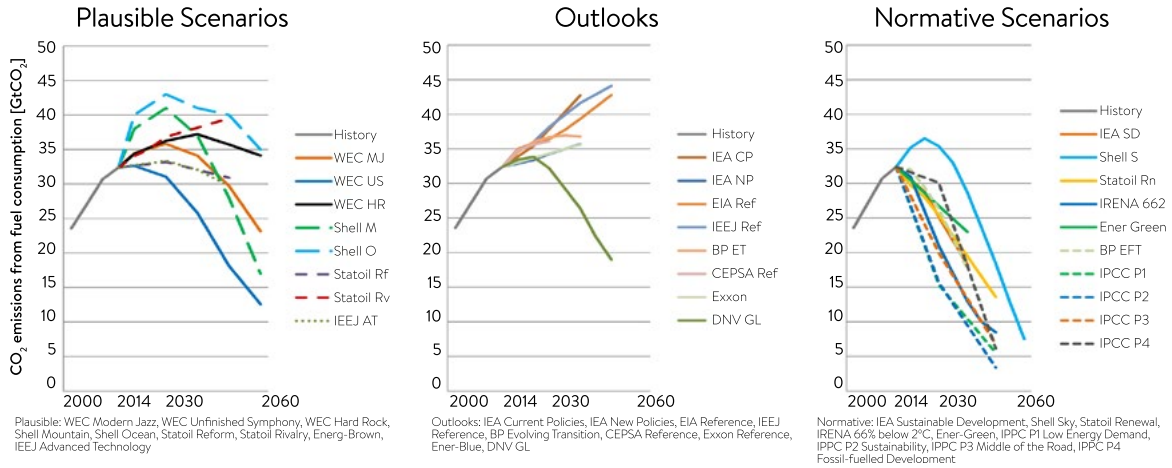
- Grid-wise, the order of magnitude expansion of renewables will have serious implications. Despite some expectations of reduced burden on the grid due to decentralisation of generation, only around 1% of the 27 PWh/year generated from PVs by 2050 will be completely off-grid (mostly in Indian and Sub-Saharan regions). For the rest, the need to balance distributed surpluses will spur grid connections by 254% to 2050 (especially in Indian and China continents) and foster direct power lines beyond 2030

- The interesting question is how to overcome challenges of renewables, which is **not only intermittency**, but also **material scarcity, geographical constraints** (dislocation of generation and demand hubs and its land-intensity) **sector saturation** (energy-intensity is not enough to substitute hydrocarbons in sectors like aviation, petrochemicals and steel manufacturing) and finally **social acceptability**

- Land use seems not to be a challenge for DNV GL, for which 30% of the 65-fold increased PV capacity will be on building roofs and the rest 70% represent only 0.3% of global land mass. Onshore wind turbines, even if projected to require 2 million km2, will be compatible with crop, grazing and forestry as well

- Important developments purported by Shell among others for the future of renewables are the possibilities of using **hydrogen** produced from renewable electricity as both storage and medium of transport. These solutions are technically feasible but require great international cooperation and huge financial investments.

CO2 EMISSIONS FROM COMBUSTION



Plausible: WEC Modern Jazz, WEC Unfinished Symphony, WEC Hard Rock, Shell Mountain, Shell Ocean, Statoil Reform, Statoil Rivalry, Energ-Brown, IEEJ Advanced Technology

Outlooks: IEA Current Policies, IEA New Policies, EIA Reference, IEEJ Reference, BP Evolving Transition, CEPSA Reference, Exxon Reference, Ener-Blue, DNV GL

Normative: IEA Sustainable Development, Shell Sky, Statoil Renewal, IRENA 66% below 2°C, Ener-Green, IPPC P1 Low Energy Demand, IPPC P2 Sustainability, IPPC P3 Middle of the Road, IPPC P4 Fossil-fuelled Development

- Most of the outlooks project growing or at best plateauing emissions, while their decline required by the normative scenarios (except for Shell Sky) would start from today. Within the plausible range, Shell scenarios display the highest emissions up until 2030 but they all dip afterwards, with Shell Sky reaching net-zero emissions by 2070. Modern Jazz and Unfinished Symphony peak lower but at the same time, while in Hard Rock the fall is slower and delayed to 2040.

- Comparing IEA New Policies with normative scenarios it is clear that **Paris 2015 Nationally Determined Contributions (NDCs) are not sufficient to limit warming below 2°C.** According to the IPCC any ambitious supplement after 2030 would be too late. To achieve the 1.5°C target, net zero CO2 emissions are to be reached by 2050 and concurrent deep reductions of other climate forcers, like methane and sulphur dioxide, are essential as well.

- Unlike other outlooks, DNV GL's emissions peak around 2030 and start decreasing significantly. This is due to several factors like **carbon pricing schemes** (new local, regional, and sectoral), cost effective **removal of carbon dioxide** in steam methane reforming processes (whereby natural gas is converted into hydrogen without carbon emissions), and significant improvements in **energy efficiency**

- CDR (Carbon Direct Removal) is used in all 1.5°C pathways, especially in the pathways delaying emissions peak. Its use at scale though is not proven yet and the reliance on it is a major risk. The main CDR measures are bioenergy with carbon capture and storage (BECCS) and afforestation. This might generate some **trade-offs with other sustainability objectives, mostly through increased land, energy and water investment demand**

Part three
Scenarios Overview

Plausible: Shell Mountain*

Purpose: Plausible future pathways, **examining the implications** for the pace of global economic development, types of energy used, and the growth in greenhouse gas emissions.
Highlight areas of public policy likely to have the greatest influence on developing cleaner fuels and renewables, improving energy efficiencies and moderating emissions.

Key Elements:

- **Government-driven, top-down; locking-in of incumbent power.**
- **Advantage creates advantage**: influence remains concentrated in the hands of the currently powerful.
- **Transport**: Gas and **electrification** / Shorter urban journeys.
- **Innovation**: Governed by intellectual property / Big-scale supply. Increasing CO2 and environmental stresses are moderated by slower overall growth; the **substitution of coal for natural gas**, and the success of **CCS technologies**. Nevertheless, the global average temperature rise overshoots the current 2° C goal.
- **Rigid power structures and institutions hamper economic development**. With fewer power-brokers, positive advances in secondary policy areas are feasible – e.g. compact urban development, energy and environmental stress.
- **Positive resource expectations are realised** and, with supportive policy frameworks in place, **natural gas becomes a backbone** of the global energy system.

Plausible: Shell Ocean*

Purpose: Plausible future pathways, **examining the implications** for the pace of global economic development, types of energy used, and the growth in greenhouse gas emissions.
Highlight areas of public policy likely to have the greatest influence on developing cleaner fuels and renewables, improving energy efficiencies and moderating emissions.

Key Elements:

- **Market-driven**, bottom-up.
- Innovation: Open innovation / Local responses (supply, efficiency).
- **Transport**: More efficient gasoline and diesel transport. **Liquid fuels and coal continue to play a leading role** in the energy mix until **solar overtakes in the latter part of the century**. Natural gas grows but undershoots high expectations due to inadequate policy frameworks and resource disappointments.
- **Electricity**: More distributed / Management of intermittency
- New or **competing economic and political interests** are accommodated intermittently.
- Reform unleashes **new economic productivity** and increases aspirations for further reform.
- **Empowered constituencies** with new vested interests **hinder** secondary **policy progress** until resource stresses become acute e.g. urban growth sprawls, CCS is delayed.
- Rising prices unlock **more expensive energy resources and drive end-user efficiency**.
- **Greenhouse gas emissions peak and remain high** for a prolonged period until reduced by the combination of biomass, CCS, and solar.

*. Source: Shell (2013) New Lens Scenarios (2100) https://www.shell.com/content/dam/royaldutchshell/documents/corporate/scenarios-newdoc.pdf

Plausible: Statoil Reform*

Purpose: Built on the NDCs pledged by nations around the world in the framework of the Paris Agreement from COP21. Market forces coexist with climate policies.

Key Elements:

- **R&D** and **tech development** are driven largely by commercial and national interests.
- Market-based solutions drive and deliver **energy efficient** and low-carbon technologies.
- Assumed that only those changes that can be accomplished through **market-optimal, non-subsidised investments** are sustained.
- **Mandatory standards and regulations coexist with market forces** in the scenario, both play a role in shaping consumers' decisions, and both contribute to innovation and technology developments.
- National policy-making, reflecting national and private economic self-interest tempered by international policy-making.
- **Global warming and extreme weather events** dent economic activity from the mid-30s, with greater impact during the 40s.
- Lower prices of fossil fuels and varying degrees of commitment to the tightening of climate contribution targets translate into **higher oil and gas demand early in the forecast period**.
- Shift from carbon fuels to **green energy technologies**, notably in the electricity sector, and a technology shift for **light duty vehicles** that enables significant electrification of the global car fleet, once electric cars become cost-competitive.
- Not a sustainable scenario in the long run, leaving a **wide gap when compared to the ambitions of the Paris agreement**.

Plausible: Statoil Rivalry*

Purpose: Built on the NDCs pledged by nations around the world in the framework of the Paris Agreement from COP21.

Key Elements:

- Multipolar world, populist, nationalist, inward-looking and short-term priorities.
- Climate scepticism runs high.
- Disorder, conflict and power struggle apply at the expense of cooperation and trust.
- Climate scepticism runs high and where disorder, conflict and power struggle apply at the expense of cooperation and trust.
- The geopolitical scene is turbulent. Economic inequality within and between states erodes social and international cohesion. Conventional politics and principles are overrun by xenophobia and protectionism.
- Challenging geopolitics hamper international trade and the deployment of new technology.
- Long periods of underinvestment in new production capacity and higher demand for fossil fuels allow the development of higher cost assets, leading to higher energy prices and to volatility related to unrest in producing countries.
- Carbon pricing falls off policy agendas. No economic incentive to support R&D in CCS technologies.
- Global climate ambitions are nominally still in place, but are in practice ignored. This scenario is clearly unsustainable also from a climate perspective.

*. Source: Statoil (2017) Energy Perspectives (2050) https://www.equinor.com/content/dam/statoil/documents/energy-perspectives/energy-perspectives-2017-v2.pdf

Plausible: IEEJ - Advanced Technology*

Purpose: Unanimous **implementation by all countries of energy and environment policies** contributing toward a secure and stable energy supply and enhancing climate change countermeasures. **Maximised policy effects**.

Key Elements:

- **Environmental regulations and national targets**: environmental tax, emission trading, RPS, efficiency standards, low carbon fuel standards, efficiency labelling.
- **Technology development and international cooperation**: R&D investment, cooperation in efficient technology
- New **demand side** technologies in **industry** (steel, cement, paper-pulp and oil refining), **transport** (fuel efficient, hybrid, plug-in hybrid, electric vehicles, fuel cell vehicles) and **buildings** (electric appliances, water-heating and conditioning systems, insulation)
- New **supply side technologies** in renewables, nuclear, fossil fuel-fired power generation, transmission and distribution networks, CCS.
- **Energy efficiency**: 20% savings by 2050 compared to reference in final consumption.
- **Renewables**: increase in primary consumption from 14% to 22%, strongly driven by solar and wind, especially in developing countries where low-cost loans are a major factors. Grid expansion and stabilisation through information technologies.
- **Nuclear**: diverse promotion among countries (maintain, dismantle or increase capacity). Overall increase in share of primary mix from 5% to 10% by 2050.
- **Primary energy demand**: substantial reduction of demand (20% below the reference). Fossil fuel share falling from 82% to 68% by 2050. Non-OECD will contribute to 70% of the energy conservation.
- **Final energy demand**: Zero Emission Vehicles (ZEVs) spread, and oil share for road transportation drops from 94% to 77% by 2050. Increased power generation efficiency.
- **CO2 emissions**: will peak around 2025. Non-OECD countries make up 3/4 of the contribution, mainly due to coal consumption cuts.

Plausible: Ener Data - Ener Brown†

Purpose: Support or strategic planning and policy making on energy evolutions and challenges according to climate constraints and technologies.

Key Elements:

- The world of **durably low fossil fuel energy prices**; unconventional oil and gas resources intensifies and expands
- **Low global cooperation**
- **Oil and gas prices are expected to remain weak**: prices slowly recover from present collapse, but remain well below the last decades' highs.
- Confirmed energy commitments in some regions. Technological innovation foster significant **development of low energy intensive processes and technologies**.
- **Renewables achieve a substantial deployment**, but affordable fossil fuels remain a competitive and attractive source of energy.
- Without a global agreement, non-coordinated policies result in **soaring CO_2 emissions across the world, towards 5/6°C temperature increase** by the end of the century

*. Source: IEEJ (2018) Outlook (2050) https://eneken.ieej.or.jp/data/7570.pdf

†. Source: Enerdata (2016) Energy Scenarios to 2040 https://cleanenergysolutions.org/sites/default/files/documents/enerdata-global-energy-scenarios-to-2040-webinar.pdf

Outlook: IEA - Current Policies*

Purpose: Provide a baseline that shows how energy markets would evolve if underlying trends in energy demand and supply are not changed. **Serve as a benchmark** for the assessment of recent or announced development of energy and climate policy

Key Elements:

- **Market imbalances** and energy prices
- Dramatic **falls in the costs of key renewable technologies**
- **Rapidly evolving demand patterns** and traditional distinctions **between consumer and producer countries**
- Market imbalances maintain downward pressure on prices, not only for oil and gas, but also for other parts of the energy sector such as PV panels
- **Fast changing energy system**, with the dramatic falls in the costs of key renewable technologies upending traditional assumptions on relative costs
- **Expansion in low-carbon power generation**, led by rapid deployment of wind and solar
- **Reduction in the energy intensity** of global gross domestic product (GDP)
- **Fall in estimated global coal use**, driven by developments in China and coal-to-gas switching in the United States

Outlook: IEA New Policies†

Purpose: Provide a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy, such as Paris NDCs and other decisions of sub-national authorities

Key Elements:

- **Rapid deployment and falling costs of clean energy technologies**; growing electrification
- **US** emphasis on national resources (**shale gas and tight oil**) and **withdrawal from Paris Agreement**
- **China's** plans for an "**energy revolution**"; shift to a more services-oriented economy and a cleaner energy mix
- **Stronger commitment to renewables and electric mobility in India**.
- Plans to **shift the power mix in Korea in favour of gas and renewables**
- Global energy needs rise slower than in the past, but still expand by 30% between today and 2040
- **Coal strikes out** with the lead now taken by natural gas, the rapid rise of renewables and energy efficiency. Renewables capture 2/3 of global investment in power plants as they often become the least-cost option
- Electricity will make up 40% of the rise in final consumption to 2040
- **Growing EVs** but persistence of oil due to US near-term downward pressure on prices. **Rapid switch to electric cars keep oil prices lower for longer**
- **Natural gas grows** to account for a quarter of global energy demand by 2040, becoming the second-largest fuel in the global mix after oil
- **Universal access to electricity remains elusive**, and scaling up access to clean cooking facilities is even more challenging. **Policy attention to air quality is rising**
- Despite their recent flattening, **global energy-related CO_2 emissions increase slightly to 2040** in the New Policies

*. Source: IEA (2017) World Energy Outlook (2040) http://www.iea.org/weo/

†. Source: IEA (2017) World Energy Outlook (2040) http://www.iea.org/weo/

Outlook: BP - Evolving Transition‡

Purpose: Explore the forces shaping the global energy transition out to 2040 and the key uncertainties surrounding that transition. **Inform and support the corporate strategy** that is resilient to all these possibilities and many more, ensuring that organisation fits and ready to meet the energy needs of tomorrow's world, whatever form they take

Key Elements:

- The scenarios assumes that **government policies, technology and social preferences continue to evolve in a manner and speed seen over the recent past**
- The **world GDP more than doubles by 2040**, as more than 2.5 billion people are lifted from low incomes
- **Energy demand increases** by only around one third over the next 25 years
- Industrial demand for energy accounts for around half of the increase in energy consumption; growth in transport demand slows sharply relative to the past
- The **world continues to electrify**, with almost 70% of the increase in primary energy going to the power sector.
- **Renewable energy is the fastest-growing energy source**, accounting for 40% of the increase in primary energy
- **Demand for oil and other liquid fuels grows**, but gradually slows and plateaus in the later years
- The increase in liquids production is initially dominated by US tight oil, but is later driven by OPEC, as members adopt a strategy of increasing their market share
- **Natural gas grows strongly**, supported by broad-based demand and the continuing expansion of liquefied natural gas (LNG), increasing the availability of gas globally
- **Global coal consumption flatlines**, with Chinese coal demand declining
- **Carbon emissions continue to rise**, signalling the need for a comprehensive set of actions to achieve a decisive break from the past

Outlook: IEEJ - Reference§

Purpose: Provide an energy outlook developed according to the past trends as well as the energy and environment policies that have been in place so far

Key Elements:

- **Population and economic growth in non-OECD countries**, especially Asia
- Ambitious plans for **changing the market structure towards non-fossil fuels in China and India**
- Oil will still be the main source of energy followed by gas
- **Natural gas production increases** by 80% from 2015 to 2050, with the largest increase coming from Middle East
- **Growing demand for electricity** with growing relevance of solar and wind
- By 2050 population will be 1.3 larger, economy 1.5 larger and energy consumption 1.5 greater than today. **71% of energy consumption will be from non-OECD countries**
- Fossil fuel will meet most of new demand (almost a 1:3 ratio between non-fossil and fossil energy increase). 21% non-fossil share by 2050
- **Coal growth will slow down**, but it is still indispensable for countries like China and India
- **Electricity share in final consumption will grow** from 19% to 24% in 2050. More advanced electrification in OECD
- **Nuclear will grow but less than other sources**, shrinking its share in the energy mix by 2%
- Solar and wind will account for 13% of total power generation by 2050

‡. Source: BP (2018) Energy Outlook (2040) https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

§. Source: IEEJ (2018) Outlook (2050) https://eneken.ieej.or.jp/data/7570.pdf

Outlook: CEPSA - Reference*

Purpose: Provide a perspective on the foreseeable future to enable businesses in the energy sector to be responsive and proactive in a complex and rapidly changing environment, identifying uncertainties, threats, and opportunity

Key Elements:

- **Fossil fuels still dominate the energy mix**. Oil demand will keep growing and gas will replace coal
- Electricity main final energy contributor, with wind and solar dominating the power mix
- **Efficiency gains to slow energy demand growth** and curb emissions
- The **middle class will grow strongly**, particularly in Asia, supporting levels of economic growth similar to the last 15 years
- **Renewables, batteries, and digitisation will continue to grow rapidly, and have the potential to significantly disrupt the energy system**
- **New urban mobility models** will be shaped by three main factors: electrification, autonomous cars, and sharing platforms
- **Global energy demand will grow** at half the rate of the previous 15-year period as efficiency improves
- The global energy mix will continue to be dominated by fossil sources, though its share will be trimmed by the pace of growth in renewables
- **Wind and solar** power generation will occupy the **largest share of new electricity generation** as lifecycle costs continue to dip
- **Oil demand will continue to grow**, albeit at a lower rate as fuel efficiency improves and a switch is seen to other energy sources; **natural gas will be the fastest growing fossil fuel**, displacing coal
- **Emissions growth will be curbed** thanks to efficiency gains and fast emerging renewables

Outlook: Exxon - Reference†

Purpose: Provide an outlook to inform long-term business strategies and investment plans in the ongoing energy transition

Key Elements:

- **Carbon emissions will peak by 2040**
- By 2030, world's middle class will expand from 3 billion to more than 5 billion people, and living standards will rise, resulting in rising energy use in many developing countries
- Despite efficiency gains, **energy demand will rise by 25% to 2040, led by non-OECD nations** (China, India), where it will increase by 40% (the same energy consumed in the Americas today)
- Global **electricity** demand will rise by 60% between 2016 and 2040, led by a near doubling of power demand in non-OECD countries
- The combined share of **solar and wind** to global electricity supplies is likely to triple by 2040, helping the CO2 intensity of electricity to fall by 30%
- **Natural gas** use will increase more than any other source due to its versatility and low carbon intensity
- EVs and efficiency improvements in ICEs will lead to a peak in liquid fuels by light-duty fleet by 2030. However, **oil will continue** to play a leading role in the energy mix, mainly **driven by commercial transportation** and chemical industry
- Energy efficiency gains and switch to less carbon intensive sources will contribute to a 45% decline in **carbon intensity** of GDP. Energy related CO_2 will peak by 2040 10% above 2016 level

*. Source: CEPSA (2017) Energy Outlook 2030 https://www.cepsa.com/stfls/corporativo/FICHEROS/Cepsa_Energy_Outlook_2030_2017.pdf

†. Source: ExxonMobil (2018) Outlook for Energy: A View to 2040 https://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2018/2018-outlook-for-energy.pdf

Normative: IEA Sustainable Development*

Purpose: Demonstrate a plausible path to concurrently achieve universal energy access, set a path towards **meeting the objectives of the Paris Agreement** on climate change, and significantly **reduce air pollution** (SDG 7, SDG 13, SDG 3 and 11)

Key Elements:

- Expanding **electrification. Electricity demand**, spurred by increased use of electrical appliances and the electrification of heating and transportation, is **predicted to rise to 40% of final energy consumption by 2040**, the same share of growth occupied by oil for the previous 25 years
- Declining cost and rapid expansion of **renewables**. The 30% growth in global energy demand by 2040 is met mostly by **natural gas, renewables, and energy efficiency**.
- **Cleaner** and more diversified energy production in **China**. As **China's economy** transitions toward a services-based model, it is expected to **increasingly rely on electricity, natural gas**, and **digital technologies** to slow demand growth from 8% per year between 2000-2012 to 1% per year by 2040
- **Share of low-carbon sources in the energy mix doubles** to 40% in 2040. Energy efficiency is increased, demand for coal immediately declines, power generation is decarbonised, and electric vehicles are quickly mainstreamed
- The **US will become a net exporter of oil and natural gas** by the late 2020's, spurred by cost-effective tight oil and shale gas production

Normative: Shell SKY†

Purpose: Hold the increase in the global average temperature to well **below 2°C above pre-industrial levels** and to pursue efforts to limit the temperature increase to **1.5°C above pre-industrial levels. Have zero net-emissions by 2070**

Key Elements:

- Significant change in **consumer mindset**. A change in consumer mindset means that people preferentially choose low-carbon, high-efficiency options to meet their energy service needs
- A step-change in the **efficiency** of energy use
- Adoption of **carbon-pricing** mechanisms
- **Environmental Plus** – deforestation issues
- A step-change in the **efficiency of energy use** leads to gains above historical trends
- **Carbon-pricing mechanisms** are adopted by governments globally over the 2020s, leading to a meaningful cost of CO2 embedded within consumer goods and services
- The **rate of electrification of final energy more than triples**, with global electricity generation reaching a level nearly five times today's level
- New **energy sources grow up to fifty-fold**, with primary energy from renewables eclipsing fossil fuels in the 2050s
- Some 10,000 **large carbon capture and storage facilities are built**, compared to fewer than 50 in operation in 2020
- **Net-zero deforestation is achieved.** In addition, an area the size of Brazil being reforested offers the possibility of limiting warming to 1.5°C, the ultimate ambition of the Paris Agreement

*. Source: IEA (2017) World Energy Outlook (2040) http://www.iea.org/weo/

†. Source: Shell (2018) New Lens Scenarios (2100) Sky https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

Normative: Statoil Renewal*

Purpose: Have 50% probability to limit global worming to 2 °C, achieving a long-term stabilisation of CO2-equivalent concentrations of 450 ppm in the atmosphere

Key Elements:

- **International Climate framework** and national targets
- **Stable policy**, regulatory frameworks, and consistent emphasis on green technologies mobilise clean investments
- **Geopolitical environment is driven by cooperation** rather than competition; radical action in national policy; **tightening emission targets every 5 years** according to Paris Agreement; increasing influence of emerging economies in international institutions and legal frameworks
- Decrease in coal and oil dependence and **boost in efficiency and green energy**; initial growth slower than BAU scenarios because of lower focus on short-term return, but higher growth afterwards; fast **phasing out of fossil fuel subsidies, high carbon prices** and development of **large-scale CCS** to cover the sector with no fossil alternatives
- Stable policy and regulatory frameworks and consistent emphasis on **green tech mobilise clean investments**: energy efficiency improvements, power generation decarbonisation and a radical transport electrification
- Policies are **market based, interventionist, and oriented towards R&D**. Key results: declining costs of renewable technologies and car batteries, widespread of charging points for EVs, affordability of large-scale electricity storage, smart grids, strengthening of transmission networks and significant re-furbishing of the building stock. CO2 emissions cut by the fast decline of energy intensity and fuel switch

Normative: Irena - 66% chance below 2° C*

Purpose: Keep the global average temperature rise well below °2C by 2050 as per the Paris Agreement . Cumulative **carbon budget of 790 Gt CO2** to have a 66% probability to meet the target, 470 Gt less than current policies would require

Key Elements:

- **Synergetic** deployment of **renewable energy** and **energy efficiency measures**
- Intense **electrification** of transports, buildings and industry
- **System-wide innovation** and **lifecycle thinking**
- **Socio-economic alignment** with transition
- 120 trillion **investment** in **low-carbon technologies** and **power grid flexibility**. Increase in cumulative investment between 2015-2050 from USD 93 trillion (current/planned policies) to 120 trillion, of which 18 trillion for power grid and energy flexibility
- **Renewables**: share of renewables in energy consumption from 15% to 65% by 2050; share in power sector from 25% (2017) to 85% by 2050, mostly through solar and wind
- **Electricity**: wide diffusion of EVs and heat-pumps. Renewable electricity 60% of renewable energy use (x2.5 present), with renewable fuels and direct uses needed for heat and transports
- **Economy**: energy transition would cost USD 1.7 tril./year but deliver 6 tril./year through savings by 2050 and USD 52 tril. cumulative gain in GDP by 2050. It will generate a 15% increase in welfare, 1% in GDP, and 0.1% in employment
- Focus area for **policy**: synergies between energy efficiency and renewable energy.

*. Source: Statoil (2017) Energy Perspectives (2050) https://www.equinor.com/content/dam/statoil/documents/energy-perspectives/energy-perspectives-2017-v2.pdf

*. Source: IRENA (2017) Perspective for energy transition https://www.iea.org/publications/insights/insightpublications/PerspectivesfortheEnergyTransition.pdf

Normative: Ener Data - Ener-green*

Purpose: Have a below 2°C temperature increase; upward review of NDCs in time; regular updates of energy efficiency targets

Key Elements:

- Stringent **climate policies**
- Strong deployment of **renewables** and fossil fuels **subsidies phase-out**
- **70% electricity decarbonisation** through RES, CCS and nuclear
- Global **stabilisation of energy demand** (below 14 Gtoe), ambitious energy efficiency **policies, fossil fuels subsidies phase-out** with a share lower than 50% by 2040 (coal halved)
- Strong development of renewables with **power sector emitting 70% less CO_2 by 2040** (mainly due to RES and CCS or nuclear)
- **EVs share around 45% by 2040**
- **Price increase** reflecting policies and CO2 constraints

*. Source: Enerdata (2016) Energy Scenarios to 2040 https://cleanenergysolutions.org/sites/default/files/documents/enerdata-global-energy-scenarios-to-2040-webinar.pdf

ACKNOWLEDGEMENTS

The project team would like to thank the individuals who informed the project's approach, supplied information, provided ideas, and reviewed drafts. Their support and insights have made a major contribution to the development of the report.

PROJECT MANAGEMENT

Christoph Frei (Secretary General); Angela Wilkinson (Senior Director, Scenarios and Business Insights); Ged Davis (Executive Chair, Scenarios).

PROJECT TEAM

Anastasia Belostotskaya (Senior Manager, Scenarios); Rami Fakhoury (Energy Transition Insights); Valerio Cappuccio (Energy Transition Insights); Jorge Romeo (Manager Digital Content & Marketing).

WORLD ENERGY COUNCIL SCENARIOS WORKING GROUP CONTRIBUTORS

Burkhard von Kienitz, Germany; Frank Sammeth, France; Nujood Al. Mulla, Saudi Arabia; Praveen Gautam, India; Ryo Fukushima, Japan.

WORLD ENERGY COUNCIL STUDIES COMMITTEE

Jean-Marie Dauger (Chair), France; Angela Wilkinson (Secretary), United Kingdom; Alessandro Costa, Italy; Arturo Vaca, Mexico; Atsushi Noda, Japan; Atul Sobti, India; Dan Ioan Gheorghiu, Romania; Gautam Vivek, India; Jan Antonczyk, Poland; Jean-Paul Bouttes, France; Jim Doull, United States of America; John W. M. Cheng, Hong Kong; Klaus Hammes, Sweden; Lauro Valdir de Souza, Brazil; Mehdi Sadeghi, Iran; Nastaran Rahimi, Iran; William D'haeseleer, Belgium; Kang Yanbing, China.

TRUSTEES

YOUNGHOON DAVID KIM
Chair

JEAN-MARIE DAUGER
Co-Chair; Chair - Studies Committee

KLAUS-DIETER BARBKNECHT
Vice-Chair: Finance

LEONHARD BIRNBAUM
Chair-Elect: Studies Committee

OLEG BUDARGIN
Vice Chair – Responsibility for Regional Development

JOSE DA COSTA CARVALHO NETO
Chair – Programme Committee

CLAUDIA CRONENBOLD
Vice Chair – Latin America/Caribbean

ROBERT HANF
Vice Chair – North America

CÉDRIC LEWANDOWSKI
Vice Chair – Europe

ELHAM MAHMOUD IBRAHIM
Vice Chair – Africa

ERIC MARTEL
Chair-Elect – Programme Committee

SHIGERU MURAKI
Vice Chair – Asia Pacific/South Asia

IBRAHIM AL-MUHANNA
Vice Chair – Gulf States/Middle East

MATAR AL-NEYADI
Vice Chair – 2019 Congress Abu Dhabi

JOSÉ ANTONIO VARGAS LLERAS
Chair – Communications & Strategy Committee

WORLD ENERGY COUNCIL PATRONS

Accenture Strategy

Electricité de France

ENGIE

GE Power

Hydro-Quebec

Marsh & McLennan Companies

Masdar

Oliver Wyman

Rosatom

PJSC Rosseti

Siemens AG

Swiss Re Corporate Solutions

Tokyo Electric Power Co

WORLD ENERGY INNOVATION PARTNERS

California ISO

PricewaterhouseCoopers

WORLD ENERGY SCENARIOS PARTNERS

Accenture Strategy

The Paul Scherrer Institute

WORLD ENERGY COUNCIL

Algeria
Argentina
Armenia
Austria
Bahrain
Belgium
Bolivia
Botswana
Brazil
Bulgaria
Cameroon
Canada
Chad
Chile
China
Colombia
Congo (Dem. Rep.)
Côte d'Ivoire
Croatia
Cyprus
Dominican Republic
Ecuador
Egypt (Arab Rep.)
Estonia
Ethiopia
Finland
France
Germany
Ghana
Greece
Hong Kong, China
Hungary
Iceland
India
Indonesia
Iran (Islamic Rep.)
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea (Rep.)
Latvia
Lebanon
Libya
Lithuania
Malaysia
Mexico
Monaco
Mongolia
Morocco
Namibia
Nepal
Netherlands
New Zealand
Niger
Nigeria
Pakistan
Panama
Paraguay
Peru
Poland
Portugal
Romania
Russian Federation
Saudi Arabia
Senegal
Serbia
Singapore
Slovakia
Slovenia
South Africa
Spain
Sri Lanka
eSwatini
Sweden
Switzerland
Syria (Arab Rep.)
Tanzania
Thailand
Trinidad & Tobago
Tunisia
Turkey
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay

Published by the World Energy Council 2019

Registered Office
62–64 Cornhill
London EC3V 3NH
United Kingdom

World Energy Council
Registered in England and Wales
No. 4184478

VAT Reg. No. GB 123 3802 48

T (+44) 20 7734 5996
F (+44) 20 7734 5926
E info@worldenergy.org
www.worldenergy.org | @WECouncil