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Global Energy Outlook 2019: The Next Generation of Energy

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About the Project

The Global Energy Outlook project seeks to enhance the comparability of long-term energy outlooks by harmonizing key assumptions underlying these projections. Details on the project, including downloadable data and an interactive visualization tool, are available at **www.rff.org/geo**.

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Abstract

The global energy landscape has experienced substantial changes over the last 25 years, with much larger changes potentially in store in the future. This report provides an analysis of long-term energy projections from governmental, intergovernmental, and private organizations using a unique methodology that allows for “apples-to-apples” comparisons. These projections agree that—absent ambitious climate policies—global energy consumption will grow 20–30% or more through 2040 and beyond, led largely by fossil fuels. This growth is driven by population and economic growth in the global “East,” while energy consumption in the “West” remains roughly flat. The global economy becomes more energy efficient over time, though carbon dioxide (CO_2) emissions continue to grow unless there is a shift in current policy and technology trends. Renewable energy, led by wind and solar power, grow rapidly, though they primarily add to, rather than displace, fossil fuels unless more ambitious climate policies are put into place. Electricity plays an ever-growing role in final energy consumption, and while electric vehicles also play an important role in the future of transportation, their effect is more likely to restrain the growth of, rather than lead to a decline in, global oil demand over the next two decades. Under ambitious climate scenarios, the global economy becomes much more energy efficient, global coal consumption declines by more than half relative to current levels, oil use falls by up to 20%, natural gas increases modestly, nuclear energy grows by more than 50%, renewables more than double, and carbon capture and storage (CCS) technologies are deployed at scale by 2040.

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Cover Photo Credit: Emrah Turudu/Getty Images

1. Introduction

The global energy sector has changed dramatically over the last 25 years, with larger changes possible over the next 25. The magnitude and direction of these changes, however, is highly uncertain. Numerous public and private organizations produce long-term energy projections that vary widely based on their assumptions and methodologies. This report provides a unique “apples-to-apples” comparison of these projections, providing the full scope of potential changes to the energy system as envisioned by some of its most expert organizations. The outlooks and major scenarios included are shown in Table 1.

Table 1. Outlooks and Key Scenarios

Author	Outlook	Scenario(s)	Years
Grubler[1]	Historical	-	1800–1970
IEA[2]	Historical	-	1970–2015
BNEF[3]	New Energy Outlook 2018	[unnamed central scenario]	To 2050
BP[4]	Energy Outlook 2018	Evolving Transition	To 2040
Equinor[5]	Energy Perspectives 2018	Reform, Renewal, Rivalry	To 2050
ExxonMobil[6]	Outlook for Energy 2018	[unnamed central scenario]	To 2040
IEA[7]	World Energy Outlook 2018	Current Policies (CPS), New Policies (NPS), Sustainable Development (SDS)	To 2040
IEEJ[8]	Outlook 2019	Reference	To 2050
OPEC[9]	World Oil Outlook 2018	Reference	To 2040
Shell[10]	Shell Scenarios 2018	Sky	To 2100
US EIA[11]	International Energy Outlook 2017	Reference	To 2050

Note: We focus on the US EIA’s *2017 International Energy Outlook* because the 2018 edition includes limited data for a limited number of countries.

A brief description of our methodology is provided in the Data and Methods section, with select data indicators in the Key Statistics section. For the full methodology, dataset, and interactive graphing tools, visit **www.rff.org/geo**.

Table 2 provides a legend to assist in interpreting the figures included in this report. We use a consistent labeling system as described below, which includes distinct line types for different scenario types. For "Reference" scenarios, which assume no new policies, and for Equinor's Rivalry scenario, assumes continued geopolitical challenges, we use a dashed line: this set includes EIA Reference, Equinor Rivalry, IEA CPS, IEEJ Reference, and OPEC Reference. For "Evolving Policies" scenarios, which assume that policies and technologies develop according to recent trends and/or the expert views of the organization producing the outlook, we use solid lines: this set includes BP Evolving Transition, Equinor Reform, ExxonMobil, and IEA NPS. For "Ambitious Climate" scenarios, which are built around achieving climate goals that extend beyond the 2015 Paris Agreement to limit global mean temperature rise to 2° Celsius or lower by 2100, we use dotted lines: this includes Equinor Renewal, IEA SDS, and Shell Sky. For additional detail on scenarios, see Table 5.

Table 2. Legend for Different Scenario Types

Reference	Evolving Policies	Ambitious Climate
EIA Reference	BP Evolving Transition	Equinor Renewal
Equinor Rivalry	Equinor Reform	IEA SDS
IEA CPS	IEA NPS	Shell Sky
IEEJ Reference	ExxonMobil	
OPEC Reference		

Finally, figures and tables in this report frequently refer to regional groupings of "East" and "West." Those regional groupings are described briefly in Table 3.

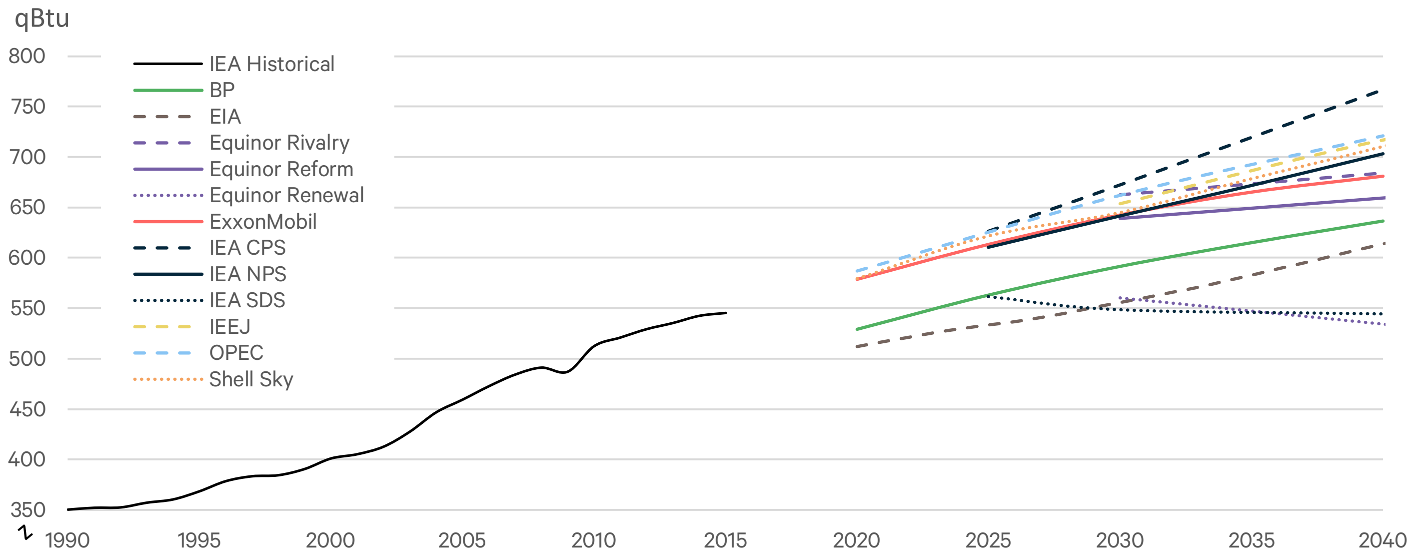
Table 3. Regional Definitions for "East" and "West"

"East"	Africa, Asia-Pacific, Middle East
"West"	Europe, Eurasia, North America, South and Central America

2. Key Findings

Global **primary energy** consumption has grown rapidly over the past 25 years, reaching 546 quadrillion Btu (qBtu) in 2015, more than 190 qBtu higher than 1990 levels. Over the next 25 years, growth is projected to slow, increasing by roughly 110 to 160 qBtu in Evolving Policies scenarios, and declining by as much as 4 qBtu under Ambitious Climate scenarios (Fig. 1).

Figure 1. Global Primary Energy Consumption



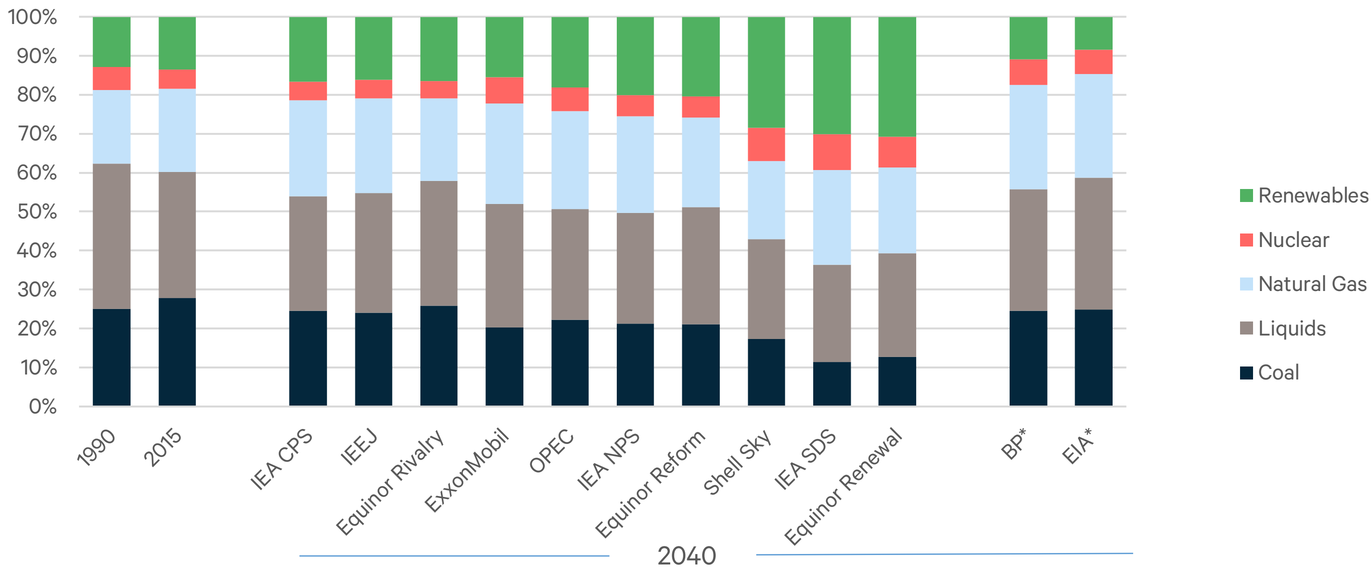
The IEA CPS shows the highest consumption in 2040 at 767 qBtu, an increase of 41% over 2015. OPEC and the IEEJ project consumption of roughly 720 qBtu in 2040, similar to the absolute levels of growth from the previous 25 years. Evolving Policies scenarios project moderately slower growth, led by the IEA NPS (703 qBtu), ExxonMobil (681 qBtu), and Equinor's Reform Scenario (659 qBtu).

Under two of three Ambitious Climate scenarios (IEA SDS and Shell Sky), global energy consumption is roughly flat to 2040. In the IEA SDS, demand is 544 qBtu in 2040, while Equinor Renewal projects consumption falling to 534 qBtu in 2040. On the other hand, under Shell's Sky, demand grows to 711 qBtu by 2040, higher than any Evolving Policies scenarios.

BP and EIA do not include **non-marketed traditional biomass** (e.g., wood and dung), making comparison to other organizations difficult. Using comparable historical data, BP and EIA respectively project growth from 2015 to 2040 of 139 qBtu and 116 qBtu, with EIA's slower energy demand growth reflecting its assumptions of slower population and GDP growth relative to other outlooks (see Table 9).

Fossil fuels, which made up 82% of global primary energy in 2015, dominate across Reference and Evolving Policies scenarios, ranging from 74% to 79% in 2040 (Fig. 2). Under Ambitious Climate scenarios, fossil fuels decline to 60% to 62%.

Figure 2. Shares of Global Primary Energy Consumption by Fuel



Note: The scenarios are ordered in decreasing shares of fossil energy. BP and EIA exclude non-marketed biomass energy, while other outlooks include this in renewables.

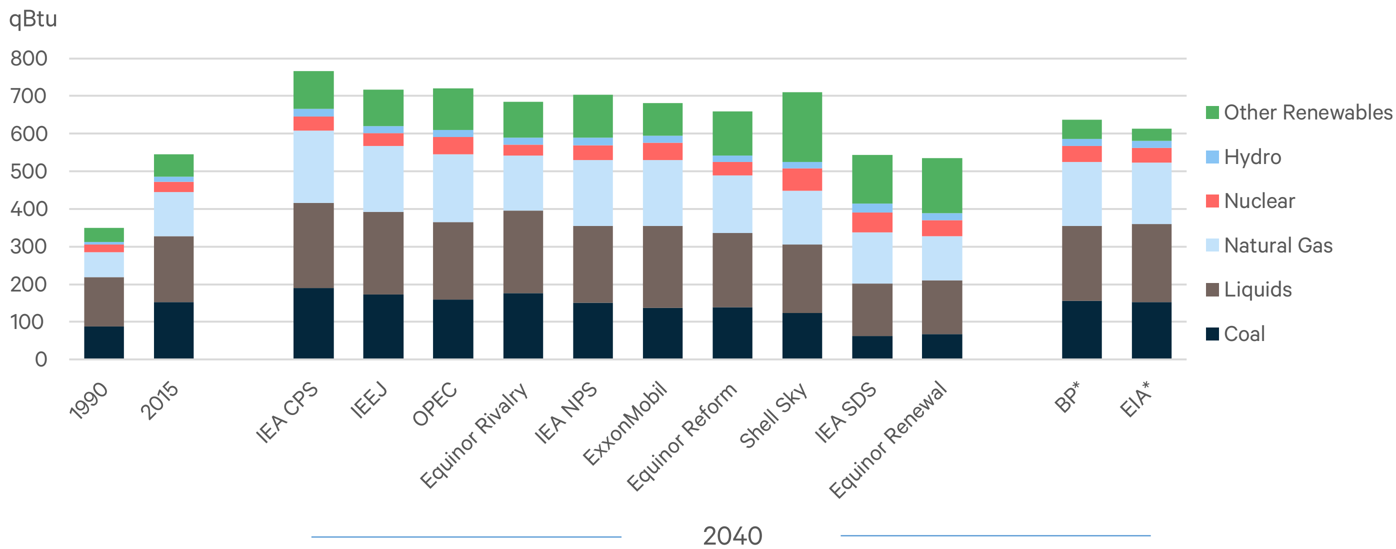
Liquid fuels—primary **oil**—continue to be the single largest fuel source in the energy mix across most outlooks, though its share shifts from 32% in 2015 to between 28% and 32% in Evolving Policies scenarios. Under Ambitious Climate policies, liquids still account for 26% to 27% by 2040, but of a smaller aggregate energy base in the case of IEA SDS and Equinor Renewal. **Natural gas** becomes the second largest source in most outlooks, rising from 21% in 2015 to between 21% and 27% by 2040.

Coal loses market share across all projections. Under Ambitious Climate scenarios, coal declines from 28% of the mix in 2015 to between 12% and 17% by 2040. Under Evolving Policies, it falls to 20% to 22%. **Renewables**—led by wind and solar—grow under all projections, though the rate of growth varies widely. Under Reference scenarios, renewables increase from 14% of the mix in 2015 to between 16% and 17%. Under Ambitious Climate scenarios, they become the largest source of global primary energy, overtaking petroleum to reach as high as 31% in 2040.

Projections for **nuclear's** share of the mix also vary substantially, and is highest under Ambitious Climate scenarios, where it provides 8% to 9% of global primary energy, up from 5% in 2015. For other scenarios, nuclear accounts for 4% to 7% of the mix.

Most projections show continued **additions** to all forms of energy, while Ambitious Climate scenarios envision a true **transition** away from carbon-intensive fuels (Fig. 3).

Figure 3. Levels of Global Primary Energy Consumption by Fuel



Note: The scenarios are ordered in decreasing levels of fossil energy. BP and EIA exclude non-marketed biomass energy, while other outlooks include this in renewables.

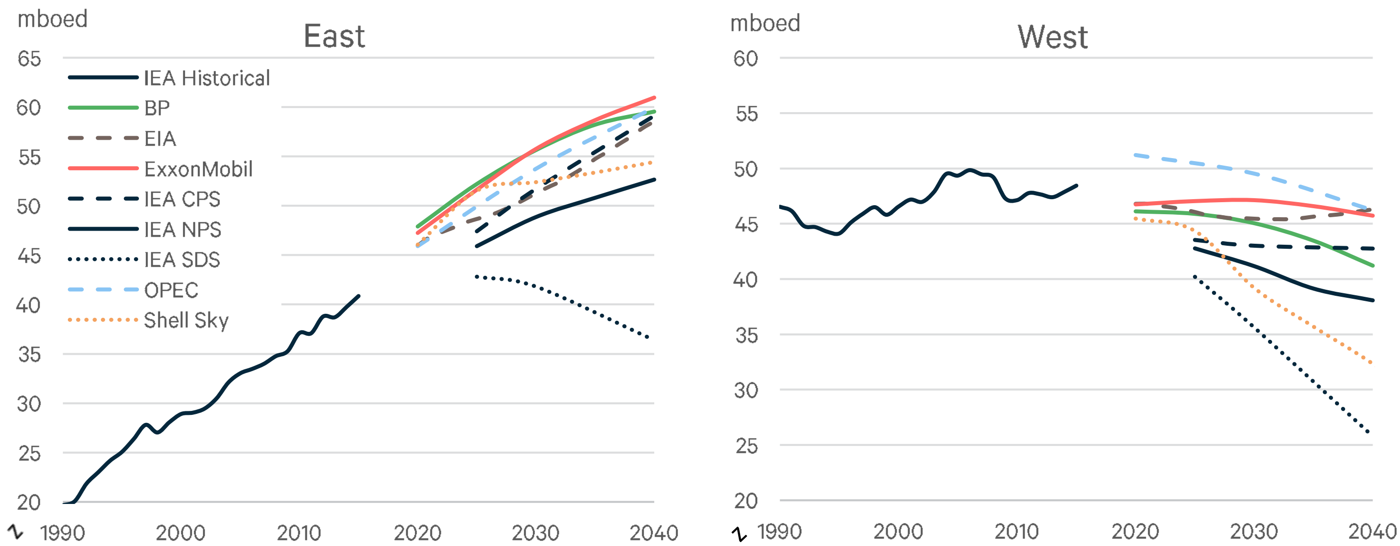
Historically, no major fuel source has seen its overall level of demand decline globally. Rather than energy transitions, the world has undergone a series of energy additions. This dynamic may change in the decades to come, but most outlooks suggest that actual reductions in fossil fuel use will require Ambitious Climate policies.

For example, coal consumption from 2015 to 2040 increases or remains flat under roughly half of the scenarios examined here, including the IEA's NPS. Liquids consumption increases substantially under all scenarios other than the IEA SDS and Equinor Renewal, while natural gas grows under every scenario. Nuclear and hydro see uniformly modest growth, while renewables grow dramatically.

In absolute terms, **renewables** are the fastest growing energy source in roughly half of the scenarios, including the IEA NPS, where they grow slightly more than **natural gas**. Under projections from ExxonMobil, IEEJ, OPEC, and the IEA CPS, natural gas consumption increases the most by 2040, while **liquids** consumption leads demand growth in Equinor Rivalry.

Liquids demand grows strongly in the East but declines in the West under most projections, with major economies in Asia driving consumption growth under all but the Ambitious Climate scenarios (Fig. 4).

Figure 4. Liquids Consumption in the East and West



Notes: Converted from qBtu using a factor of 0.506 mboed/qBtu (see Table 8). Includes biofuels. Excludes bunkers for all outlooks except OPEC.

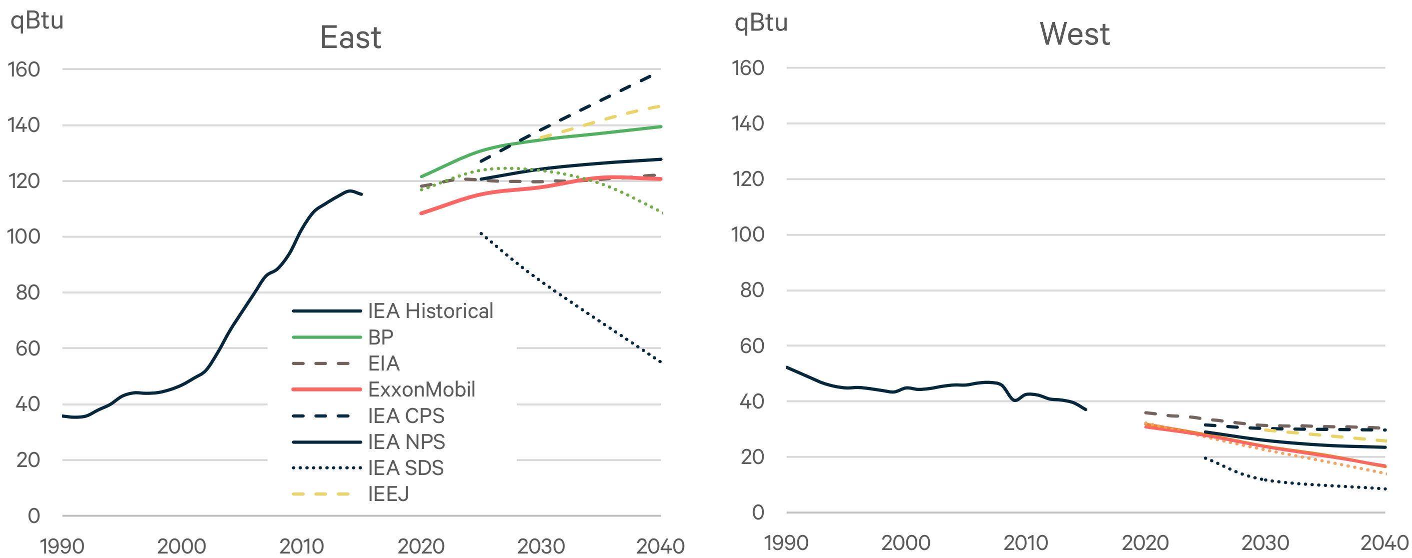
Under all scenarios other than the IEA SDS, **liquids** demand in the East drives global consumption due to growth in commercial transportation, aviation, and petrochemicals. Demand for passenger vehicles is moderated by **energy efficiency**, but still increases substantially in the East. Liquids consumption in 2040 is 29% to 46% higher than 2015, with the exception of the IEA SDS, where consumption is 11% lower in the region.

In the West, **liquids** demand falls across all scenarios, with 2040 consumption at 4% below 2015 levels, with rapid declines occurring under Ambitious Climate scenarios such as the IEA SDS and Shell Sky. For BP and the IEA NPS, consumption falls by 15% and 21% respectively, led by enhanced **energy efficiency** along with smaller contributions from vehicle electrification.

On net, **liquids** growth in the East outpaces declines in the West, with global demand growing by 13% to 29% by 2040 for non-Ambitious Climate scenarios. In some Evolving Policies scenarios (BP, Equinor Reform, IEA NPS), global growth dramatically slows or begins to decline in the 2030 to 2040 period, while in Ambitious Climate scenarios, consumption peaks by 2025, then begins to fall. For IEA SDS and Equinor Renewal, global liquids demand is roughly 20% below 2015 levels by 2040, while global demand rises by 3% under Shell Sky.

Coal consumption continues to decline in the West, while the pace of growth in the East varies widely depending on assumptions about climate policies and other factors. Globally, coal grows by as much as 24% above 2015 levels (IEA CPS) and falls by as much as 58% (IEA SDS) (Fig. 5).

Figure 5. Coal Consumption in the East and West



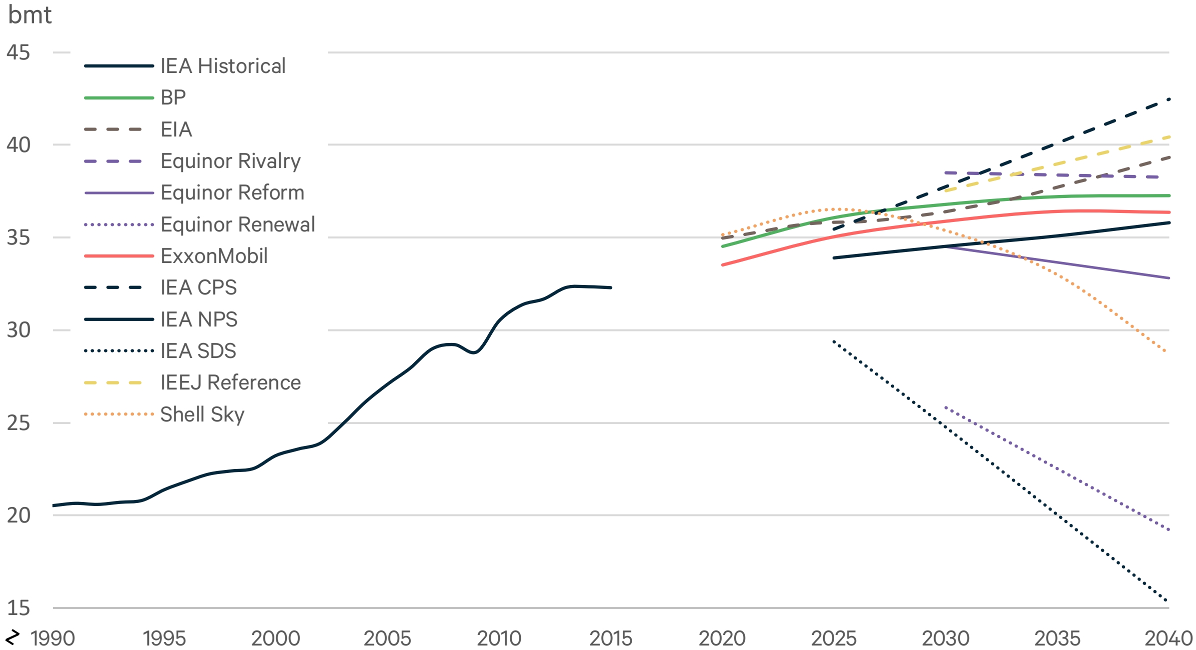
Over the last 25 years, **coal** consumption has boomed, driven by fast-growing economies in Asia, particularly China. Between 1990 and 2015, coal demand in the East more than tripled, while consumption in the West fell by nearly 30%. While concerns over local pollution and climate change have dampened expected growth, many outlooks project a continued increase in global coal demand.

Even under Reference scenarios, projections range widely. The IEA CPS projects **coal** consumption growth of 38% in the East, while the US EIA projects growth of just 6% for the region. In the West, coal demand falls by 18% and 19% for the US EIA and IEA CPS respectively, and declines by 30% in the IEEJ Reference scenario. Under Evolving Policies scenarios from BP and the IEA, consumption in the East grows by 21% and 11% respectively, while consumption in the West falls by 35% and 54% respectively.

Under Ambitious Climate scenarios, projections also vary widely—in part due to assumptions about future deployment of **carbon capture and storage (CCS)** and **carbon dioxide removal (CDR)** technologies such as **bioenergy** with **CCS**. Under Shell Sky, which assumes large-scale CDR in the second half of the twenty-first century, coal consumption declines by just 5% in the East, compared with a decline of 52% under the IEA SDS. In the West, coal demand declines by 62% under Shell Sky and 76% under the IEA SDS.

Under most scenarios, **carbon dioxide (CO_2)** emissions from the global energy system are on a path to far exceed international targets of the Paris Agreement. CO_2 emissions grow from 32 billion metric tons (bmt) in 2015 to as high as 43 bmt, while Ambitious Climate scenarios show emissions falling below 20 bmt by 2040 (Fig. 6).

Figure 6. Global Energy-Related Net Carbon Dioxide Emissions



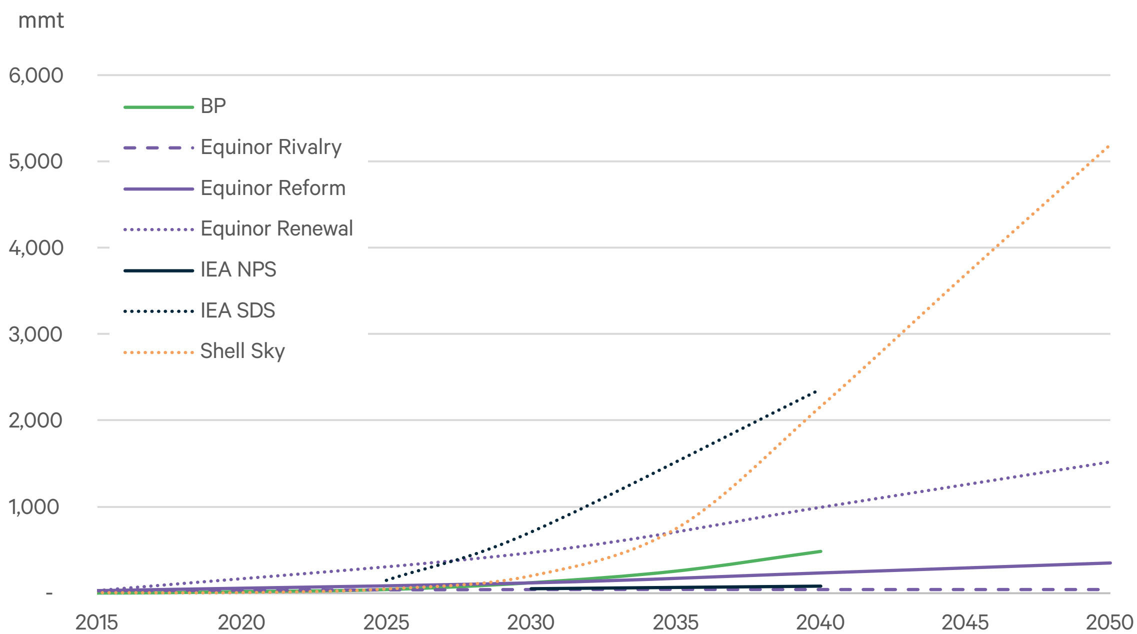
Outlooks vary in how they report CO_2 emissions. While most report emissions in gross terms, Equinor and Shell report *net* CO_2 emissions, which subtract emissions reductions from CDR from gross emissions levels. Here, we harmonize across projections by subtracting CDR from gross emissions for each outlook, then report net CO_2 emissions. In practice, large scale CDR occurs only in Ambitious Climate scenarios (see following section).

The IEA SDS projects net emissions falling to 15 bmt, and Equinor Renewal projects emissions of 19 bmt in 2040. These scenarios both include higher carbon prices, which propel substantial improvements in energy efficiency, rapid growth of renewable electricity, and deployment of **CCS** at scale (see following section). Shell Sky projects net CO_2 emissions rising to 36 bmt in 2025, then falling to 29 bmt in 2040 and reaching net-zero by 2070, followed by net **negative emissions** at very large scale in the following decades.

The IEA CPS and the IEEJ Reference Case, both Reference scenarios, show the highest **CO_2** emissions, growing to more than 40 bmt in 2040. Most Evolving Policies scenarios such as those from BP, ExxonMobil, and the IEA NPS show emissions growth slowing and roughly flattening by 2040, reaching between 35 and 37 bmt, still well above the levels needed to achieve the goals of the Paris Agreement.

As of 2018, 23 commercial-scale **carbon capture and storage (CCS)** projects were in operation or under construction around the world, capturing an estimated 40 million metric tons (mmt) of CO_2 annually.[12] However, this total is negligible relative to the scale of global emissions, and Ambitious Climate scenarios envision a rapid scale-up of CCS technologies (Fig. 7).

Figure 7. Carbon Capture and Storage

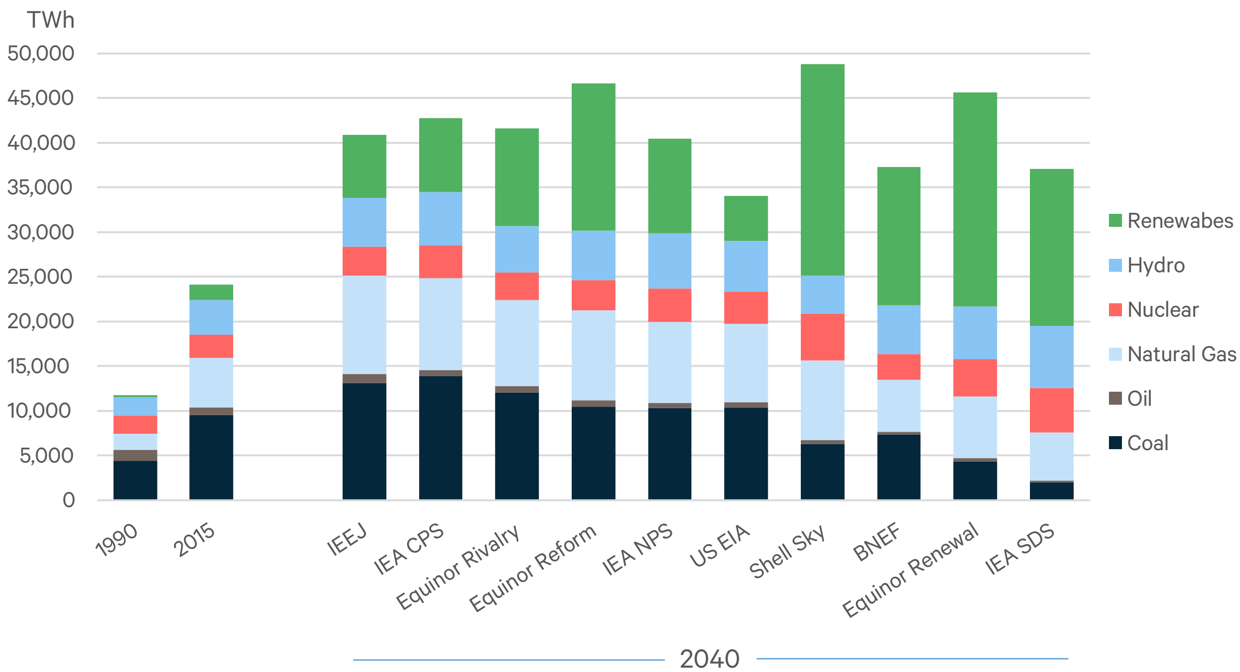


Not every outlook and scenario publishes projections of **CCS** deployment. Of the scenarios for which CCS data are available, the IEA SDS and Shell Sky scenarios envision the most rapid growth, rising to more than 2,000 mmt annually by 2040, with Shell's estimates for CCS growing even more rapidly in the following decades. As noted above, Shell's Sky scenario includes large-scale **CDR**, which is reliant upon the deployment of CCS paired with **bioenergy**. Equinor's Renewal Scenario projects slower deployment of CCS, reaching roughly 1,000 mmt by 2040.

Among other outlooks, BP, Equinor's Reform, and the IEA NPS scenarios are the only ones that publish data showing **CCS** deployment at scale. For BP, CCS captures roughly 500 mmt of CO_2 by 2040, compared with less than 250 mmt for Equinor's Reform scenario and just 83 mmt for the IEA NPS.

Global demand for **electricity** surges as the power mix changes rapidly**.** In most outlooks, wind, solar, and natural gas provide the bulk of new capacity, while coal remains roughly flat or declines (Fig. 8).

Figure 8. Global Electricity Generation by Fuel



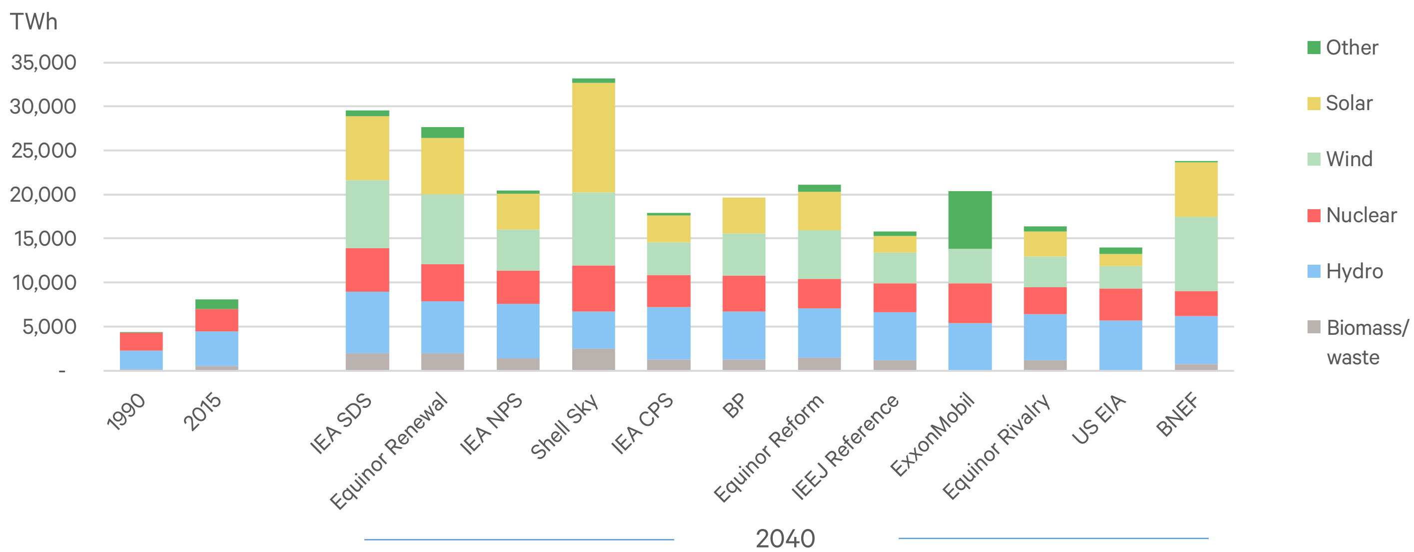
Across all scenarios, global **electricity** generation ranges from 34,000 terawatt-hours (TWh) to 49,000 TWh in 2040. The Shell Sky and the Equinor Renewal scenarios have the highest levels of generation in 2040, while the US EIA has the lowest projection, partly because it reports net generation while others use gross generation. The difference between net and gross generation is, on average, roughly 5% for OECD nations.[13]

Coal provided 39% of global electricity in 2015, but its share declines across all outlooks by 2040. In absolute terms, coal generation grows by up to 46% under the IEA CPS and 38% under IEEJ, while growing 9% under the IEA NPS. **Natural gas** provided 23% of global electricity generation in 2015, and its share grows under most scenarios, though not under those with Ambitious Climate policies. In absolute terms, gas-fired generation increases under all scenarios other than the IEA SDS. Under other Ambitious Climate scenarios from Equinor and Shell, natural gas generation grows by 24% and 61%, respectively, while BNEF projects growth of just 6% through 2040.

Non-hydro **renewables** grow dramatically across all scenarios. Even the most bearish projection (US EIA) shows their share more than doubling from 7% in 2015 to 15% in 2040. Under the IEA NPS and BNEF (an Evolving Policies scenario), renewables respectively account for 26% and 41% of generation, while Ambitious Climate scenarios reach between 47% and 61% of electricity by 2040.

Nuclear and **renewables** grow from roughly 8,000 TWh (34% of global generation) in 2015 to a high of 33,200 TWh (80%) and a low of 14,400 TWh (39%). Evolving Policies scenarios from BP, Equinor (Reform), and IEA (NPS) show nuclear and renewables providing roughly 50% of global electricity by 2040 (Fig. 9).

Figure 9. Global Nuclear and Renewables Electricity Generation



Note: 1990 and 2015 historical data from IEA, and include wind and solar in the "Other" category. "Other" includes solar and biomass for ExxonMobil and biomass for the US EIA.

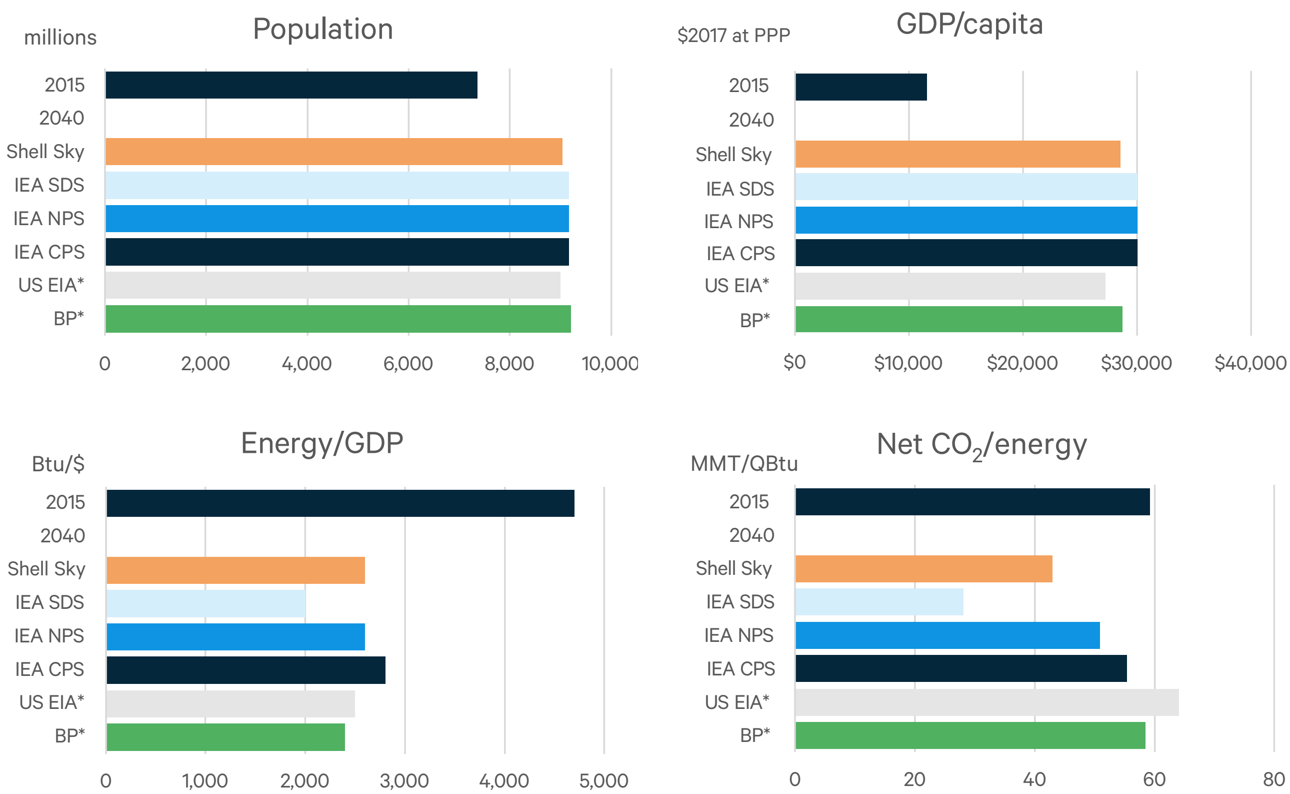
In 2015, **nuclear** and **renewables** (including **hydro**) made up about 2,500 TWh (11%) and 5,500 TWh (23%) of global generation respectively. The most bullish projections for nuclear and renewables come from Shell Sky (33,000 TWh), IEA SDS (30,000 TWh), and Equinor Renewal (28,000 TWh). Under Reference scenarios from the IEA (CPS), EIA, and IEEJ, nuclear and renewables contribute far less, ranging from 8,300 TWh to 12,000 TWh in 2040.

Estimates for **wind** vary based on policy and technology assumptions. EIA and Equinor Rivalry are among the lowest respective estimates at 2,500 TWh (7%) and 3,500 (9%). Projections from BNEF, Equinor Renewal, and Shell Sky are at the high end, ranging from 7,900 TWh to 8,300 TWh (17% to 22%) in 2040, while the IEA NPS and BP respectively project 4,700 TWh (12%) and 4,800 TWh (12%).

The outlook for **solar** also varies widely. Again, EIA has the lowest 2040 estimate at 1,400 TWh (4%). The most bullish projection comes from Shell Sky, which estimates 12,400 TWh (25%) in 2040, followed by the IEA SDS (7,300 TWh; 20%), Equinor Renewal (6,400 TWh; 16%), and BNEF (6,200 TWh; 16%). For the IEA NPS and BP, solar provides roughly 4,100 TWh (10% to 11%) in 2040.

Macroeconomic assumptions play a crucial role in shaping the outcomes of long-term outlooks. The **Kaya identity** is a helpful tool to understand some of these key drivers. The identity decomposes global energy and CO_2 emissions into four components: population, GDP per capita, energy use per unit of GDP, and CO_2 emissions per unit of energy. When multiplied, the first three factors yield energy use and when the fourth is added it yields CO_2 emissions (Fig. 10).

Figure 10. Global Macroeconomic Assumptions, 2040



Note: BP and EIA exclude non-marketed biomass energy, while other outlooks and historical data include them.

While not all outlooks provide sufficient data for full decomposition, several issues are notable. First, the US EIA's relatively low assumptions for global population and GDP per capita are key drivers of their relatively low levels of projected energy consumption through 2040.

Second, the IEA SDS and Shell Sky scenarios, both Ambitious Climate scenarios, differ markedly, with the IEA projecting substantially lower energy consumption per unit of GDP, along with lower CO_2 emissions per unit of energy.

Third, most variation between outlooks is found in the energy intensity (energy/GDP) and carbon intensity (net CO_2/energy) measures, suggesting that these factors are most subject to assumptions about the evolution of policies and energy technologies.

3. In Focus

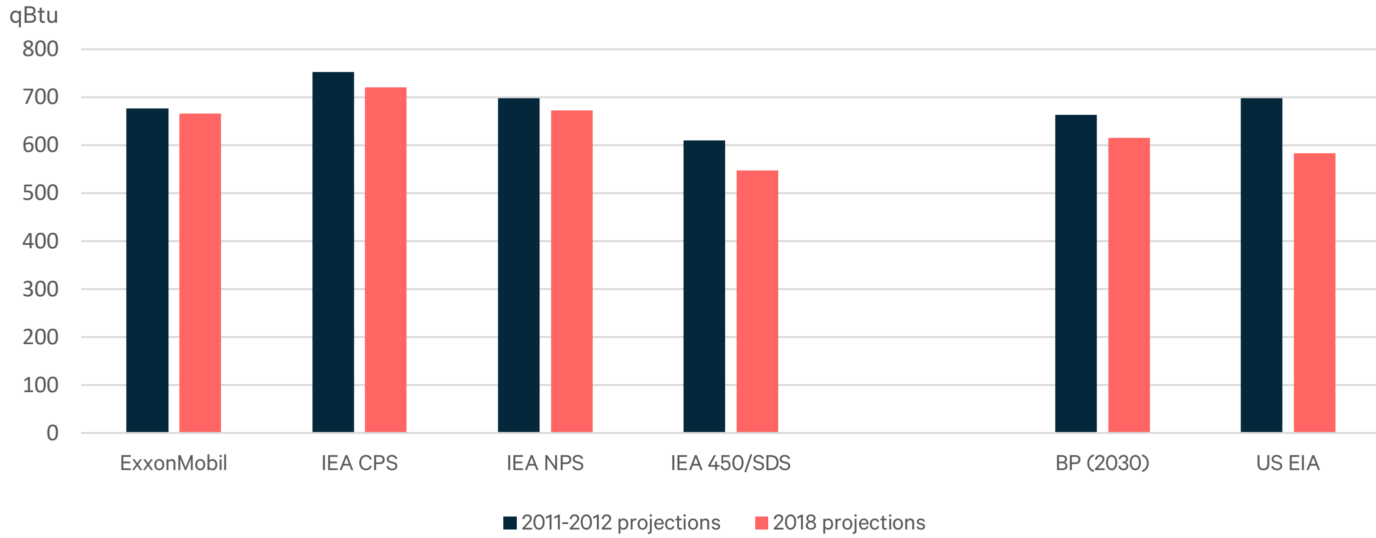
3.1. Retrospective Analysis of 2011–2012 Outlooks

The global energy system has changed rapidly in recent years. The magnitude and—in some cases—direction of these changes have taken analysts by surprise, leading to debate over the ability of models to reliably project trends in technologies such as US shale gas and tight oil, or wind and solar power, where steep declines in costs have led to faster-than-projected growth.[14,15] Here, we compare the most recent outlooks to others produced in 2011 and 2012, which were analyzed using the current methodology in our initial 2013 Global Energy Outlook.[16]

2018 outlooks project moderately lower primary energy consumption than those produced in 2011 and 2012.[16] Evolving Policies scenarios from BP, ExxonMobil, and the IEA are 2% to 4% lower in the benchmark year of 2035 (2030 for BP). The largest difference between projections emerges from the US EIA, whose 2017 projection for energy demand is 16% lower than 2011's Reference Case for 2035. These declines stem from heightened expectations for energy efficiency, as projections from each organization for global population and per capita GDP are well above 2011 levels (discussed below in more detail).

For the IEA's Ambitious Climate scenarios, 2018's SDS projects global primary energy demand of roughly 10% lower than 2011's 450 Scenario, which included a similar climate target as the SDS. As greenhouse gas emissions have continued to grow since 2011, the emissions reductions required to achieve long-term atmospheric concentration targets (such as 450 ppm CO_2) have grown steeper, implying the need for greater energy efficiency in the coming decades (Fig. 11).

Figure 11. Global Primary Energy Consumption in 2035



Notes: BP and US EIA exclude non-marketed biomass. BP data for year 2030. US EIA projection based on 2017 International Energy Outlook. 2011–2012 projections data from Newell and Iler (2013).[16]

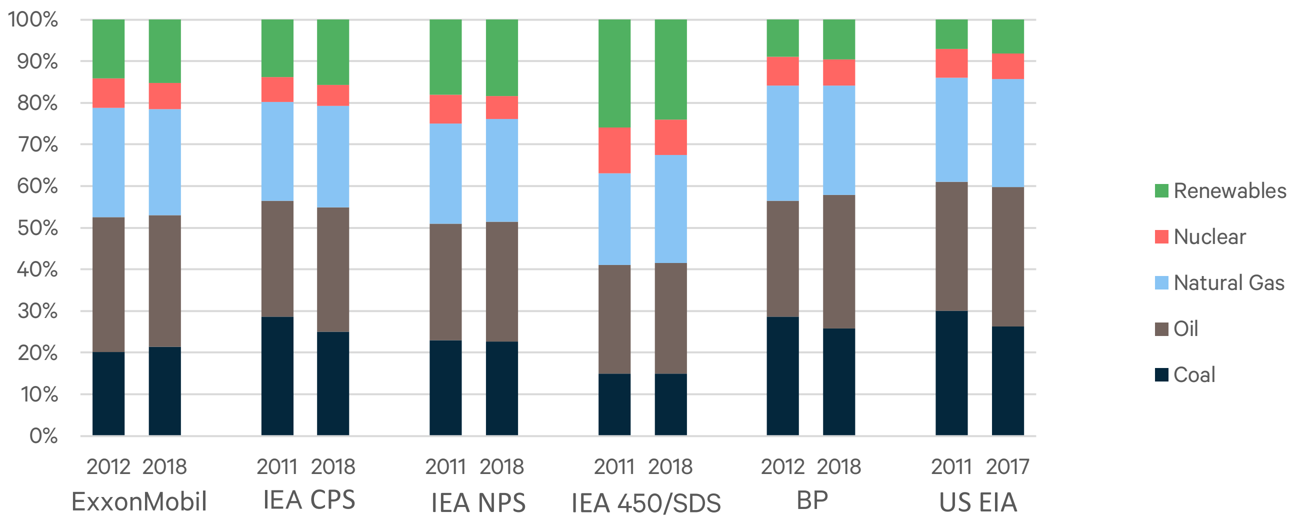
As noted above, declines in projected energy consumption are largely due to greater energy efficiency. Assumptions for global GDP in 2035 under the most recent IEA NPS are 19% higher than 2011's outlook, while energy consumption is 4% lower. For the US EIA, the global economy in 2035 is 8% larger while energy consumption is 16% lower. These shifts occur despite higher assumptions for global population, as shown in Table 4.

Table 4. Comparing IEA and EIA Projections for 2035

Projection	**Pop.** (M)	**GDP** ($T, 2017 at PPP)	**Primary energy consumption** (qBtu)	**GDP/capita** ($1,000)	**Energy/GDP** (1,000 Btu/$)	**Energy/capita** (million Btu/ person)
IEA 2011 NPS	8,556	198	697	23.1	3.5	81.5
IEA 2018 NPS	8,893	235	672	26.4	2.9	75.5
US EIA 2011	8,453	200	698	23.6	3.8	82.6
US EIA 2017	8,691	215	583	24.8	2.7	67.1

Expectations for the global energy mix have also changed, with some organizations seeing large shifts and others seeing relatively minor adjustments. For most outlooks, the expected share of coal in the future energy mix has declined, while the expected share of oil has increased modestly. The expected contribution of renewable energy has grown substantially in a number of outlooks, particularly in the IEA's CPS and NPS, while the expected share of nuclear energy has decreased across all outlooks, most notably falling from 11% to 8% of the energy mix in the IEA's Ambitious Climate scenarios (450 for 2011 and SDS for 2018) (Fig. 12).

Figure 12. 2011/2012 and 2017/2018 Projections for Shares of Global Primary Energy in 2035



Notes: BP and US EIA exclude non-marketed biomass, which is included in "renewables" for other outlooks. BP data for year 2030. 2011–2012 projections from Newell and Iler (2013).[16]

The decline of coal in the global energy mix is a generally consistent trend across outlooks, and is particularly notable in projections from BP, the US EIA, and the IEA's CPS. None of these scenarios include major new initiatives on climate policy, indicating that coal's decline has been driven in large part by market forces, along with a focus on local pollutants in rapidly growing Asian economies.

Despite substantial interest in the notion of "peak oil demand," most of today's projections see a larger relative role for oil in 2035 than those of 2011 and 2012. Oil's share of the energy mix ranges from 28% to 32% of global primary energy in 2035 under 2018 projections, compared with a range of 26% to 32% in projections from 2011 and 2012. Under all scenarios other than ExxonMobil's, oil's share is either the same or higher in 2035 than under projections from 2011 and 2012.

Renewable energy sees the largest relative growth, as costs for wind and solar power in particular have declined far more rapidly than expected. Expectations for the growth of nuclear energy, on the other hand, have waned for a variety of reasons, including safety concerns following the 2011 Fukushima Daiichi disaster, and high construction costs for new projects in developed economies such as the UK and US.

Certain topics have become far more prominent in recent years. For example, the growth of—and prospects for—electric vehicles receive prominent attention in several 2018 outlooks, but relatively little in 2011.

In its 2011 NPS, the IEA projected that the global stock of EVs (including PHEVs) would total roughly 31 million in 2035. In its 2018 NPS, the IEA projects a global stock of more than 300 million by 2040, as EVs reach cost parity with conventional vehicles by the early- to mid-2020s in major markets such as Europe, China, and India.

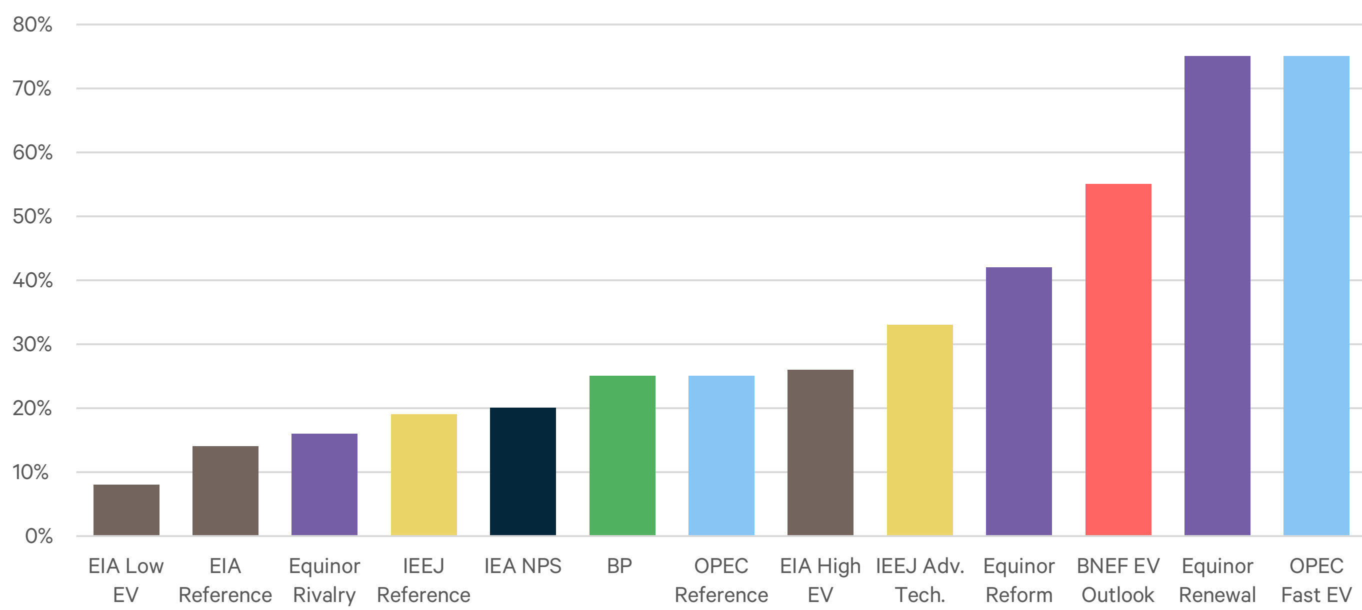
In its 2011 Reference Case, the US EIA projected that global electricity consumption in the transportation sector would reach 1.4 qBtu in 2035, roughly 1% of transportation energy demand. In its 2017 Reference Case, this figure reaches 3.4 qBtu, roughly 2.5% of global energy demand in the transport sector. As discussed in the following section, these higher projections of electricity consumption for transportation from the US EIA remain well below those of most other outlooks.

3.2. Electric Vehicles and Global Oil Demand

As electric battery costs have declined and government support has strengthened, global electric vehicle (EV) sales grew from just 7,500 in 2010 to more than 1 million in 2017, with more than 3 million EVs on the road (including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).[17] Annual sales of other modes of electric transport have also grown rapidly, with 30 million two-wheelers and 100,000 buses sold globally in 2017, mostly in China. While these vehicles currently account for a very small share of the global fleet, the combination of further declines in battery costs and continued policy support will make EVs a more common sight in years to come. However, projections for the pace of EV deployment, along with the ensuing effect on global oil markets, vary widely across outlooks.

By 2040, all outlooks anticipate EVs to account for much more than their current share of less than 1% of global car sales. Under the most bearish projection, this figure grows to 8% of sales by 2040 (EIA Low EV), and up to 75% in the most bullish projections (Equinor Renewal and OPEC Fast EV). As Figure 13 highlights, there is wide variation even among Evolving Policies scenarios such as BNEF's EV Outlook,[18] IEA's NPS, and Equinor's Reform scenario (Fig. 13).

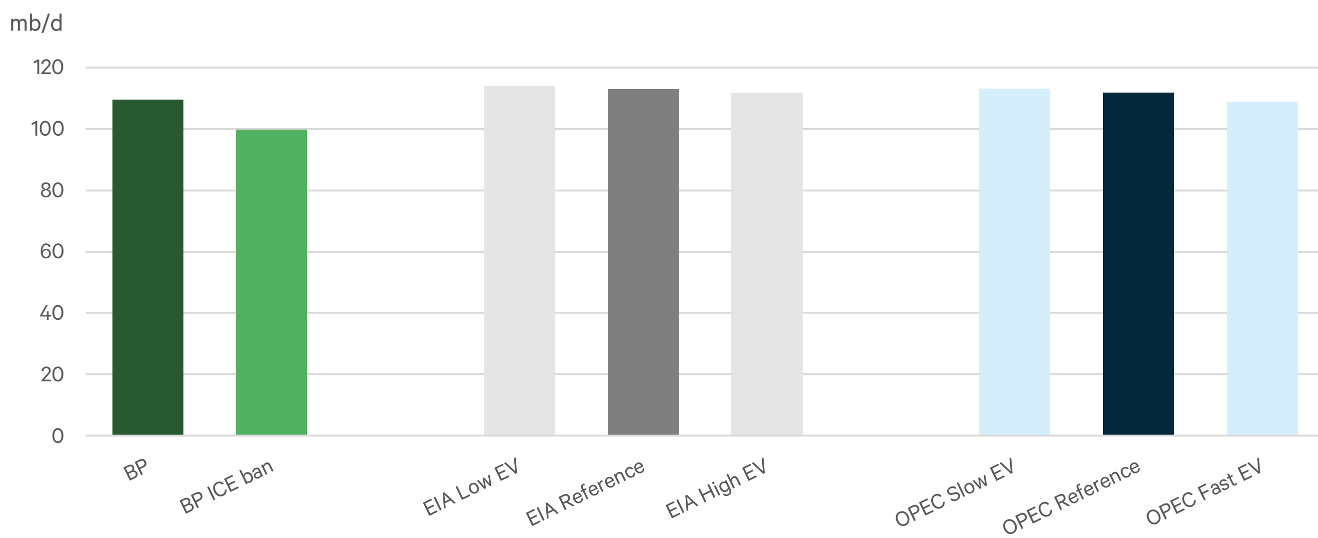
Figure 13. EV Share of Global Car Sales in 2040



How might growth in EV penetration affect global oil demand? Several projections address this question, though each use different scenario assumptions, making direct comparison difficult. In general terms, most projections find modest effects on global liquids demand from high EV penetration, as oil consumption from other sectors such as commercial transportation and petrochemicals continue to grow robustly.

Three outlooks provide data sufficient to compare directly: BP, EIA, and OPEC. BP examines a scenario in which new sales of cars with internal combustion engines (ICE) are banned by 2040, which reduces global oil demand by roughly 10 mb/d in that year. In the US EIA's high EV penetration scenario, global demand is roughly 1.3 mb/d lower as passenger EV sales reach 26% in 2040, compared with 14% under the Reference scenario. For OPEC's Fast EV scenario, where EVs account for 75% of new car sales in 2040, global oil demand is roughly 3 mb/d lower than the Reference Case, where EV sales are 25% in 2040. The effects of higher EV sales accumulate over time, as these vehicles become a higher share of the overall stock, growing further post-2040 (Fig. 14).

Figure 14. Global Liquids Consumption Under Different Assumptions for EVs, 2040



Other projections offer useful perspectives. BNEF projects that EVs and electric buses will displace 7.3 mb/d in global oil demand by 2040, as dynamic pricing systems and other enhanced technologies enable vehicle charging during times of peak renewables production when power prices are lowest.

ExxonMobil estimates that for every additional 100 million EVs on the road, global liquids demand declines by roughly 1.2 mb/d in 2040. Under a 2040 scenario where 100% of the passenger vehicle fleet are EVs, global demand is roughly 20 mb/d lower. While ExxonMobil does not provide estimates for the total number of passenger cars on the roads by 2040, the IEA NPS estimates this number at over 2 billion.

However, the effect on global CO_2 emissions for many of these estimates is relatively small. Under BP's ICE ban scenario, for example, global emissions are just 3% lower in 2040. ExxonMobil estimates that its 100% EV scenario would lead to emissions reductions of roughly 5%, though this estimate includes the assumption that 60% of the additional electricity required to power EVs would be supplied by coal. For the US EIA and OPEC, the effects on global emissions under bullish EV scenarios are even more modest.

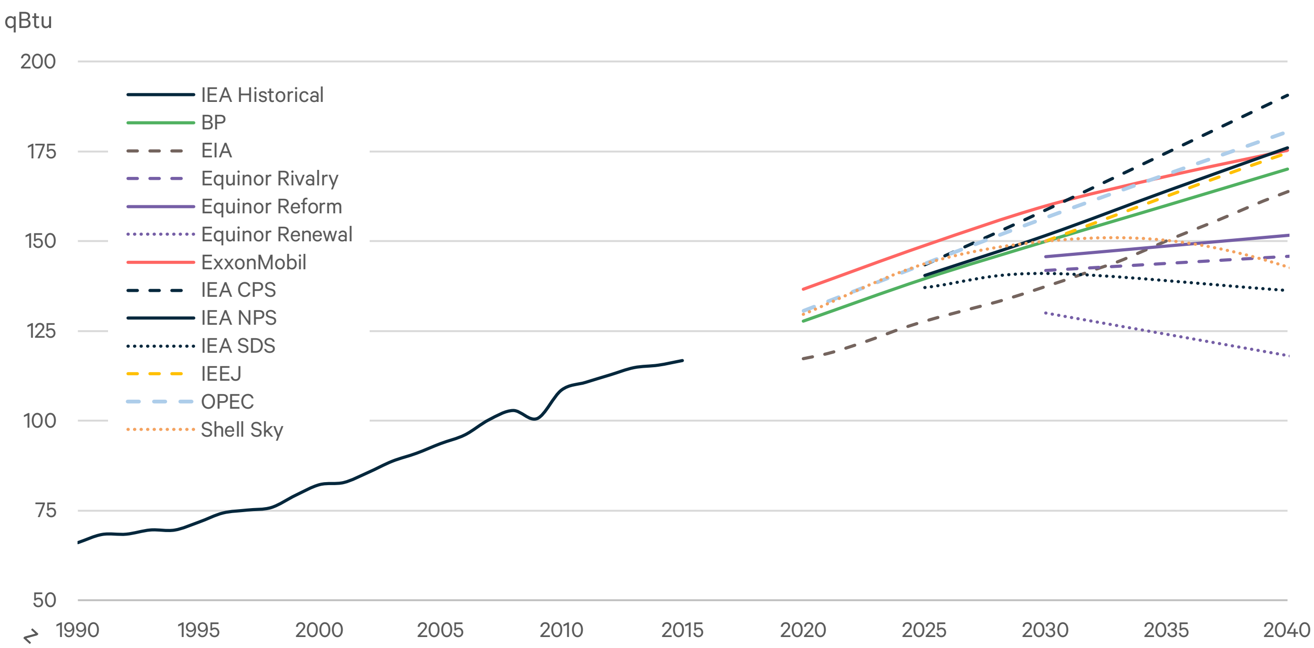
Along with its effects on oil demand, some outlooks publish estimates on changes in electricity consumption associated with higher or lower levels of EV deployment. The highest estimate comes from BNEF, which projects 2,000 TWh of annual demand from EVs in 2040 (5.3% of global electricity demand) and 3,400 in 2050 (8.9% of global demand), with much of this consumption occurring in the afternoons, as EVs charge from distributed solar PV networks. The IEA, in its Future is Electric scenario, projects EV consumption of 1,870 TWh in 2040 (4.4% of global demand in that scenario), while Equinor's Renewal estimates 2,500 TWh in 2050 (5.8% of global demand in that scenario). For reference, these estimates are equal to roughly 2 to 3 times the electricity consumption of the entire Middle East in 2016, which was roughly 880 TWh.[13]

3.3. Natural Gas and Deep Decarbonization

What is the role of natural gas in a carbon-constrained world? Since 1950, global natural gas consumption has increased from roughly 7 quadrillion (10^{15}) British thermal units (qBtu) to almost 125 qBtu in 2017, rising from 7% to 22% of primary energy consumption during that period. Because it emits less CO_2 than coal or oil when combusted, natural gas has the potential to continue growing in the decades to come, even under Ambitious Climate policies (though methane emissions would need to be kept to very low levels).[19, 20]

Most scenarios project natural gas's share of the energy mix to continue increasing, though the absolute level of growth varies widely. As Figure 15 illustrates, the three Ambitious Climate scenarios show the lowest levels of natural gas consumption in 2040, increasing above 2017 levels by 16% and 10% under the Shell Sky and IEA SDS scenarios, and remaining roughly flat under the Equinor Renewal scenario. Each of these scenarios include large-scale CCS deployment by 2040, though it is unclear to what extent CCS technologies are deployed to facilities that consume natural gas relative to other fuels such as coal or biomass (Fig. 15).

Figure 15. Global Natural Gas Primary Energy Demand

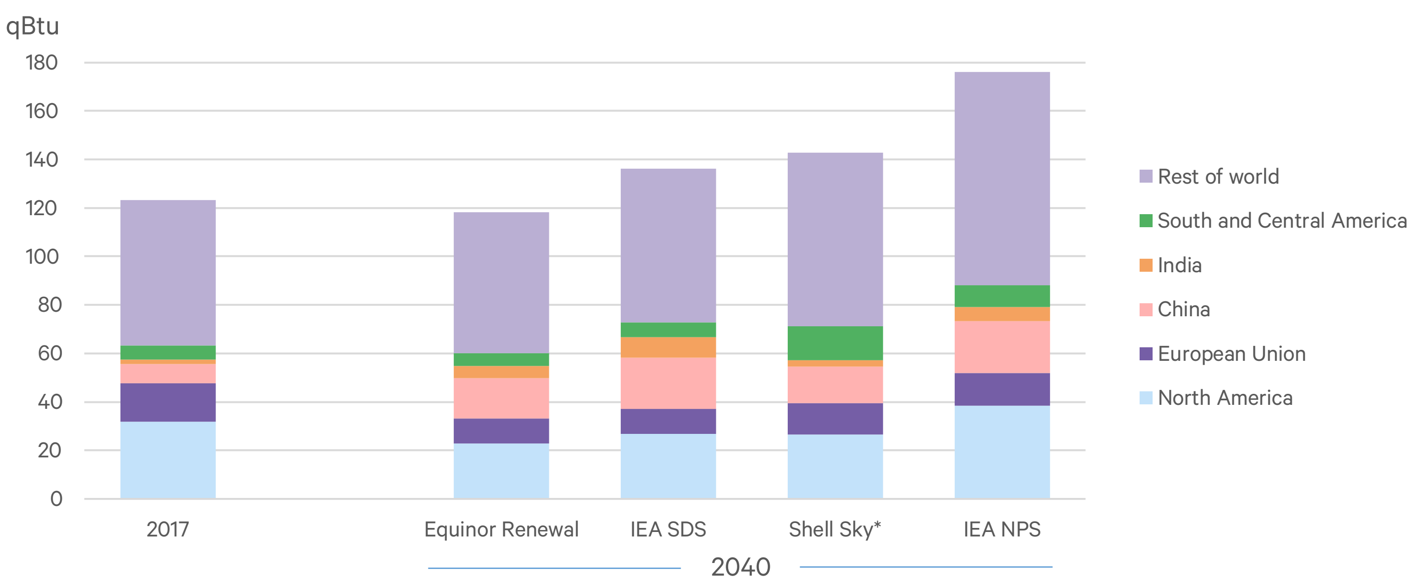


Under most Reference and Evolving Policies scenarios, natural gas demand grows across nearly every region, with the exception of the EU and Japan, where consumption is roughly flat in a number of scenarios, and declines by 10% to 20% in the IEA NPS and Exxon Mobil's Outlook.

However, under Ambitious Climate scenarios, the prospects for natural gas diverge across regions. In North America, Shell Sky and IEA SDS project declines of roughly 16%, while Equinor Renewal sees demand declining by 28%. In the European Union, gas consumption falls by roughly 35% under IEA SDS and Equinor Renewal, while Shell Sky projects total European consumption declining by 18% (EU data are not available for Shell Sky).

In developing regions, natural gas consumption generally grows rapidly, but with substantial differences between outlooks. In China, consumption more than doubles in IEA SDS and Equinor Renewal and grows by 91% under Shell Sky. In South and Central America, Shell Sky projects growth of 140%, while Equinor Renewal and the IEA SDS see relatively small changes in demand. In India, Equinor Renewal and IEA SDS are more bullish on gas, projecting growth of 153% and 331%, respectively, while Shell Sky projects growth of just 46%, with more demand growth met by coal (Fig. 16).

Figure 16. Regional Natural Gas Demand under Select Scenarios



Notes: 2017 data via IEA. Shell Sky “European Union” category includes all of Europe.

4. Data and Methods

In this paper, we examine projections from the following publications:

- International Energy Agency: *World Energy Outlook 2018*, November 2018
- US Energy Information Administration: *International Energy Outlook 2017*, September 2017
- ExxonMobil: *Outlook for Energy 2018*, February 2018
- BP: *Energy Outlook 2018*, February 2018
- OPEC: *World Oil Outlook 2018*, September 2018
- Shell: *Sky Scenario*, published in April 2018
- Bloomberg New Energy Finance (BNEF): *New Energy Outlook 2018*, June 2018
- Equinor: *Energy Perspectives 2018*, June 2018
- Institute for Energy Economics, Japan: *Outlook 2019*, October 2018

These outlooks vary due to a variety of factors, including distinct modeling techniques, different historical data, varying economic growth assumptions, and a variety of policy scenarios. Generally, policy scenarios can be grouped into three categories: (1) Reference scenarios, which assume no major policy changes; (2) Evolving Policies scenarios, which incorporate the modeling team's expectations of policy trends; and (3) alternative scenarios, which are typically based on certain policy targets or technology assumptions. Each of these approaches are represented in the outlooks we examine, summarized in Table 5 below.

Table 5. Outlooks and Scenarios

Author	Scenario(s)	Description
Grubler[1]	-	Historical data
IEA[2]	-	Historical data
BNEF[3]	[unnamed central scenario]	Power sector only. Based on internal views on technological change, which drives the development of markets and business models.
BP[4]	Evolving Transition	The main focus of BP's outlook, but just one of a number of scenarios examined the outlook. Policies, technologies, and social preferences continue to evolve along recent trends.
Equinor[5]	Rivalry, Reform, Renewal	Rivalry: Global geopolitical disputes continue, resulting in slower economic growth and more limited climate policies. Reform: Markets and technologies continue along recent trends, 2015 Paris INDCs form policy "backbone." Renewal: Ambitious policies push the energy system towards limiting warming to 2°C by 2100.
ExxonMobil[6]	[unnamed central scenario]	Based on internal views on technology and policy evolution.
IEA	Current Policies, New Policies, Sustainable Development	CPS: No new policies NPS: Includes existing and announced policies, including climate targets. SDS: Achieves UN Sustainable Development Goals, including universal access to energy, reduced air and water pollution, consistent with 1.7-1.8°C warming by 2100.
IEEJ[8]	Reference	No new policies
OPEC[9]	Reference	Incorporates policies that have been enacted, assumes some future policy changes.
Shell[10]	Sky	Achieves Paris target of "well below" 2°C warming by 2100, includes carbon pricing, large changes in consumer demand, energy efficiency, CCS, new energy technologies, and more.
US EIA[11]	Reference	No new policies

4.1. Harmonization

Different scenarios and modeling assumptions produce useful variation between outlooks, allowing analysts to view a wide range of potential energy futures. However, outlooks also have a variety of important methodological differences, which can make direct comparison between outlooks challenging and complicate a reader's ability to draw insights.

One key difference between outlooks is the choice of reporting units. For primary energy, outlooks use different energy units such as quadrillion (10^{15}) British thermal units (qBtu), million tonnes of oil equivalent (mtoe), or terajoules (TJ). In this report, we standardize all units to qBtu. For fuel-specific data, outlooks also vary, using units such as million barrels per day (mbd) or million barrels of oil-equivalent per day (mboed) for liquid fuels, billion cubic meters (bcm) or trillion cubic feet (tcf) for natural gas, and million tonnes of coal-equivalent (mtce) or short tons for coal. Table 6 presents these different reporting units for each outlook examined here, and provides relevant conversion factors.

Table 6. Units of Energy Consumption Used in Different Outlooks

	IEA	BP	Exxon-Mobil	US EIA	OPEC	Equinor	IEEJ	Shell
Primary energy units	mtoe	mtoe	qBtu	qBtu	mboed	Btoe	mtoe	EJ
Fuel/sector-specific units								
Liquids	mbd	mbd	mboed	mbd	mbd	mbd	N.A.	N.A.
Oil	mbd	mbd	mboed	mbd	mbd	N.A.	mboed	N.A.
Biofuels	mboed	mboed	mboed	mbd	mbd	N.A.	N.A.	N.A.
Natural gas	bcm	bcfd	bcfd	tcf	mboed	bcm	bcm	N.A.
Coal	mtce	btoe	N.A.	short ton	mboed	N.A.	N.A.	N.A.
Electricity	TWh	TWh	TWh	TWh	N.A.	TWh	TWh	N.A.

Note: Units are per year unless otherwise noted. "N.A." indicates that fuel-specific data are not available for a given source. See Newell and Raimi (2019) for more details.[21]

Table 7. Conversion Factors for Key Energy Units

Primary energy	Multiply by	Natural gas	Multiply by	Coal	Multiply by
mtoe to qBtu	0.0397	bcm to bcfd	0.0968	mtce to short ton	1.102
mboed[1] to qBtu	1.976	bcm to tcf	0.0353	mtce to mtoe	0.7
EJ to qBtu	0.948				

Notes: (1) There is no agreed-upon factor for barrels of oil equivalent. The IEA reports that typical factors range from 7.15 to 7.40 boe per toe, and OPEC uses a conversion factor of 7.33 boe per toe. We derive 1.976 qBtu/mboed by multiplying 49.8 mtoe/mboed (=1 toe / 7.33 boe * 365 days per year) by 0.03968 qBtu/mtoe.

A second key difference between outlooks is assumptions about the energy content of fossil fuels. Different assumptions about the energy content in a given physical unit of fuel result in different conversion factors between data presented in energy units (e.g., mtoe) from those presented in physical units (e.g., mbd or bcm). Among the outlooks we examine, these assumptions can vary by up to 11%.[1] While these differences in conversion units may appear small, they can produce significant differences when applied across the massive scale of global energy systems, and particularly over multi-decade time horizons.

Another important difference results from varying decisions over whether to include non-marketed biomass such as wood or dung in historical data and projections for primary energy consumption. BP and the US EIA do not include non-marketed biomass in their outlooks, unlike all other organizations examined in this report. The inclusion of these fuels can yield an 8% to 11% difference in global primary energy consumption.

A third major difference relates to comparing the energy content of fossil fuels with non-fossil fuels. The primary energy content of oil, natural gas, and coal is relatively well understood and similar across outlooks. However, a substantial portion of that embodied energy is wasted as heat during fossil fuel combustion. Because non-fossil fuels such as hydroelectricity, wind, and solar do not generate substantial amounts of waste heat, identifying a comparable metric for primary energy is difficult, and outlooks take a variety of approaches.

Other differences in outlooks include, but are not limited to: (1) different categorizations for liquids fuels and renewable energy; (2) different regional

1 For example, the US EIA use gross calorific values (GCV) when reporting the energy content of natural gas, while the IEA and other organizations use net calorific values (NCVs), contributing to this large difference.

groupings for presenting aggregated data and projections; (3) the use of net versus gross calorific values when reporting energy content of fossil fuels; (4) the use of net versus gross generation when reporting electricity data; and (5) whether and how to include flared natural gas in energy consumption data.

To address these challenges, Newell and Iler[16] apply a harmonization process to allow for more accurate comparison across outlooks. We update and apply that process here. For details, see Newell and Raimi (2019).[21]

5. Key Statistics

This section provides a variety of key statistics for global and regional energy projections. It primarily uses IEA historical data as a baseline. IEA historical data are available through year 2017, but we use 2015 as a base year to create consistent 25-year increments (i.e., 1940, 1965, 1990, 2015, 2040), providing historical context.

Table 8. Key Global Indicators

	Population	Energy	GDP	Net CO_2	GDP/ Capita	Energy/ GDP	Energy/ Capita	Net CO_2/ Energy
	Millions	qBtu	$T, 2017 at PPP	BMT	$1,000/ person	1,000 Btu/$	1,000 Btu/ person	MMT/qBtu
2015	7,358	546	116	32.3	15.7	4.7	74.1	59.2
2040								
BP	9,200	637	264	37.3	28.7	2.4	69.2	58.5
US EIA	8,993	614	244	39.3	27.2	2.5	68.3	64.0
Equinor Reform	9,210	659	-	32.8	-	-	71.6	49.8
Equinor Renewal	9,210	534	-	19.2	-	-	58.0	35.9
Equinor Rivalry	9,210	684	-	38.3	-	-	74.3	55.9
ExxonMobil	9,200	681	-	36.3	-	-	74.0	53.4
IEA CPS	9,172	767	275	42.5	30.0	2.8	83.6	55.4
IEA NPS	9,172	703	275	35.8	30.0	2.6	76.6	50.9
IEA SDS	9,172	544	275	15.3	30.0	2.0	59.3	28.1
IEEJ	9,172	717	-	40.4	-	-	78.2	56.4
OPEC	9,210	721	266	-	28.9	2.7	78.3	-
Shell Sky	9,043	711	257	28.7	28.5	2.8	78.6	40.4

Notes: 2015 data from IEA. BP and EIA exclude non-marketed biomass energy, which is included in all other outlooks. Equinor, ExxonMobil, and IEEJ do not produce GDP estimates in PPP terms, but instead use Market Exchange Rate (MER).

Table 9. World Primary Energy Consumption

qBtu	Total	Coal	Oil	Natural gas	Nuclear	Hydro	Other renewables
1940	85	35	11	4	0	1	34
1965	184	59	66	27	0.4	3	30
1990	350	88	131	66	21	7	38
2015 (incl. non-marketed biomass)	546	152	176	117	27	13	60
2040 (incl. non-marketed biomass)							
Equinor Reform	659	139	198	152	36	18	117
Equinor Renewal	534	67	142	118	42	20	145
Equinor Rivalry	684	177	219	146	30	18	95
ExxonMobil	681	138	217	175	46	19	87
IEA CPS	767	189	228	191	38	20	108
IEA NPS	703	151	203	176	39	21	101
IEA SDS	544	63	139	136	51	24	113
IEEJ	717	173	220	175	34	18	130
OPEC	721	160	205	180	45	20	97
Shell Sky	711	123	182	143	61	17	186
2015 (excl. non-marketed biomass)	490	151	175	115	26	13	152
2040 (excl. non-marketed biomass)							
BP	637	156	199	170	42	19	51
US EIA	614	153	207	164	38	19	33

Note: Historical data from Grubler (1940, 1965 [interpolated from 1960 and 1970 data]), IEA (1990 and 2015 including non-marketed biomass) and US EIA (2015 excluding non-marketed biomass).

Table 10. Regional Liquids Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	121	-	-	86	-	-	35	-	-
2015	172	2.1	1.4%	90	0.2	0.2%	82	1.9	3.5%
2040									
BP	199	1.1	0.6%	81	-0.3	-0.4%	117	1.4	1.4%
US EIA	207	1.4	0.7%	91	0.1	0.1%	115	1.3	1.4%
Equinor Reform	198	1.0	0.6%	-	-	-	-	-	-
Equinor Renewal	142	-1.2	-0.8%	-	-	-	-	-	-
Equinor Rivalry	219	1.9	1.0%	-	-	-	-	-	-
ExxonMobil	217	1.8	0.9%	-	-	-	-	-	-
IEA CPS	228	2.2	1.1%	84	-0.2	-0.2%	117	1.4	1.4%
IEA NPS	203	1.2	0.7%	75	-0.6	-0.7%	104	0.9	0.9%
IEA SDS	139	-1.3	-0.8%	51	-1.5	-2.2%	72	-0.4	-0.5%
IEEJ	220	1.9	1.0%	-	-	-	-	-	-
OPEC	205	1.3	0.7%	87	-0.1	-0.1%	118	1.4	1.5%
Shell Sky	182	0.4	0.2%	64	-1.0	-1.3%	108	1.0	1.1%

Note: Global liquids consumption values may not equal to the sum of West and East because international marine bunkers and international aviation are not included in regional groupings for some outlooks. Regional data for ExxonMobil and IEEJ are excluded due to insufficient regional biofuels data. Historical data from IEA.

Table 11. Regional Natural Gas Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	66	-	-	55	-	-	9	-	-
2015	117	2.0	2.3%	74	0.8	1.2%	43	1.3	6.3%
2040									
BP	170	2.1	1.5%	88	0.6	0.7%	82	1.6	2.6%
US EIA	164	1.9	1.4%	84	0.4	0.5%	79	1.4	2.5%
Equinor Reform	152	1.4	1.0%	-	-	-	-	-	-
Equinor Renewal	146	1.2	0.9%	-	-	-	-	-	-
Equinor Rivalry	118	0.1	0.0%	-	-	-	-	-	-
ExxonMobil	175	2.3	1.6%	88	0.6	0.7%	87	1.8	2.9%
IEA CPS	191	3.0	2.0%	97	0.9	1.1%	93	2.0	3.1%
IEA NPS	176	2.4	1.7%	88	0.6	0.7%	87	1.7	2.8%
IEA SDS	136	0.8	0.6%	64	-0.4	-0.6%	72	1.1	2.1%
IEEJ	175	2.3	1.6%	89	0.6	0.7%	85	1.7	2.7%
OPEC	180	2.5	1.8%	-	-	-	-	-	-
Shell Sky	143	1.0	0.8%	74	0.0	0.0%	67	1.0	1.8%

Note: Historical data from IEA.

Table 12. Regional Coal Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1965	55	-	-	45	-	-	10	-	-
1990	88	1.3	1.8%	52	0.3	0.6%	36	1.0	5.1%
2015	152	2.4	2.1%	37	-0.6	-1.3%	115	2.9	4.4%
2040									
BP	156	0.2	0.1%	17	-0.9	-3.1%	139	1.1	0.8%
US EIA	153	0.0	0.0%	30	-0.2	-0.8%	122	0.3	0.2%
Equinor Reform	139	-0.5	-0.4%	-	-	-	-	-	-
Equinor Renewal	67	-3.0	-3.2%	-	-	-	-	-	-
Equinor Rivalry	177	0.9	0.6%	-	-	-	-	-	-
ExxonMobil	138	-0.5	-0.4%	17	-0.7	-3.1%	121	0.2	0.2%
IEA CPS	189	1.3	0.9%	30	-0.3	-0.9%	159	1.6	1.3%
IEA NPS	151	0.0	0.0%	24	-0.5	-1.8%	128	0.5	0.4%
IEA SDS	63	-3.2	-3.4%	9	-1.0	-5.7%	55	-2.1	-2.9%
IEEJ	173	0.9	0.5%	26	-0.5	-1.4%	147	1.4	1.0%
OPEC	160	0.3	0.2%	-	-	-	-	-	-
Shell Sky	123	-1.0	-0.8%	14	-0.8	-3.8%	109	-0.2	-0.2%

Note: Historical data from IEA (1990) and Grubler (1965).

Table 13. Regional Nuclear Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	21	-	-	18	-	-	3	-	-
2015	27	0.2	1.1%	22	0.2	1.0%	5	0.1	1.8%
2040									
BP	42	0.6	2.3%	18	-0.2	-0.7%	23	0.8	16.5%
US EIA	38	0.5	1.7%	19	-0.1	-0.6%	19	0.6	12.9%
Equinor Reform	36	0.4	1.4%	-	-	-	-	-	-
Equinor Renewal	42	0.6	2.3%	-	-	-	-	-	-
Equinor Rivalry	30	0.1	0.5%	-	-	-	-	-	-
ExxonMobil	46	0.8	2.9%	23	0.0	0.2%	23	0.7	16.3%
IEA CPS	38	0.4	1.7%	20	-0.1	-0.3%	18	0.5	11.4%
IEA NPS	39	0.5	1.8%	19	-0.1	-0.5%	19	0.6	13.0%
IEA SDS	51	1.0	3.7%	24	0.1	0.4%	27	0.9	19.5%
IEEJ	34	0.3	1.1%	19	-0.1	-0.6%	15	0.4	8.1%
OPEC	45	0.7	2.7%	-	-	-	-	-	-
Shell Sky	62	1.4	5.1%	23	0.1	0.2%	33	1.3	28.7%

Note: Historical data from IEA.

Table 14. Regional Renewables (incl. Hydro) Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	45	-	-	16	-	-	29	-	-
2015 (incl. non-marketed biomass)	74	1.2	2.6%	28	0.5	3.0%	46	0.7	2.3%
2040 (incl. non-marketed biomass)									
Equinor Reform	135	2.4	3.3%	-	-	-	-	-	-
Equinor Renewal	165	3.6	4.9%	-	-	-	-	-	-
Equinor Rivalry	113	1.6	2.1%	-	-	-	-	-	-
ExxonMobil	105	1.3	1.7%	-	-	-	-	-	-
IEA CPS	122	1.9	2.6%	44	0.6	2.2%	78	1.3	2.8%
IEA NPS	134	2.4	3.3%	47	0.8	2.7%	87	1.7	3.6%
IEA SDS	154	3.2	4.4%	60	1.3	4.5%	92	1.9	4.1%
IEEJ	116	1.7	2.3%	44	0.6	2.2%	71	1.0	2.2%
OPEC	130	2.3	3.1%	-	-	-	-	-	-
Shell Sky	202	5.1	7.0%	82	2.2	8.4%	121	3.0	6.8%
2015 (excl. non-marketed biomass)	24			15			9		
2040 (excl. non-marketed biomass)									
BP	70	1.8	7.7%	31	0.7	4.4%	39	1.2	13.0%
US EIA	52	1.1	4.7%	26	0.5	3.1%	26	0.7	7.4%

Note: Historical data from IEA (including marketed biomass) and US EIA (excluding marketed biomass).

Table 15. Regional Non-Hydro Renewables Consumption

qBtu	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	38	-	-	10	-	-	27	-	-
2015 (incl. non-marketed biomass)	60	0.9	2.4%	21	0.4	4.0%	40	0.5	1.8%
2040 (incl. non-marketed biomass)									
Equinor Reform	117	2.3	3.7%	-	-	-	-	-	-
Equinor Renewal	145	3.4	5.6%	-	-	-	-	-	-
Equinor Rivalry	95	1.4	2.3%	-	-	-	-	-	-
ExxonMobil	87	1.1	1.7%	-	-	-	-	-	-
IEA CPS	101	1.6	2.7%	33	0.5	2.3%	68	1.1	2.9%
IEA NPS	113	2.1	3.5%	37	0.6	3.0%	76	1.5	3.7%
IEA SDS	130	2.8	4.6%	49	1.1	5.3%	80	1.6	4.0%
IEEJ	97	1.5	2.4%	35	0.6	2.7%	61	0.9	2.2%
OPEC	111	2.0	3.3%	-	-	-	-	-	-
Shell Sky	186	5.0	8.3%	72	2.0	9.7%	114	3.0	7.5%
2015 (excl. non-marketed biomass)	11			7			4		
2040 (excl. non-marketed biomass)									
BP	51	1.6	15.1%	22	0.6	8.3%	29	1.0	28.5%
US EIA	33	0.9	8.2%	16	0.4	5.0%	17	0.5	14.6%

Note: Historical data from IEA (including marketed biomass) and US EIA (excluding marketed biomass).

Table 16. Global Electricity Generation

TWh	Coal	Natural gas	Hydro	Nuclear	Other renewables	Oil
1990	4,403	1,752	2,142	2,013	172	1,242
2015	9,524	5,543	3,888	2,571	1,720	843
2040						
BNEF	7,355	5,849	5,443	2,869	15,456	266
US EIA[1]	10,388	8,770	5,678	3,657	5,024	531
Equinor Reform	10,450	10,050	5,550	3,400	16,500	700
Equinor Renewal	4,350	6,900	5,900	4,200	23,950	350
Equinor Rivalry	12,050	9,650	5,200	3,050	10,950	700
IEA CPS	13,910	10,295	5,973	3,648	8,288	610
IEA NPS	10,335	9,071	6,179	3,726	10,573	527
IEA SDS	1,982	5,358	6,990	4,960	17,595	197
IEEJ	13,096	11,012	5,415	3,287	7,074	992
Shell Sky	6,261	8,927	4,210	5,287	23,682	418

Note: Historical data from IEA. (1) US EIA reports net electricity generation, while other organizations report gross generation.

Table 17. Global Renewable Electricity Consumption

TWh	Hydro	Biomass/ waste	Wind	Solar	Other	Total
1990	2,142	131	-	-	5	2,278
2015	3,888	528	-	-	1,111[1]	5,528
2040						
BNEF	5,443	718	6,169	8,445	140	20,899
BP	5,485	1,240	4,123	4,806	310	15,654
US EIA[2]	5,678	-	1,390	2,525	756	10,349
Equinor Reform	5,550	1,500	4,350	5,500	800	17,700
Equinor Renewal	5,900	2,000	6,400	7,900	1,250	23,450
Equinor Rivalry	5,200	1,200	2,850	3,500	550	13,300
ExxonMobil	5,426	-	-	3,927	6,582[3]	15,935
IEA CPS	5,973	1,228	3,075	3,679	306	14,261
IEA NPS	6,179	1,427	4,061	4,690	395	16,752
IEA SDS	6,990	1,968	7,264	7,730	633	24,585
IEEJ	5,415	1,182	1,923	3,501	468	12,489
Shell Sky	4,210	2,471	8,279	12,423	509	27,892

Note: "-" indicates data not available. (1) includes wind and solar. (2) US EIA reports net electricity generation, while other organizations report gross generation. (3) includes wind and biomass.

Table 18. Global Energy-Related Gross Carbon Dioxide Emissions

	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	BMT	BMT	CAAGR	BMT	BMT	CAAGR	BMT	BMT	CAAGR
1990	20.5			13.9			6.0		
2015	32.3	0.47	2.30%	13.0	-0.04	-0.27%	18.2	0.49	8.12%
2040									
BP	37.3	0.20	0.61%	12.1	-0.04	-0.28%	25.2	0.28	1.55%
US EIA	39.3	0.28	0.87%	14.3	0.05	0.40%	25.0	0.28	1.52%
Equinor Reform	32.8	0.02	0.06%						
Equinor Renewal	19.2	-0.52	-1.62%						
Equinor Rivalry	38.3	0.24	0.74%						
ExxonMobil	36.3	0.16	0.50%	12.4	-0.02	-0.18%	23.9	0.23	1.27%
IEA CPS	42.5	0.41	1.26%	13.0	0.00	0.01%	27.4	0.37	2.03%
IEA NPS	35.9	0.14	0.44%	11.1	-0.08	-0.58%	22.9	0.19	1.05%
IEA SDS	17.6	-0.59	-1.81%	5.9	-0.28	-2.19%	10.7	-0.30	-1.63%
IEEJ	40.4	0.32	1.00%	12.3	-0.03	-0.20%	26.3	0.33	1.79%
Shell Sky	28.7	-0.14	-0.44%	8.6	-0.18	-1.36%	19.3	0.04	0.24%

Note: Historical data from IEA.

References

1. Grubler, A. "Energy Transitions." *Encyclopedia of Earth* (Environmental Information Coalition, National Council for Science and the Environment, 2008).
2. International Energy Agency. IEA World Energy Statistics and Balances. (2018). Available at: **https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en**.
3. Bloomberg New Energy Finance. *New Energy Outlook 2018*. (2018).
4. BP. *Energy Outlook 2018*. (2018).
5. Equinor. *Energy Perspectives*. (2018).
6. ExxonMobil. *Outlook for Energy: A View to 2040*. (2018).
7. International Energy Agency. *World Energy Outlook 2018*. (2018).
8. Institute of Energy Economics, Japan. *Outlook 2019: Energy transition and a thorny path for 3E challenges*. (2018).
9. OPEC. *World Oil Outlook*. (2018).
10. Shell. *Sky Scenario*. (2018).
11. US Energy Information Administration. *International Energy Outlook*. (2017).
12. Global CCS Institute. *Global Status Report*. (2018).
13. International Energy Agency. *Electricity Information 2018*. (International Energy Agency, 2018).
14. Gilbert, A. Q. & Sovacool, B. K. "Looking the wrong way: Bias, renewable electricity, and energy modelling in the United States." *Energy* 94, 533–541 (2016).
15. Daniels, D. & Namovicz, C. *On Inaccuracies in a Published Journal Article*. (US Energy Information Administration Working Paper Series, 2016).
16. Newell, R. G. & Iler, S. *The Global Energy Outlook*. (National Bureau of Economic Research, 2013). doi:10.3386/w18967
17. International Energy Agency. *Global EV Outlook 2018: Towards Cross-Modal Electrification*. (International Energy Agency, 2018).
18. Bloomberg New Energy Finance. *Electric Vehicle Outlook 2018*. (2018).
19. Alvarez, R. A. *et al*. "Assessment of methane emissions from the US oil and gas supply chain." *Science* (2018). doi:10.1126/science.aar7204
20. Tanaka, K., Cavalett, O., Collins, W. J. & Cherubini, F. "Asserting the climate benefits of the coal-to-gas shift across temporal and spatial scales." *Nature Climate Change* 1 (2019). doi:10.1038/s41558-019-0457-1
21. Newell, R. & Raimi, D. *Global Energy Outlook Comparison Methods: 2019 Update*. Report 19-07, Resources for the Future (2019).