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Global Energy Outlook 2020: Energy Transition or Energy Addition?

With Commentary on Implications of the COVID-19 Pandemic

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About the Global Energy Outlook 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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About Resources for the Future

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Abstract

Global energy consumption has grown rapidly over the past century, driven by an expanding population and increasing prosperity. Demand has risen for virtually all sources—coal, oil, natural gas, nuclear energy, and renewables. These “additions” to the global energy system reflect broadly positive trends of higher living standards, decreasing global poverty, and longer livelihoods. At the same time, rising fossil fuel consumption is the leading cause of global climate change and creates other major environmental challenges. To address these challenges, the global energy system will need to undergo a clean energy transition, whereby sources of energy that emit greenhouse gases are replaced by increasingly cleaner sources. In this annual report, we review and compare—on an apples-to-apples basis—recent long-term projections from some of the world’s leading energy institutions. These projections suggest that the world may be on the cusp of its first true energy transition, but also that more ambitious public policies and technological innovations are needed to satisfy the energy demands of the world’s growing population while also achieving long-term environmental goals. As the projections presented here were all generated well before the onset of COVID-19, they do not reflect the unprecedented global changes that have occurred in recent months. However, throughout the paper, we have added discussion boxes to address how COVID-19 might affect the projections presented, particularly in the short run.

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1. Introduction

The global energy system has grown rapidly since the industrial revolution, and that growth has accelerated considerably over the past 50 years. The next several decades may see large-scale changes in the energy system, particularly in light of global climate change. However, the magnitude and direction of many of these changes are highly uncertain.

Long-term energy projections vary widely, depending on underlying assumptions and methodologies. This report provides a unique apples-to-apples comparison of projections and addresses the full scope of potential changes to the energy system as envisioned by some of its most knowledgeable organizations. The outlooks and scenarios included are shown in Table 1.

Table 1. Outlooks and Scenarios

Source	Outlook	Scenario(s)	Years
Grubler[1]	Historical	—	1800–1970
IEA[2]	Historical	—	1970–2015
BNEF[3]	New Energy Outlook 2019	[unnamed central scenario]	To 2050
BP[4]	Energy Outlook 2019	Evolving Transition, Rapid Transition	To 2040
Equinor[5]	Energy Perspectives 2019	Reform, Renewal, Rivalry	To 2050
ExxonMobil[6]	Outlook for Energy 2019	[unnamed central scenario]	To 2040
IEA[7]	World Energy Outlook 2019	Current Policies (CPS), Stated Policies (STEPS), Sustainable Development (SDS)	To 2040
IEEJ[8]	Outlook 2020	Reference	To 2050
OPEC[9]	World Oil Outlook 2019	Reference	To 2040
Shell[10]	Shell Scenarios 2018	Sky	To 2100
US EIA[11]	International Energy Outlook 2019	Reference	To 2050

A brief description of our methodology is provided under Data and Methods (Section 4), with select data indicators under Statistics (Section 5). For the full methodology, data set, and interactive graphing tools, visit **www.rff.org/geo** and see Newell and Raimi.[12]

We use a consistent labeling system that distinguishes among the different scenarios (Table 2). For "Reference" scenarios, which assume no new policies, and for Equinor's Rivalry scenario, which assumes continued geopolitical challenges, we use a dashed line: this set comprises US EIA, Equinor Rivalry, IEA CPS, IEEJ, and OPEC. For "Evolving Policies" scenarios, which assume that policies and technologies develop according to recent trends and/or the expert views of the team producing the outlook, we use solid lines: this set comprises BNEF (which only includes electricity), BP Evolving Transition, Equinor Reform, ExxonMobil, and IEA STEPS. For "Ambitious Climate" scenarios, which are built around achieving climate goals articulated in the 2015 Paris Agreement to limit global mean temperature rise to 2°Celsius or lower by 2100, we use dotted lines: this set comprises BP Rapid Transition, Equinor Renewal, IEA SDS, and Shell Sky. For additional detail on scenarios, see Table 4 (page 38).

Table 2. Legend for Different Scenario Types

Reference	Evolving Policies	Ambitious Climate
- - - EIA Reference	—— BNEF	······ BP Rapid Transition
- - - Equinor Rivalry*	—— BP Evolving Transition	······ Equinor Renewal
- - - IEA Current Policies (CPS)	—— Equinor Reform	······ IEA Sustainable Development (SDS)
- - - IEEJ Reference	—— ExxonMobil	······ Shell Sky
- - - OPEC Reference	—— IEA Stated Policies (STEPS)	

Figures and tables in this report frequently refer to regional groupings of "East" and "West." Those regional groupings are provided in Table 3.

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

"East"	Africa, Asia-Pacific, Middle East
"West"	Americas, Europe, Eurasia

1.1. Considering COVID-19: The Global Energy Implications of the Pandemic

All projections come amid significant uncertainty in many forms, including uncertainty in technological development, energy and environmental policy, and socio-economic trajectories. The recent onset of COVID-19, along with government responses to it, is a stark instance of socio-economic uncertainty. COVID-19 has upended everyday life, with broad, and potentially long lasting, implications for economic growth in general and energy demand in particular.

As the projections presented here were all generated well before the onset of COVID-19, they do not reflect the unprecedented global changes that have occurred in recent months. However, throughout the paper, we have added discussion boxes to address how COVID-19 might affect the projections presented, particularly in the short run.

While it is still unclear how long lasting the effects of COVID-19 will be, there is already clear evidence of its immediate impacts. As of the end of April 2020, crude oil prices had **fallen more than 70%** in just two months, amid **cratering** **demand** and stubbornly elevated supply. **Real-time data on electricity use** for the United States has revealed not only falling electricity demand, but also a change its time profile as people change their habits. Similar declines have been seen in **Europe**, coinciding broadly with the timing and stringency of each country's lockdown.

More generally, the International Energy Agency (IEA) recently presented **revised projections**[19] for global energy use in light of the crisis, showing the largest decline in global energy demand since World War II, stretching across every continent. The IEA expects a 6% decline in energy use, leading to an 8% drop in global CO_2 emissions for 2020. However, emissions could rebound in 2021 if economic activity returns to pre-pandemic levels. As a result, this short-term drop associated with COVID-19 may have little appreciable long-term impact on atmospheric carbon concentrations, although it could have ripple effects on the pace of national and global policy responses and decarbonization efforts that persist for many years.

Yet the onset of COVID-19 makes clear the many uncertainties inherent in any forecast. As discussed in detail in section 3.3 (page 34), changes in economic projections can significantly alter the outlook for global energy use as one important element of the "Kaya Identity." In January 2020, the International Monetary Fund (IMF) projected a **3.3%** annual ***rise*** in global economic activity in 2020. Just three months later amid the global spread of COVID-19, the IMF revised its projection to a **3.6%** annual ***decline.*** While the IMF anticipates that economic activity could rebound in 2021, this large change in their forecast over such a small time period reveals the significant uncertainty about future economic activity. This level of uncertainty is largely not reflected by the relatively narrow range of assumed economic growth that is embedded in the economic scenarios presented in this outlook.

Indeed, many energy and emissions modeling efforts do not fully acknowledge the large degree of uncertainty in future economic outcomes. Ideally, such efforts would use approaches such as statistical uncertainty analyses to consider many possible future socio-economic trajectories. This approach requires probabilistic projections, such as those recently developed by economists **Ulrich Müller, James Stock (an RFF University Fellow), and Mark Watson**.[18] Those projections imply substantially more economic uncertainty than most energy and emissions modeling efforts have assumed, which can have important implications for scenario results. For example, RFF is currently leveraging these economic projections to incorporate socio-economic uncertainty into **estimating the Social Cost of Carbon** (SCC). This approach to uncertainty analysis is typically considered best practice, although we understand that it may not always be feasible given the structure of energy-economic models that underlie the projections considered in this paper, or the availability of necessary data. Nonetheless, COVID-19 has demonstrated why economic uncertainty merits careful consideration for modelers and analysts because of its major role in driving energy and emissions outcomes.

In addition to COVID-19's effects on economic activity, the pandemic could also affect energy and emissions outcomes through the other components of the Kaya identity—**energy intensity** of GDP and the **emissions intensity** of energy. For example, the **energy** intensity of GDP could decline if telework becomes more common after the crisis passes. Alternatively, **energy** intensity could rise if commuters increasingly opt for driving single-occupant vehicles to avoid potential exposure on public transportation.

In the short term, the **emissions** intensity of energy could also decline slightly. The **IEA** found some evidence for this, finding that renewable generation supplied a greater share of electricity demand in the first quarter of 2020. This is because wind and solar generation, which are largely driven by weather conditions, remained stable while overall electricity demand fell. The long-run impacts of COVID-19 on emissions intensity are less clear and will depend on whether it encourages more or less rapid decarbonization.

Whatever the short-run uncertainties around COVID-19, it remains to be seen whether the global economy and energy demand will eventually revert to the long-run trajectories anticipated in these modeling efforts. In that case, the model results remain informative about possible future energy outlooks. In any event, the newly salient possibility of extreme events further demonstrates the value of considering a range of projections, side by side and on an apples-to-apples basis.

2. Key Findings

Most projections show continued additions to the energy system across fuels other than **coal**, but most Ambitious Climate scenarios envision a transition away from carbon-intensive fuels. At a global scale, coal declines and **liquids** grow across most scenarios, **natural gas** grows across all scenarios, and **renewables** grow to rival and—in Ambitious Climate scenarios—surpass some fossil sources (Figure 1).

Historically, the world's appetite for every major fuel source has grown over time. Although the relative shares of the energy mix have changed substantially, aggregate levels of consumption have only increased for **biomass**, **coal**, **oil**, **natural gas**, and other sources. However, the challenge of climate change calls for a new narrative.

Under Reference scenarios, the global story of energy additions continues, with **coal** growing modestly while **oil**, **natural gas**, and **renewables** all grow strongly.

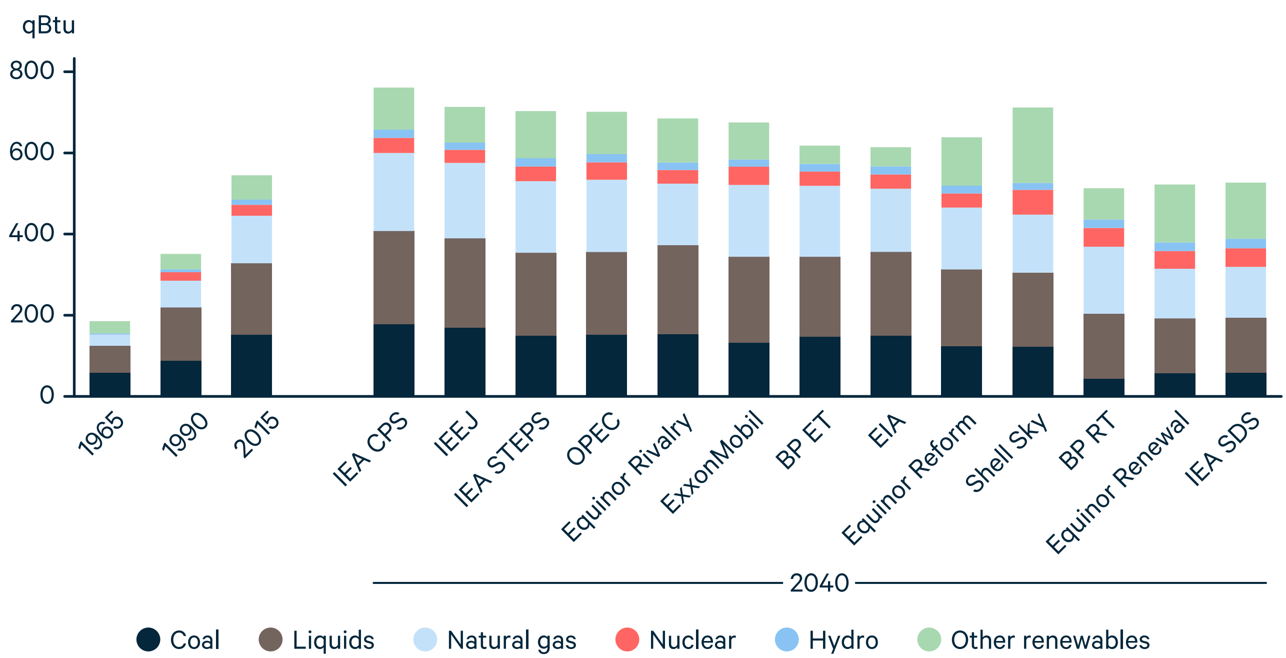
Under Evolving Policies scenarios, coal declines while oil grows more slowly. For most Ambitious Climate scenarios, coal and oil decline in absolute terms, natural gas grows modestly, and renewables take a new leading role. In several Ambitious Climate scenarios, global energy demand *declines* through 2040 despite a growing population and economy.

In Europe and North America, signs of a true energy transition have emerged and are projected to continue across scenarios, as **coal** and **liquids** consumption declines while **renewables** grow rapidly.

CONSIDERING COVID-19

The sharp contraction in GDP and deep reductions in travel resulting from the COVID-19 pandemic will reduce global energy demand dramatically in the near term. The IEA estimates that primary energy demand in 2020 could decline for oil (-9%), coal (-8%), natural gas (-5%), and nuclear (-2%), while renewables grow by 1%.

Figure 1. Levels of Global Primary Energy Consumption, by Fuel



Notes: Scenarios are ordered in decreasing levels of fossil energy. BP and US EIA exclude nonmarketed biomass energy (e.g., wood, dung); others include this in "other renewables."

Despite ambitious goals for limiting climate change under the 2015 Paris Agreement, global **carbon dioxide** (CO_2) emissions continue to rise. Projections indicate that the Paris targets will not be reached without substantial new policies along with widespread deployment of low-, zero-, and potentially negative-emissions technologies (Figure 2).

From 1998 through 2018, global energy-related **CO_2 emissions** grew by 48%. Over the next 20 years, most Ambitious Climate scenarios suggest that emissions will need to decline at roughly the same rate to align with international climate goals. Shell's Sky offers a different view, with reductions of just 14% through 2040, followed by deeper cuts and large-scale negative emissions in the second half of the 21st century. All these scenarios include large-scale use of carbon capture and storage (**CCS**) technology.

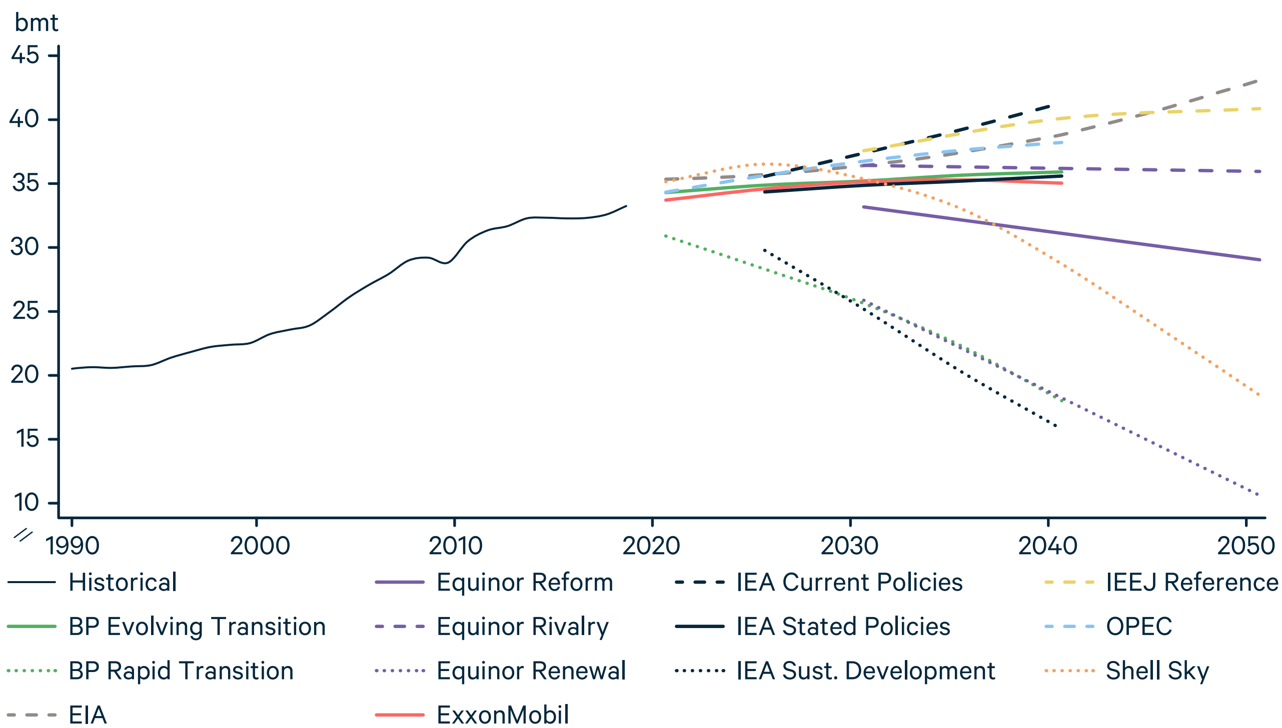
Evolving Policy scenarios from BP, ExxonMobil, and IEA project incremental growth in annual emissions, rising from 33 billion metric tons (BMT) of **CO_2** in 2018 to roughly 35 BMT by 2040. Equinor's Reform scenario shows emissions falling to 31 BMT by 2040.

Reference scenarios reflect the least ambitious climate policies, which lead to emissions growth at rates similar to those observed through the 2010s. Under the IEA and IEEJ Reference cases, emissions surpass 40 BMT **CO_2** by 2040, compared with roughly 38 BMT for US EIA and OPEC. Equinor's Rivalry and US EIA's Reference scenarios show slower emissions growth, in part because of slower global **GDP** growth.

CONSIDERING COVID-19

Reduced fossil energy consumption in 2020 is leading to lower CO_2 emissions. The IEA estimates that emissions could fall by roughly 8% this year, roughly returning to their 2010 levels. However, absent substantial changes in public policies to address climate change, a return to economic growth likely means a return to emissions growth.

Figure 2. Global Net Carbon Dioxide Emissions



Note: Net emissions are the sum of gross CO_2 emissions plus negative emissions from technologies such as biomass with carbon capture or direct air capture.

From 1940 to 1965, global **primary energy** demand grew by roughly 100 qBtu, and from 1990 to 2015, it grew by 196 qBtu. Most projections anticipate slower growth over the next generation. Under all Reference and Evolving Policies scenarios other than the IEA CPS, global demand increases by between 100 and 170 qBtu by 2040 (Figure 3).

Despite this slower growth, global **energy demand** increases considerably across almost all scenarios. The strongest growth occurs under the IEA CPS, where demand is 34% higher than 2018 levels by 2040. Other Reference scenarios project growth of 26% (IEEJ) and 24% (OPEC), while US EIA shows growth of just 20% (using comparable baseline data, which for BP and US EIA exclude nonmarketed biomass, such as locally-gathered wood and dung).

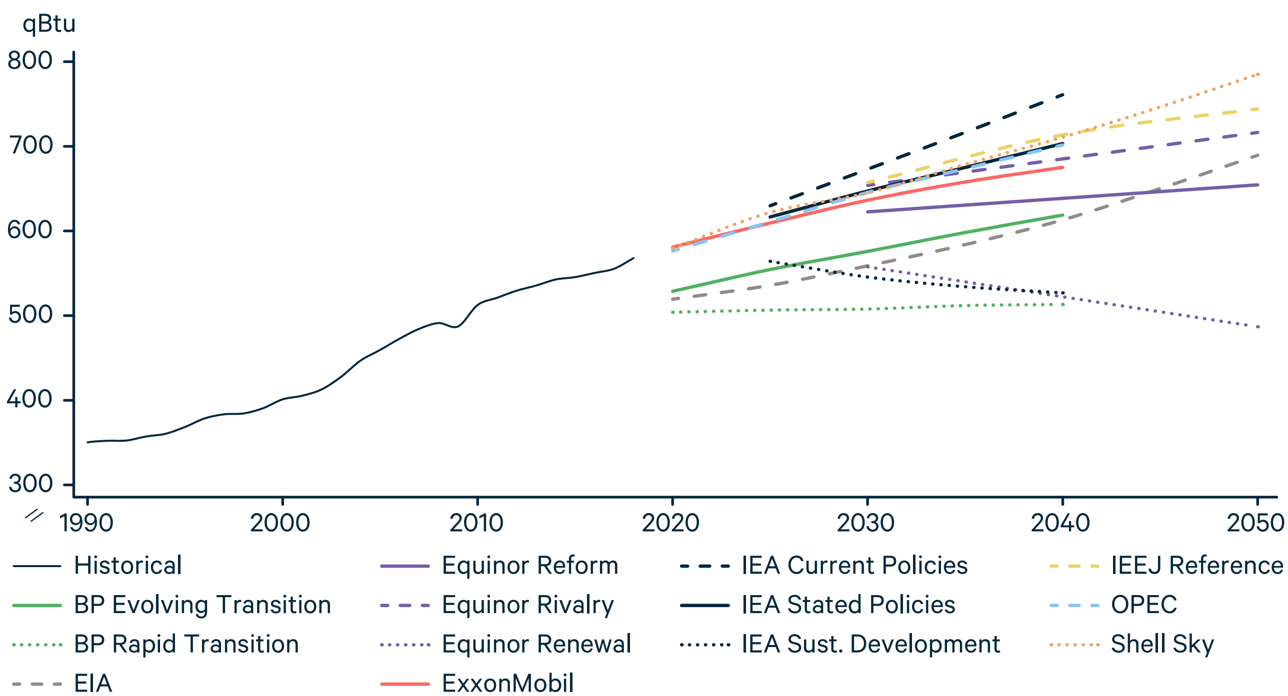
Evolving Policies scenarios project growth ranging from 19% (ExxonMobil) to 24% (IEA STEPS). As we discuss in Section 3.3, energy demand growth is heavily influenced by assumptions about the global **population** and **economy**, as well as modeling choices regarding the **energy intensity** of gross domestic product (GDP).

Considerable variation emerges across Ambitious Climate scenarios. Under Shell's Sky, global **energy demand** grows at rates similar to Reference scenarios, increasing by 25% above 2018 levels by 2040, and includes a relatively large role for **fossil fuels**. Other Ambitious Climate scenarios chart a starkly different path. In BP's Rapid Transition, global demand grows by just 2% through 2040, while **total energy** consumption declines by 7% under IEA's SDS and 8% in Equinor's Renewal.

CONSIDERING COVID-19

The IEA estimates that global primary energy demand declined by 3.8% in the first quarter of 2020, and that annual demand could decline by 6%, far greater than any percentage reduction since the 1940s. Such a sharp drop is likely to reverberate for years to come, with the scale and duration of the effect shaped by the pace and timing of economic recovery.

Figure 3. Global Primary Energy Demand



Liquids demand growth shifts entirely to the global East across all scenarios, driven by economies in China, India, and Southeast Asia. In the Americas and Europe, **oil** demand declines because of slower economic growth and public policies that enhance **energy efficiency**, particularly in the transportation sector (Figure 4).

In the global West, **liquids** demand declines across all scenarios from 2018 to 2040. This reduction ranges from 0.2% under IEA's CPS to declines of 31% and 42% under Ambitious Climate scenarios from IEA and Shell, respectively. ExxonMobil and US EIA are relatively bullish, projecting declines of only 1% and 5%, respectively, whereas Evolving Policies scenarios from IEA and BP both project a drop of 12% (using comparable baseline data).

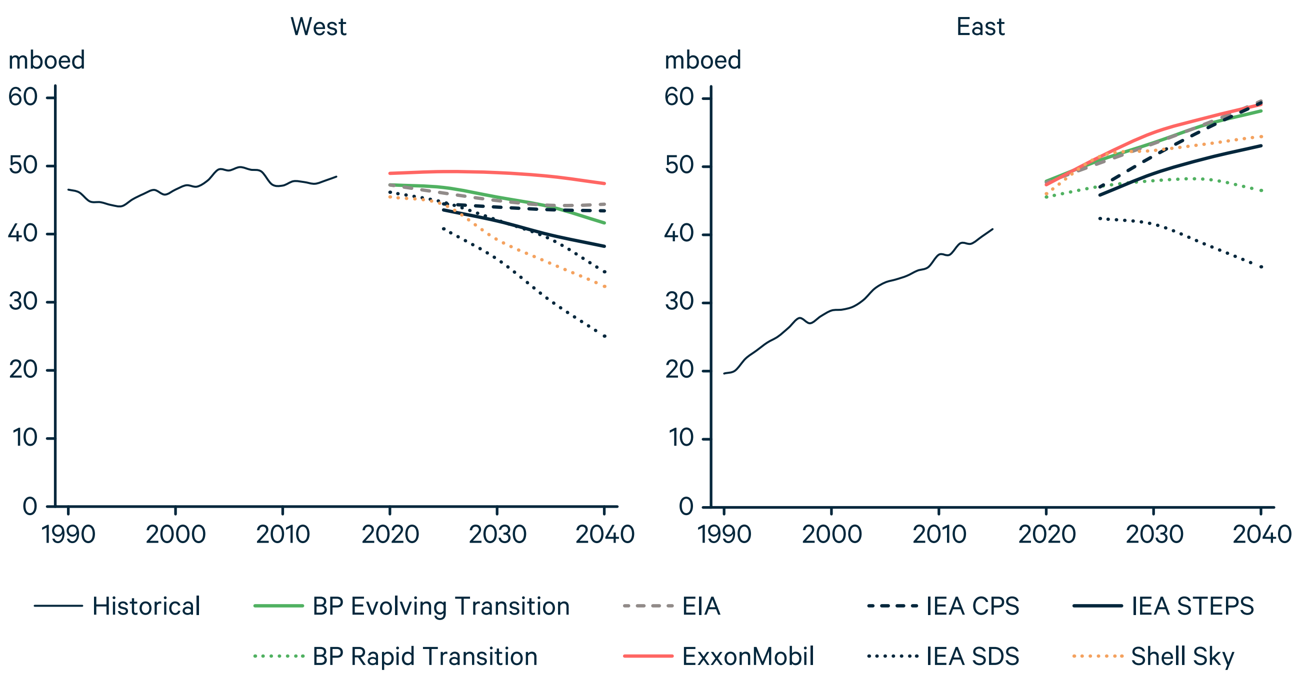
The story is very different in the global East, where **liquids** demand grows under almost all scenarios. By 2040, demand is 47% higher under the IEA CPS, and 29% to 32% higher for Evolving Policies scenarios and the US EIA Reference case. This growth is driven by rapidly rising demand, particularly in the transportation and petrochemicals sectors.

A wide range emerges for **liquids** demand in the East under Ambitious Climate scenarios. As with aggregate energy demand, Shell's Sky projects continued strong growth: 19% above 2018 levels by 2040. BP's Rapid Transition projects demand peaking in the 2030s, followed by a moderate decline; while the IEA SDS reaches a peak in the 2020s, then declines to 12% below 2018 levels by 2040.

CONSIDERING COVID-19

Abrupt and deep declines in domestic and international travel have heavily affected global oil markets, with demand in April 2020 falling by a remarkable 29 mb/d relative to April 2019. The IEA estimates that 2020 demand could contract by a more modest 9 mb/d year-on-year, with the deepest reductions coming from Europe and the United States.

Figure 4. Liquids Consumption in the West and East



Notes: Converted from qBtu to mboed using a factor of 0.506 mboed/qBtu (see Table 8). Includes biofuels. IEA projections exclude international bunkers and aviation.

Global **coal** consumption has grown rapidly over the past 15 years, driven entirely by the East. However, this growth has slowed in recent years, and most Reference and Evolving Policies scenarios project continued declines in the West and moderate growth in the East through 2040. Most Ambitious Climate scenarios, however, show rapid and deep cuts in coal consumption globally (Figure 5).

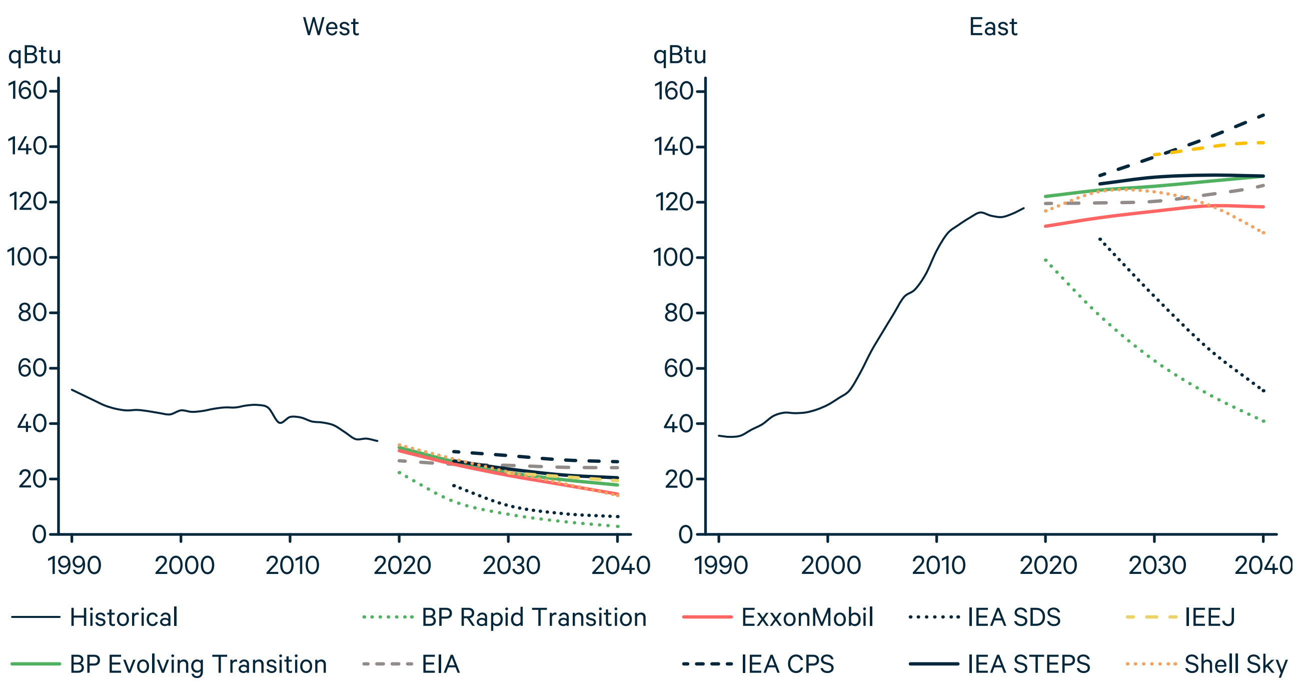
Across all scenarios, **coal** consumption is projected to decline in the West, driven down by public policies focused on climate and local pollution concerns, along with lower-cost alternatives led by **natural gas** and **renewables**. Under Ambitious Climate scenarios from BP and IEA, coal in the West falls from 34 qBtu in 2018 to just 3 and 6 qBtu, respectively, by 2040. Under Reference scenarios, coal's decline in the West is slower, falling to between 19 and 26 qBtu.

The future of **coal** is much less clear in the global East. Consumption rises under all Reference scenarios, ranging from growth of 7% (US EIA) to 29% (IEA CPS) by 2040 relative to 2018. Under Evolving Policies scenarios, growth ranges from 0.4% (ExxonMobil) to 10% (BP Evolving Transition and IEA STEPS). This moderate growth contrasts sharply with Ambitious Climate scenarios, which show coal declining by 65% and 56% under BP's Rapid Transition and IEA's SDS, respectively. Shell's Sky envisions a slower decline for coal, falling by just 8% by 2040, followed by steeper reductions and widespread **CCS** deployment in later decades.

CONSIDERING COVID-19

The IEA estimates that coal demand could decline by 8% in 2020, driven by reduced electricity demand. They project that coal consumption in China declines by 5%, while in Europe and the US it falls by 20% and 25%, respectively. The longer-term outlook for coal could become weaker still if governments opt for economic stimulus options that favor clean energy.

Figure 5. Coal Consumption in the West and East



The role of **natural gas** in a future energy transition has been subject to much debate. From 1990 to 2018, natural gas consumption has roughly doubled, growing from 66 to 130 qBtu globally. In the next 20 years, global growth continues under most scenarios, but important differences emerge across regions (Figure 6).

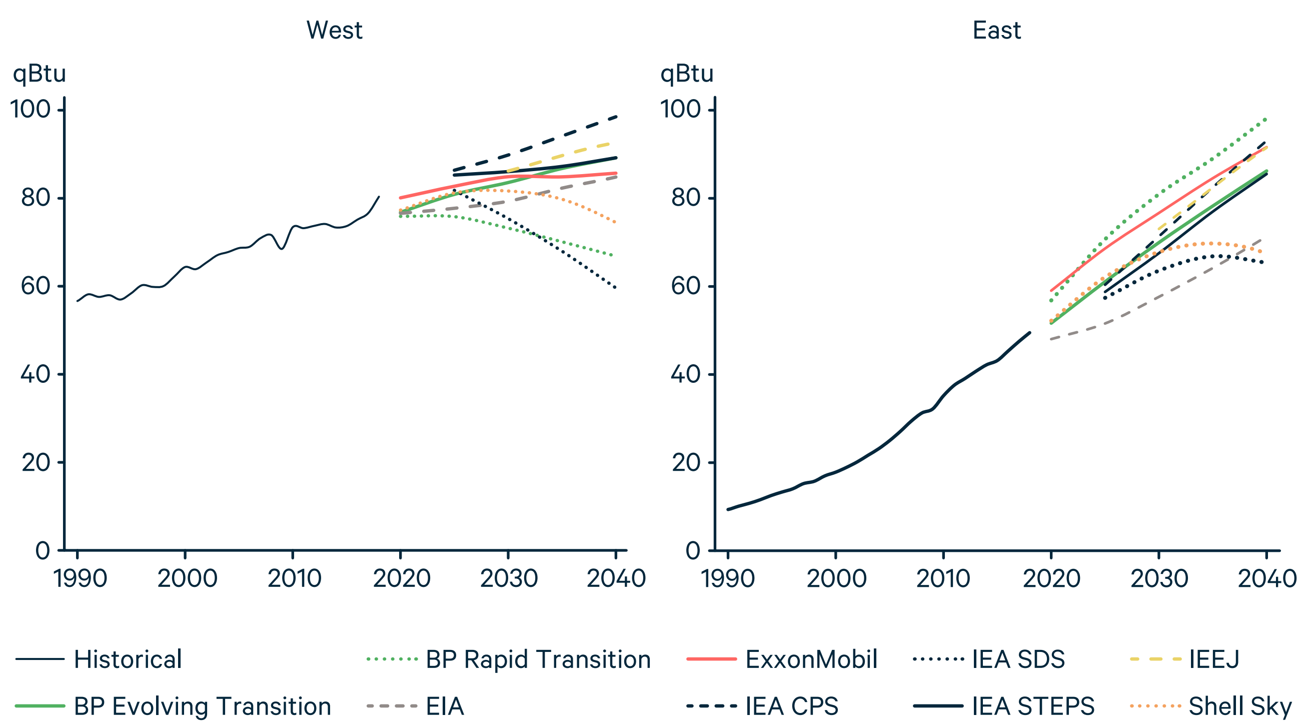
In the West, where **natural gas** consumption has risen steadily, Reference and Evolving Policies scenarios envision continued growth from 2018 to 2040, ranging from 7% (ExxonMobil) to 23% (IEA CPS). For Evolving Policies scenarios from BP and IEA, along with the US EIA Reference case, consumption in the West grows by 11% (using comparable baseline data, since US EIA uses the net rather than the gross heating value of fossil fuels). Under Ambitious Climate scenarios, natural gas consumption declines substantially in the West, falling by 7% under Shell's Sky and by as much as 23% under the IEA SDS.

In the global East, **natural gas** consumption in 2040 is substantially higher than today under all scenarios, but with wide variation, even within scenario types. For example, the strongest growth occurs in BP's Rapid Transition, where natural gas use nearly doubles, largely displacing **coal**. Ambitious Climate scenarios from IEA and Shell project gas demand in the East to peak in the 2030s, followed by a slight decline to 2040. Most other outlooks project growth ranging from 73% (IEA STEPS) to 83% (IEA CPS), although US EIA projects growth of just 52% through 2040 (using comparable baseline data).

CONSIDERING COVID-19

Reduced demand for electricity and in the industrial sector have contributed to lower demand for natural gas. The IEA estimates that 2020 demand for gas could fall by 5%, the first annual decline in over a decade. However, they also note that a faster-than-expected economic recovery could limit the decline to roughly 3%.

Figure 6. Natural Gas Consumption in the West and East



Solar electricity production has grown rapidly in recent years thanks to sharp cost declines, and it is poised to become a major contributor to the world's energy supply. In 2018, solar generated 2.3% of global electricity, but by 2040, most projections show it growing to more than 10% of the power supply, and potentially much higher (Figure 7).

Since 2009, the levelized cost of **solar photovoltaic** (PV) power has declined by nearly 90%.[13] Over that time, global solar electricity production has grown more than 10-fold. But this may be just the beginning. Because solar is a rapidly evolving technology, projecting its long-term future is challenging, but as we discuss in Section 3.1, most outlooks anticipate accelerating growth as costs continue to fall.

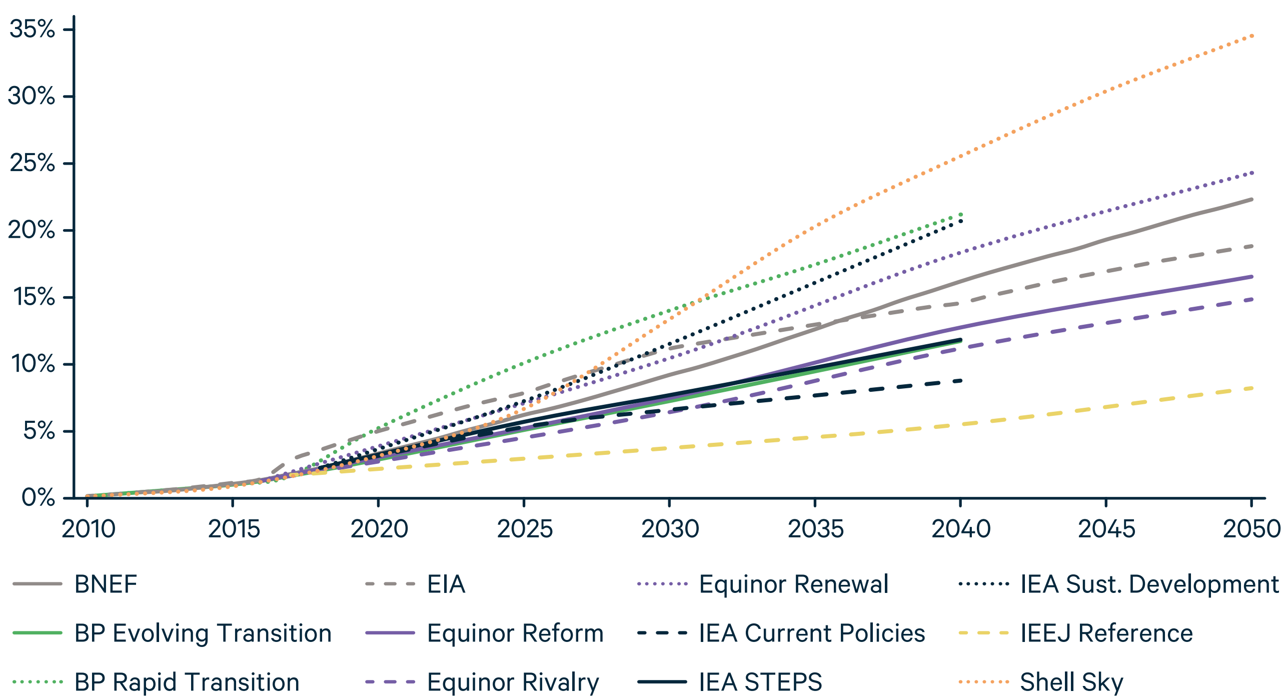
Under Ambitious Climate scenarios from BP and IEA, **solar** provides more than 20% of global power by 2040 and reaches 26% under Shell's Sky. Under most Evolving Policies scenarios, solar reaches roughly 12% by 2040, though BNEF projects faster growth, climbing to 17%. Among Reference scenarios, US EIA is by far the most bullish on solar, projecting it to grow to 15% of the power mix by 2040, compared with just 9% and 6% for the IEA and IEEJ Reference scenarios, respectively.

Some factors remain that could cloud **solar's** future. These include the availability of low-cost **electricity storage** or other technologies to address solar's intermittency; the deployment of **long-distance transmission**; and the challenges associated with quickly replacing solar power following sunset in regions with widespread deployment (sometimes referred to as the "**Duck Curve**" problem).

CONSIDERING COVID-19

Because solar installations have zero fuel costs, existing facilities will typically produce power whenever weather conditions permit. As solar capacity continues to grow, so too will generation, with the IEA estimating 15% growth in solar generation in 2020. However, supply chain disruptions could slow solar's near- to medium-term growth.

Figure 7. Solar's Share of Total Global Electricity Generation



Global demand for electricity surges across all projections, growing by more than 60% above 2015 levels by 2040 under most scenarios. For the large majority, **non-hydro renewables** dominate this growth, accounting for more than 50% of net growth in generation under all but two scenarios. **Natural gas** is the second fastest-growing source, though it varies widely (Figure 8).

Global electricity demand more than doubled between 1990 and 2015, with **fossil fuels** providing 63% and 66% of that power, respectively. By 2040, as demand rises, their share is projected to decline as cleaner sources grow. **Coal**, in particular, declines from 40% of the mix in 2015 to 23–32% under Reference scenarios, 20–28% under Evolving Policies scenarios, and just 4–13% under Ambitious Climate scenarios. In absolute terms, coal-fired power rises under half of the Reference and Evolving Policies scenarios (IEEJ, IEA CPS and STEPS, BP ET), is roughly flat or declines under the other half (Equinor Rivlary and Reform, US EIA, BNEF), and declines sharply under all Ambitious Climate scenarios.

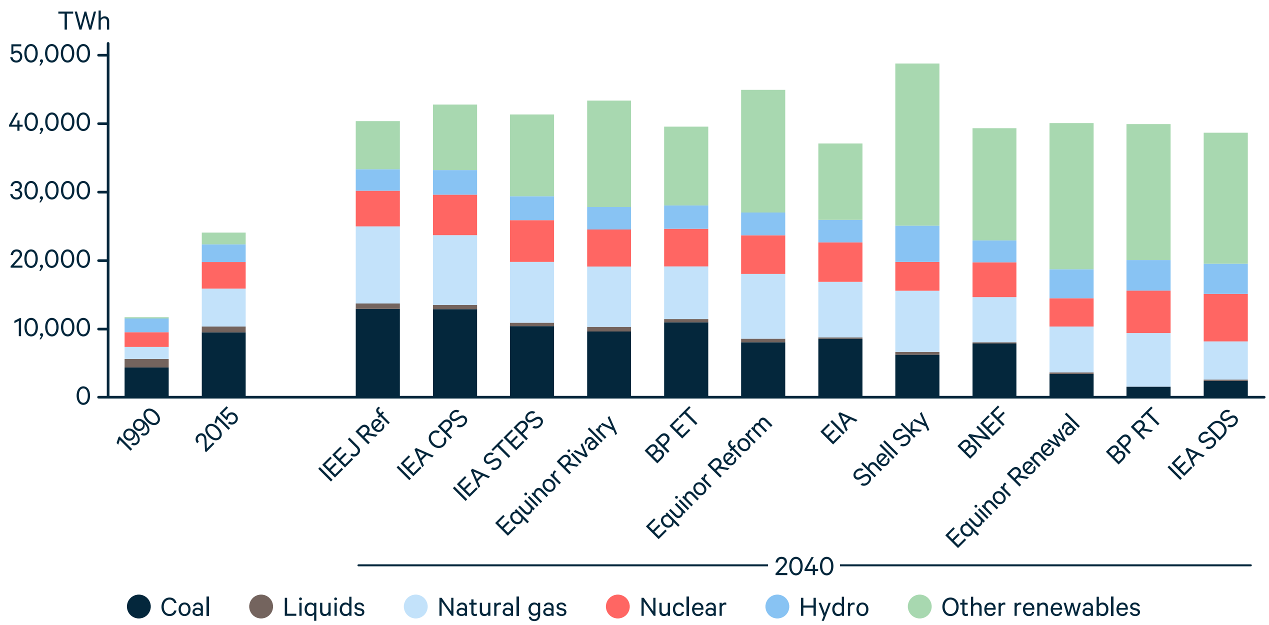
Nuclear rises under all scenarios, with the most bearish projections showing growth of 22% (IEEJ) and 24% (BNEF). Ambitious Climate scenarios from BP, Equinor, and IEA project growth of 65% to 74% by 2040, and nuclear more than doubles under Shell's Sky. As a share of the power mix, however, nuclear is roughly flat or declines across all scenarios.

Hydropower also grows under all scenarios but with wide variation in outcomes. For example, Ambitious Climate scenarios from BP and IEA show hydro growing by 59% and 78%, respectively, from 2015 to 2040. Comparable scenarios from Equinor and Shell project growth of just 7% and 8%, respectively, reflecting concerns about the local environmental and social consequences of large-scale hydro.

CONSIDERING COVID-19

With businesses shuttered due to COVID-19, demand for electricity has contracted sharply, with the IEA estimating a decline of 5% globally in 2020. Coal and natural gas-fired generation both decline markedly, with the IEA estimating respective declines of 10% and 8% in 2020. Renewables, by contrast, continue to grow strongly, reaching their highest levels on record in 2020.

Figure 8. Global Electricity Generation, by Fuel



Notes: Historical data from IEA. 2040 bars are ordered by declining level of fossil fuels.

Renewables, led by **wind** and **solar**, are projected to play a dominant role in new power generation under almost all scenarios. Under the most bearish scenario (IEEJ), renewable electricity generation more than triples from 2015 to 2040, and under Ambitious Climate scenarios, renewables increase more than 10-fold (Figure 9).

In 1990, **wind** and **solar** power together accounted for 0.03% of global electricity production. By 2015, this share had grown to more than 4%. In the decades to come, all scenarios agree that these sources will be the leaders in new generation.

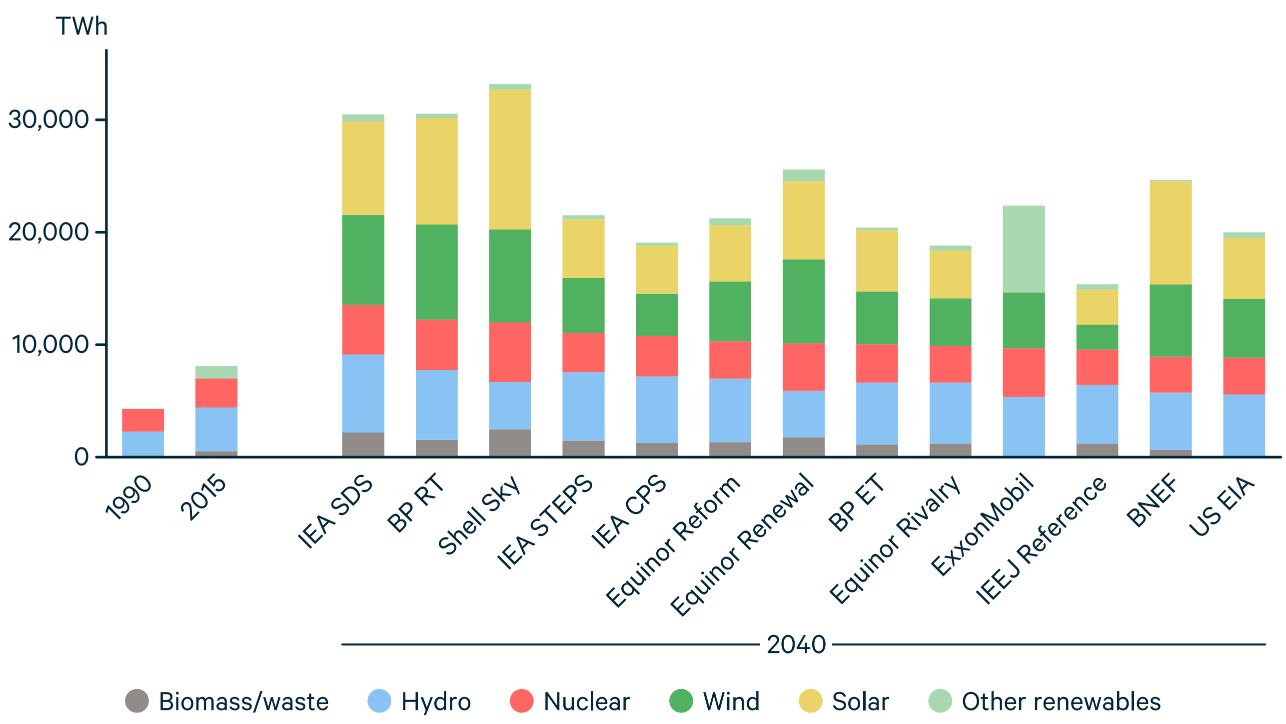
Under Reference scenarios, **wind** grows to account for 6–14% of global generation by 2040; under Evolving Policies scenarios it reaches 12–16%; under Ambitious Climate scenarios, its share is as high as 21%.

The rise of **solar** power is even more dramatic. Growing from roughly 1% in 2015, solar soars to account for more than 10% of global electricity in 2040 under most scenarios and exceeds 20% in several Ambitious Climate scenarios. Projections agree that **solar PV** technologies will drive this growth, though **concentrated solar power** (CSP) also plays a substantial role under some scenarios. We explore solar's surge in detail in Section 3.1.

CONSIDERING COVID-19

Partly due to lower global demand, the IEA estimates that wind and solar together will account for 9% of global power generation in 2020. When combined with hydro, nuclear, and other emissions-free power sources, the IEA estimates that low-carbon sources could account for roughly 40% of global power generation, surpassing coal in 2020.

Figure 9. Global Nuclear and Renewables Electricity Generation



Notes: Historical data come from IEA and include wind and solar under "Other." "Other" includes solar and biomass for ExxonMobil and biomass for US EIA. 2040 bars are ordered by declining levels of biomass, hydro, and nuclear power.

The **Kaya identity** is an analytical tool that allows for the decomposition of trends in **carbon dioxide** emissions, among other factors. It defines the level of CO_2 emissions as the product of **population**, **GDP per capita**, **energy intensity** (energy per unit of GDP), and **carbon intensity** (CO_2 emissions per unit of energy) (Figure 10). We explore these trends in detail in Section 3.3.

Since 1990, global **GDP per capita** has grown by more than 75% in real terms while **population** has increased by 43%. Informed by population and economic projections from the United Nations and the International Monetary Fund, IEA projects robust growth through 2040. Absent reductions in energy intensity and/or carbon intensity, these trends would produce further growth in CO_2 emissions.

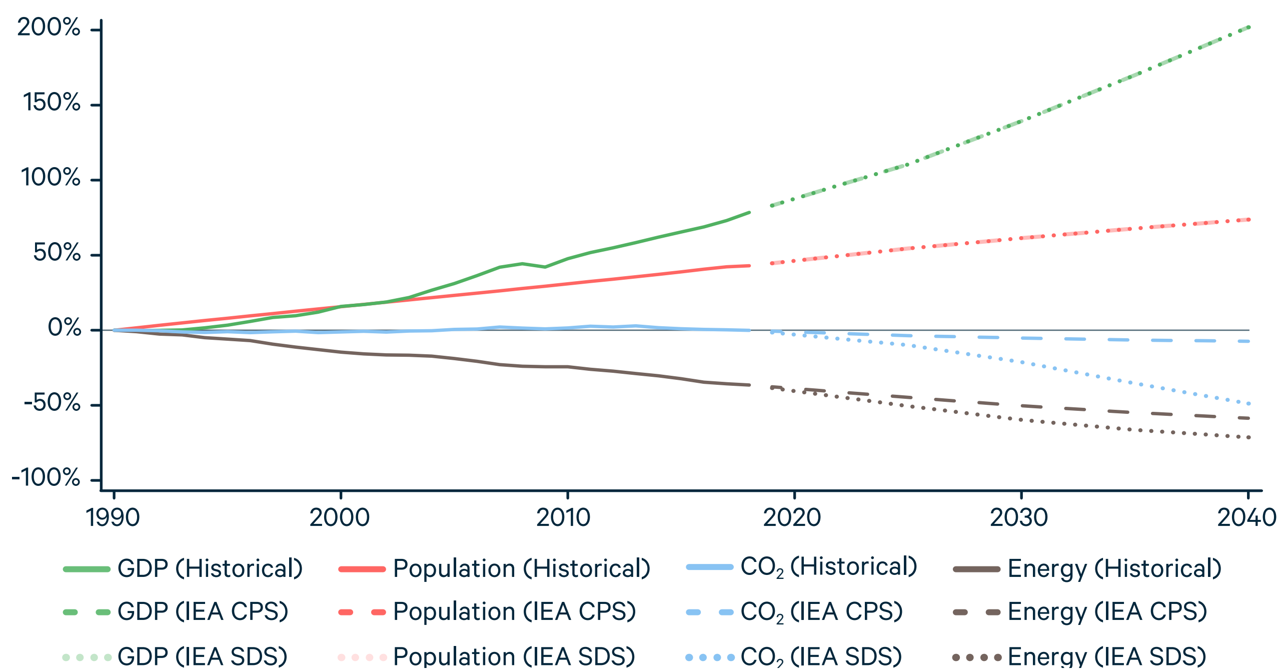
Under the IEA CPS (and other Reference scenarios), energy intensity, which has fallen by 36% since 1990, continues to decline, falling further to 59% below 1990 levels by 2040 (dashed lines in Figure 11). However, the carbon intensity of energy, which has been essentially unchanged for 30 years, declines by just 7% by 2040. As a result, global CO_2 emissions rise by almost 25% under the CPS.

Under the IEA SDS and other Ambitious Climate scenarios, the most substantial difference emerges in the carbon intensity of energy (dotted lines in Figure 11). Under the SDS, the CO_2 intensity of global energy falls by roughly 50% by 2040. In addition, enhanced energy efficiency causes the energy intensity of GDP to decline by 71% relative to 1990 levels, well beyond the efficiency gains seen in Reference or Evolving Policies scenarios. As a result, CO_2 emissions fall by more than half by 2040 under the SDS.

CONSIDERING COVID-19

While the long-term implications of COVID-19 on the factors that make up the Kaya identity are uncertain, the short term effects are fairly clear. GDP is likely to decline sharply, primarily driven by a decline in GDP per capita. Energy intensity remains roughly constant, with the IEA estimating declines in GDP and energy demand of 6% each for 2020, while the carbon intensity of energy declines moderately.

Figure 10. Historical and Projected Global Kaya Identity Trends



3. In Focus

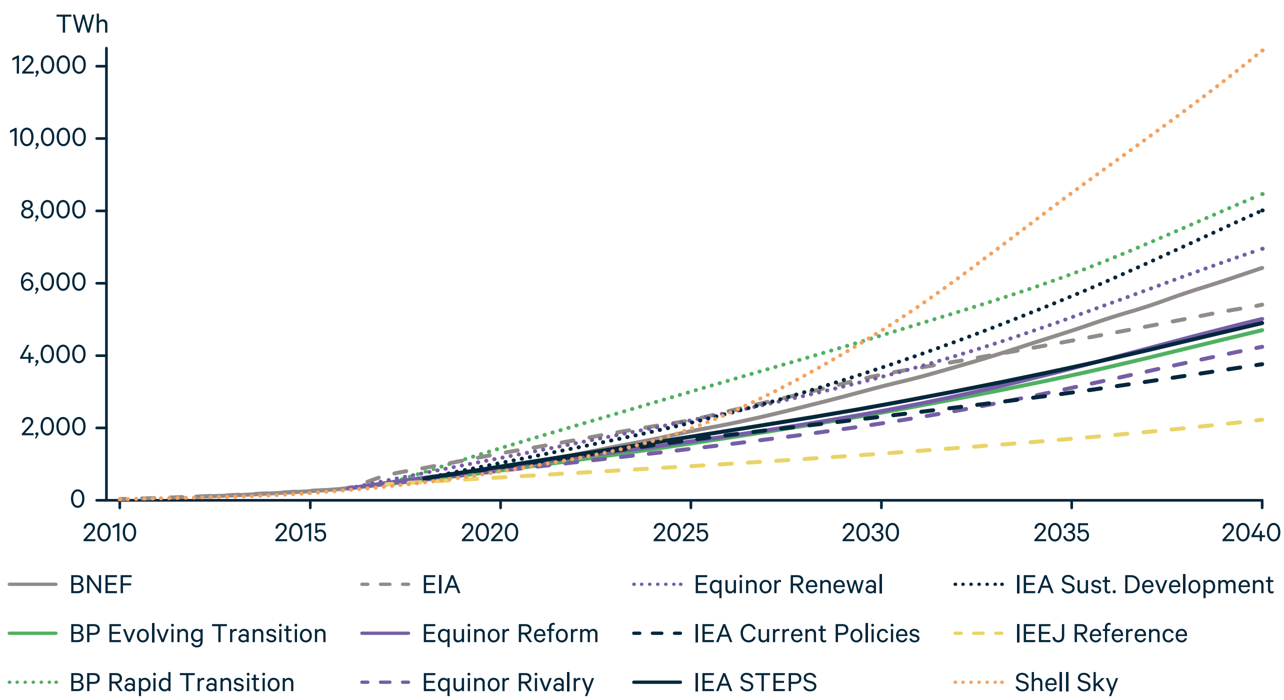
3.1. Solar Surging

Solar power has grown from supplying less than 0.01% of the world's electricity in 2008 to more than 2% in 2018. Under all scenarios from all organizations, it continues to grow in the coming decades as manufacturing and deployment costs fall further, but the speed of that growth is uncertain.

One reason for the wide range of projections is that analysts producing long-term energy outlooks must make critical assumptions about learning rates and technological improvements, which are difficult to anticipate with precision. Unsurprisingly, this has led to underestimates of deployment when technologies are changing rapidly, as seen in solar and the US shale revolution.[14,15] Another driver of differences in projections for solar power involves government policy: more ambitious climate policies generally lead to more rapid deployment of solar energy.

In absolute terms, Shell's Sky shows the most rapid growth, with solar producing more than 12,000 TWh globally by 2040 (and continuing to grow rapidly in the following decades). Ambitious Climate scenarios from BP, Equinor, and IEA also show solar rising rapidly. As in previous years, BNEF is more bullish than most other Evolving Policies scenarios, and—unlike in previous years—US EIA's projection for solar energy is near the top of the group, outpacing IEA's STEPS and other Evolving Policies scenarios (Figure 11).

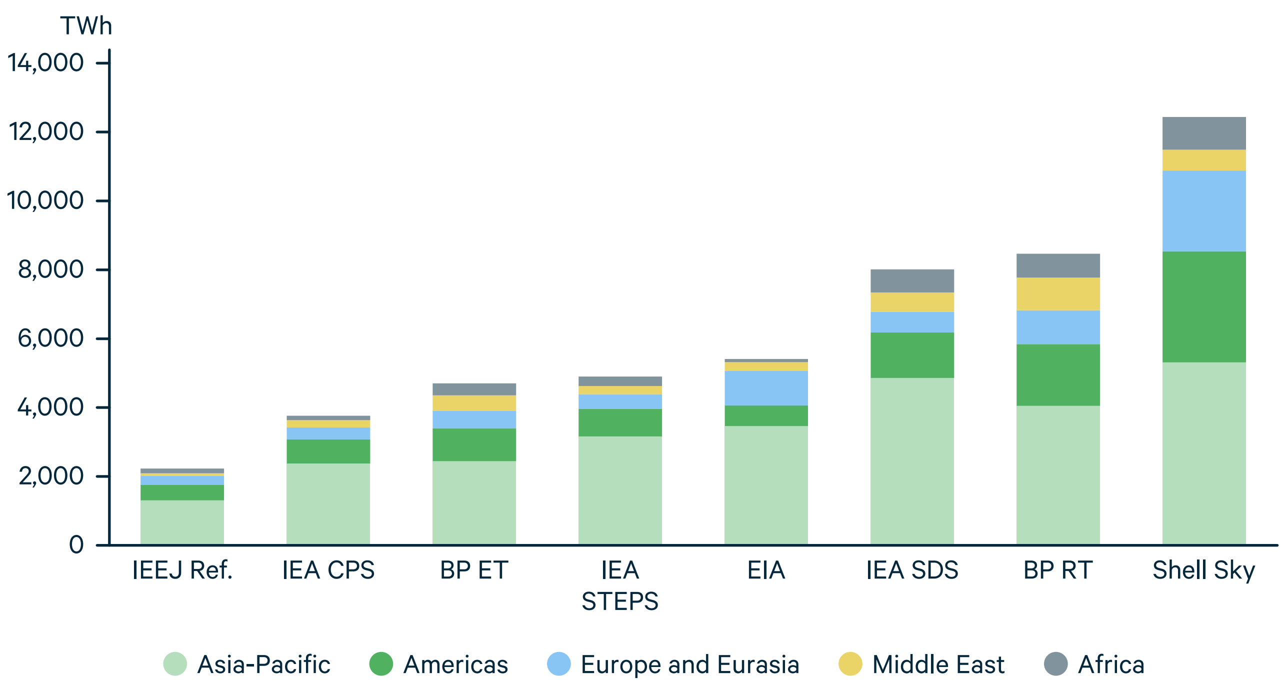
Figure 11. World Solar Electricity Generation



By 2040, solar provides 26% of the world's electricity under Shell's Sky and 21–22% under Ambitious Climate scenarios from BP and IEA. Equinor's Renewal scenario sees solar at 17%, followed by BNEF (16%) and US EIA (15%). IEEJ is the most bearish on solar's growth, projecting that it reaches just 6% of global electricity supply by 2040 under its Reference scenario.

Where is solar's growth taking place? In 2018, the Asia-Pacific region, led by China and Japan, accounted for 43% of global solar power generation. Most outlooks expect that share to increase by 2040, reaching 65% under IEA STEPS and 64% for US EIA. Europe and Eurasia, where public policies helped speed the deployment of solar (particularly in Germany),[16] accounted for 24% of global generation in 2018. But this share declines substantially under all scenarios, accounting for just 8–12% by 2040 under all scenarios except for US EIA (18%) and Shell's Sky (19%) (Figure 12).

Figure 12. Solar Power Generation in 2040, by Region



Solar generation in the Middle East, which in 2018 accounted for just 1% of the world's total, grows strongly under all scenarios. Even the most bearish projection (IEEJ Reference) shows Middle East solar generation growing from 9 TWh in 2018 to 77 TWh by 2040 (3% of the global total). Other projections are substantially more bullish, particularly BP, which projects 2040 solar generation in the Middle East of 445 TWh (9% of the global total) under its Evolving Transition scenario and 952 TWh (11% of the global total) under its Rapid Transition scenario.

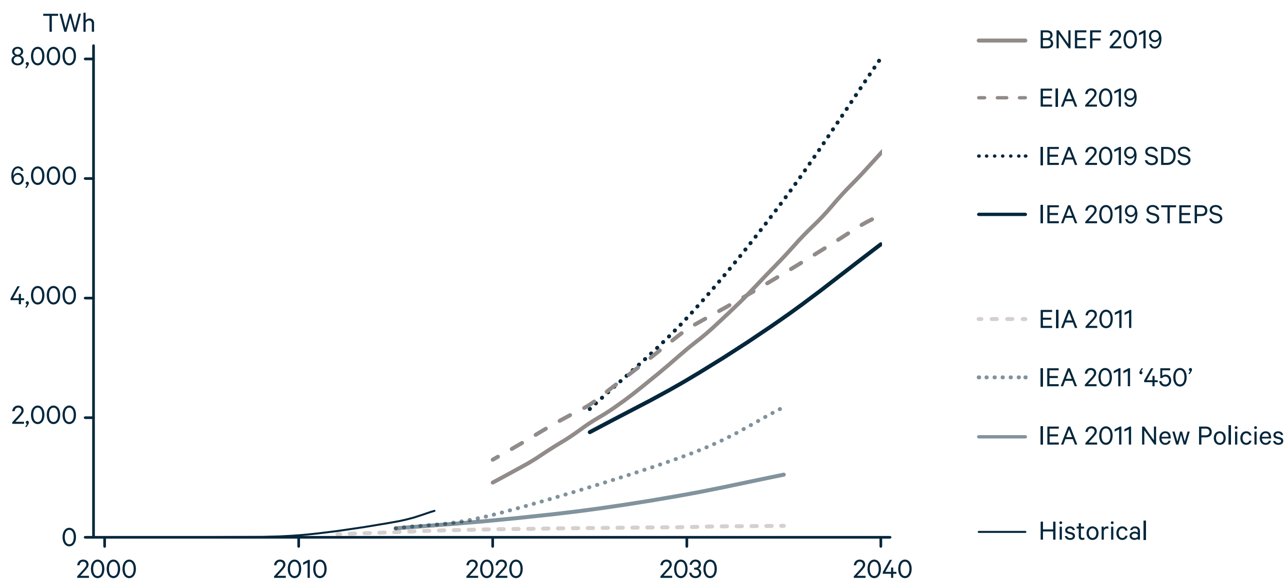
Solar in Africa similarly grows from just 2% of the world's total in 2018 to as much as 8% by 2040. Although US EIA and the IEA CPS are relatively bearish on African solar (2%

and 3% of global generation, respectively, in 2040), the continent produces 7% of the world's solar energy by 2040 under BP's Evolving Transition scenario, and 8% under Ambitious Climate scenarios from BP, IEA, and Shell.

As noted above, some recent projections for solar power have underestimated the rapid cost declines that have occurred over the last several years. For example, solar produced roughly 33 TWh of electricity globally in 2010. In 2011, US EIA projected that by 2020, this figure would nearly quadruple, to roughly 134 TWh. The IEA anticipated 282 TWh under its New Policies Scenario (the predecessor to STEPS) and 375 TWh under its 450 Scenario (the predecessor to SDS). For most energy sources, projections of multifold growth over 10 years would be seen as aggressive. Yet these projections dramatically underestimated global solar deployment because the cost declines in manufacturing and installation greatly exceeded expectations.

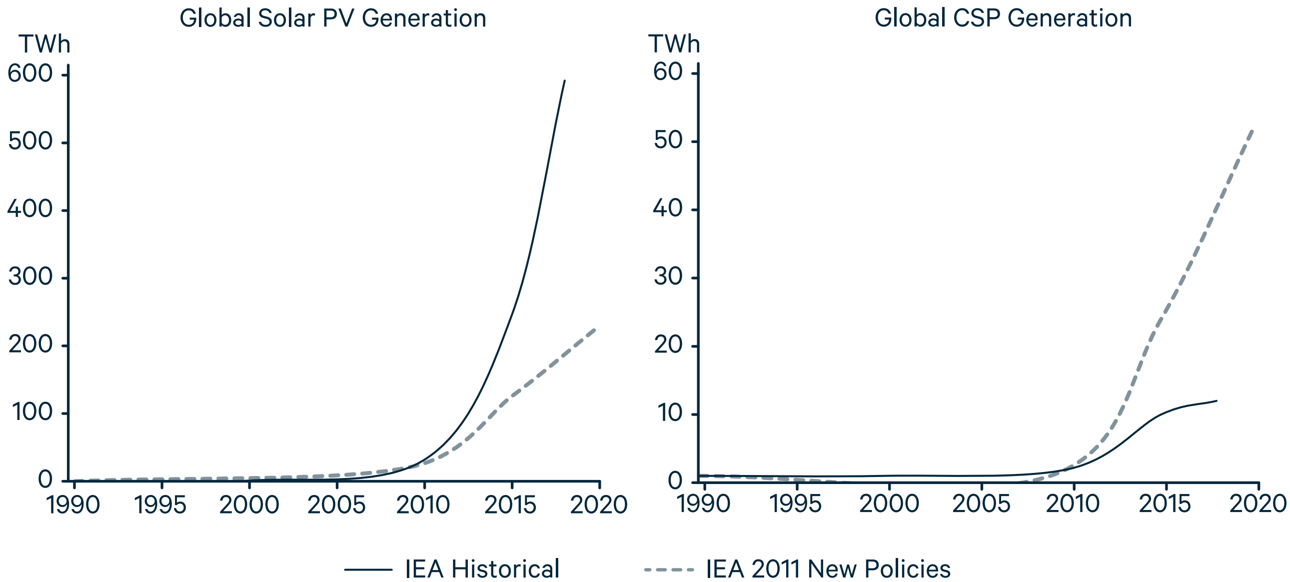
By 2018, solar provided almost 900 TWh globally. US EIA and IEA revise their projections annually based on new information, and projections from 2019 are far higher than those from 2011. Central projections from both organizations are relatively close to those from BNEF, which historically has been more bullish about solar energy (Figure 13).

Figure 13. Historical and Projected Solar Electricity Generation



Interestingly, organizations such as the IEA have not always underestimated the rise of solar technologies. In particular, IEA's projections for concentrated solar power (CSP) have consistently overestimated its growth, while projections for solar PV have been underestimates. In 2011, for example, IEA projected that solar PV would grow to roughly 200 TWh by 2020 and that CSP would reach more than 50 TWh that year. In the following seven years, PV eventually grew to nearly 600 TWh, while CSP grew to just 12 TWh (Figure 14).

Figure 14. Global Solar PV and CSP Electricity Generation



3.2. Developments in China, India, and Africa

In this section we examine current and historical outlooks for key energy trends in China, India, and the continent of Africa. These crucial regions represent economies at three distinct stages of development, with substantial differences in outlooks for future energy consumption. In China, after roughly a decade of rapid expansion, economic and energy demand growth is largely expected to slow in the coming years. In India, rapid economic growth is expected to accelerate energy demand through the next several decades, with rapid growth in coal use under Reference and Evolving Policies scenarios. In Africa, energy demand growth is projected to be somewhat slower, with traditional biomass continuing to play a major role, along with oil and natural gas taking new, leading roles in the continent's energy mix.

Expectations for future energy demand growth have changed substantially for all three regions in recent years. However, directly comparing outlooks from one year to the next can be complex, and comparable data are not always available. Here, we examine only comparable scenarios across outlook years from IEA's World Energy Outlook series: the 2006 Reference scenario, 2011 IEA CPS, and 2019 IEA CPS. Though the names differ across issues in the series, each scenario assumes that current policies continue in the decades that follow. Comparable data for other scenarios, such as STEPS or SDS, are not available for earlier years such as 2006.

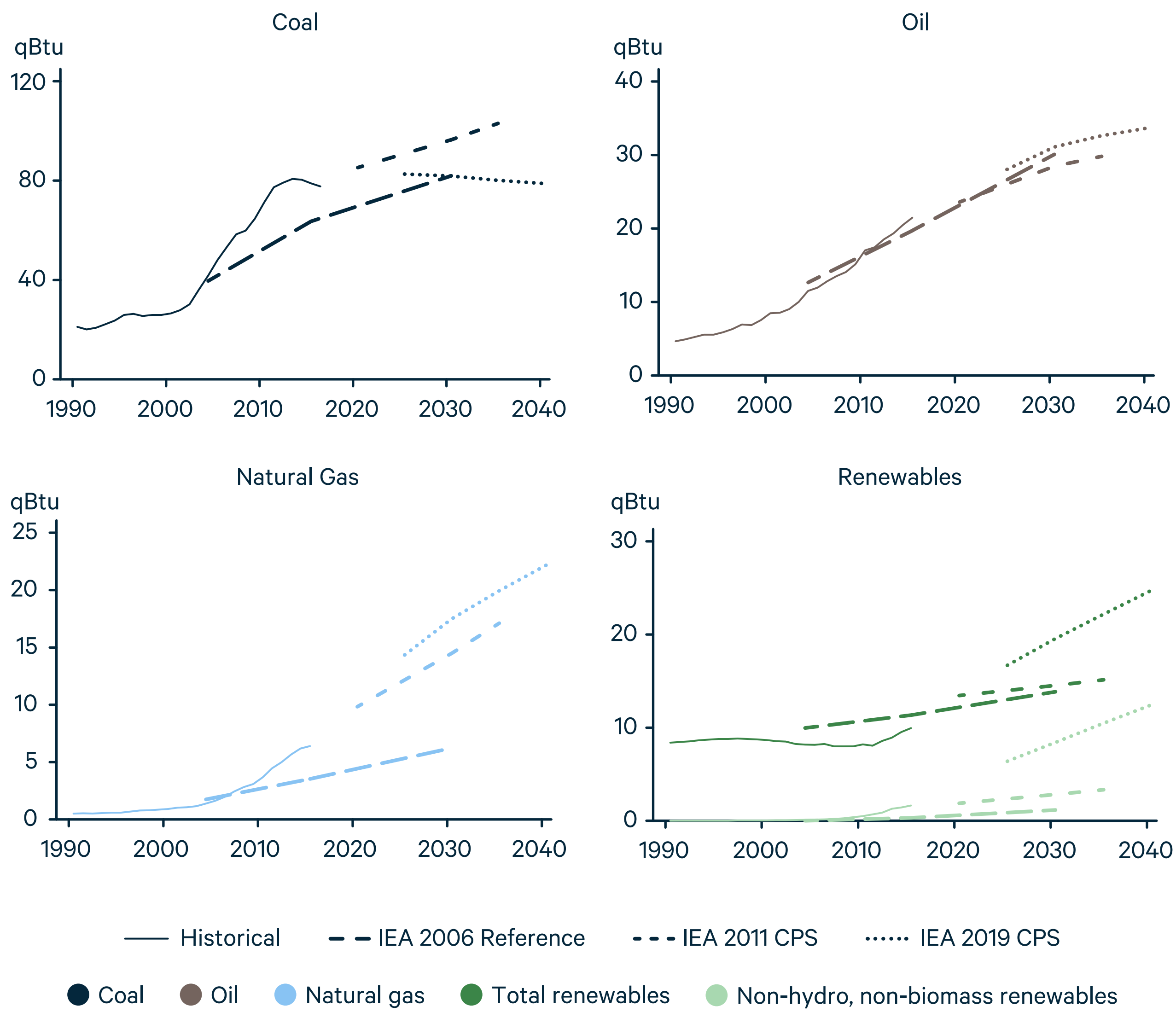
When comparing outlooks across multiple years, it is important to recognize that baseline data, assumptions regarding future population and GDP growth, and the existing policy framework all change over time. In the analysis below, we attempt to draw insights from these differences, along with the projections from which they stem.

3.2.1. China

After a period of dramatic economic growth starting in the early 2000s, China's economic expansion, and its associated growth in energy demand, has slowed. Projected growth in primary energy consumption is more modest over the next 25 years than it has been over the previous generation.

IEA's 2019 expectations for growth in Chinese coal consumption are well below those of outlooks from 2006 and 2011. An abrupt halt to coal demand growth in 2011 has informed the 2019 projection, which sees a slow but consistent decline through 2040 (Figure 15). Importantly, this decline occurs under the CPS. Coal demand under IEA's STEPS and SDS show more rapid declines.

Figure 15. Primary Energy Consumption in China



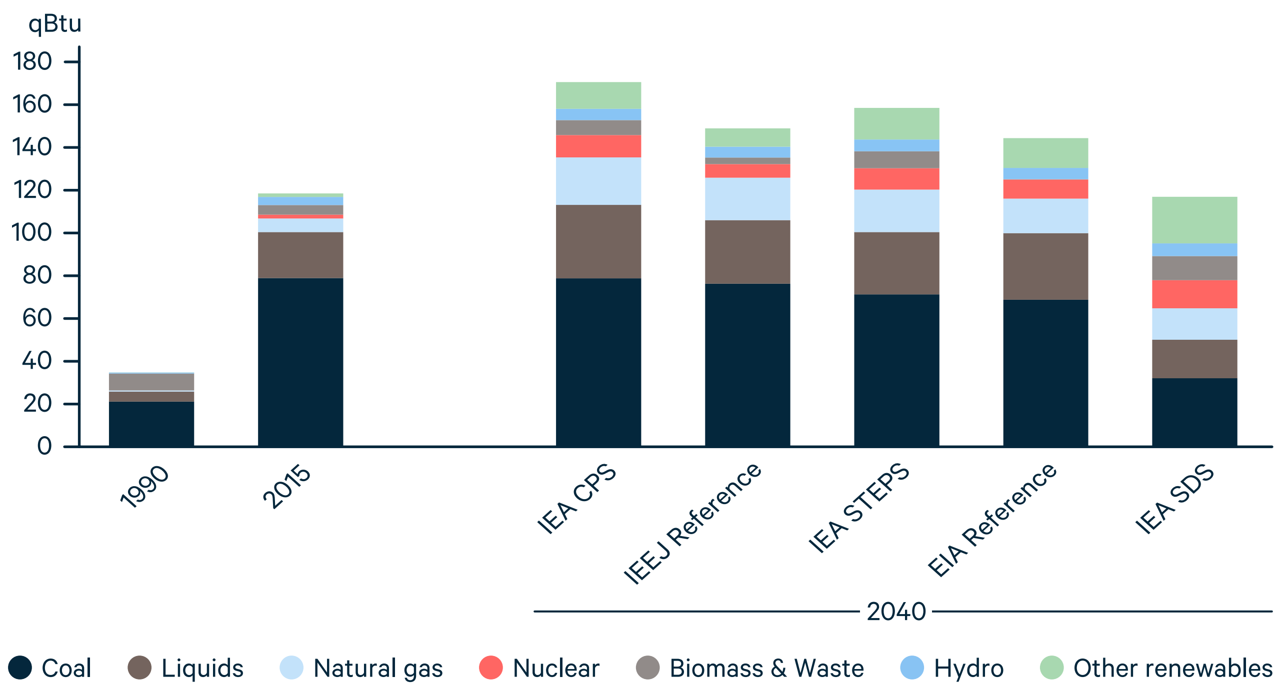
Unlike coal, oil and natural gas demand experience considerable growth under the 2019 CPS. Compared with projections from 2006 and 2011, expectations for oil demand are broadly similar, showing substantial growth through 2030, then slowing slightly in the final decade of the projection period. For natural gas in China, expectations have changed dramatically. In 2006, IEA projected natural gas to grow to 6.2 qBtu in 2030. Examining today's historical data, we find that Chinese gas demand reached 6.2 qBtu in 2014. As a result of this faster-than-anticipated growth, projections have been revised upward, reaching 14 qBtu in 2030 under the 2011 CPS and growing still higher, to 18 qBtu in 2030, under the 2019 CPS.

Because of a combination of public policies and declining costs, China has also seen a surge in renewable energy over the past 10 years, setting a trend that is projected to continue through 2040. Led by hydro, wind, and solar, renewables began growing rapidly in 2011, reaching levels well above those projected in 2006 or 2011. In the 2019 CPS, wind and solar are expected to play an even larger role, as non-hydro non-biomass renewables reach roughly 10 qBtu in 2035, more than tripling the 3 qBtu projected in 2011 for that year.

These changes in the projected fuel mix have substantial implications for China's CO_2 emissions, along with local air pollution. IEA's 2011 CPS projected that China's 2035 CO_2 emissions would be 12.9 BMT. Under the 2019 CPS, this figure has fallen to 10.5 BMT.

From 1990 to 2015, primary energy demand tripled in China, and coal accounted for 69% of this growth, making it the world's largest CO_2 emitter and creating major air quality problems. Although coal's rapid expansion appears to be ending, it is still projected to be the largest single source of primary energy in 2040 under all scenarios, including the IEA SDS (Figure 16).

Figure 16. Primary Energy Consumption in China, by Fuel



Notes: Historical data from IEA. 2040 bars are ordered by declining level of fossil fuels. US EIA excludes non-marketed biomass energy.

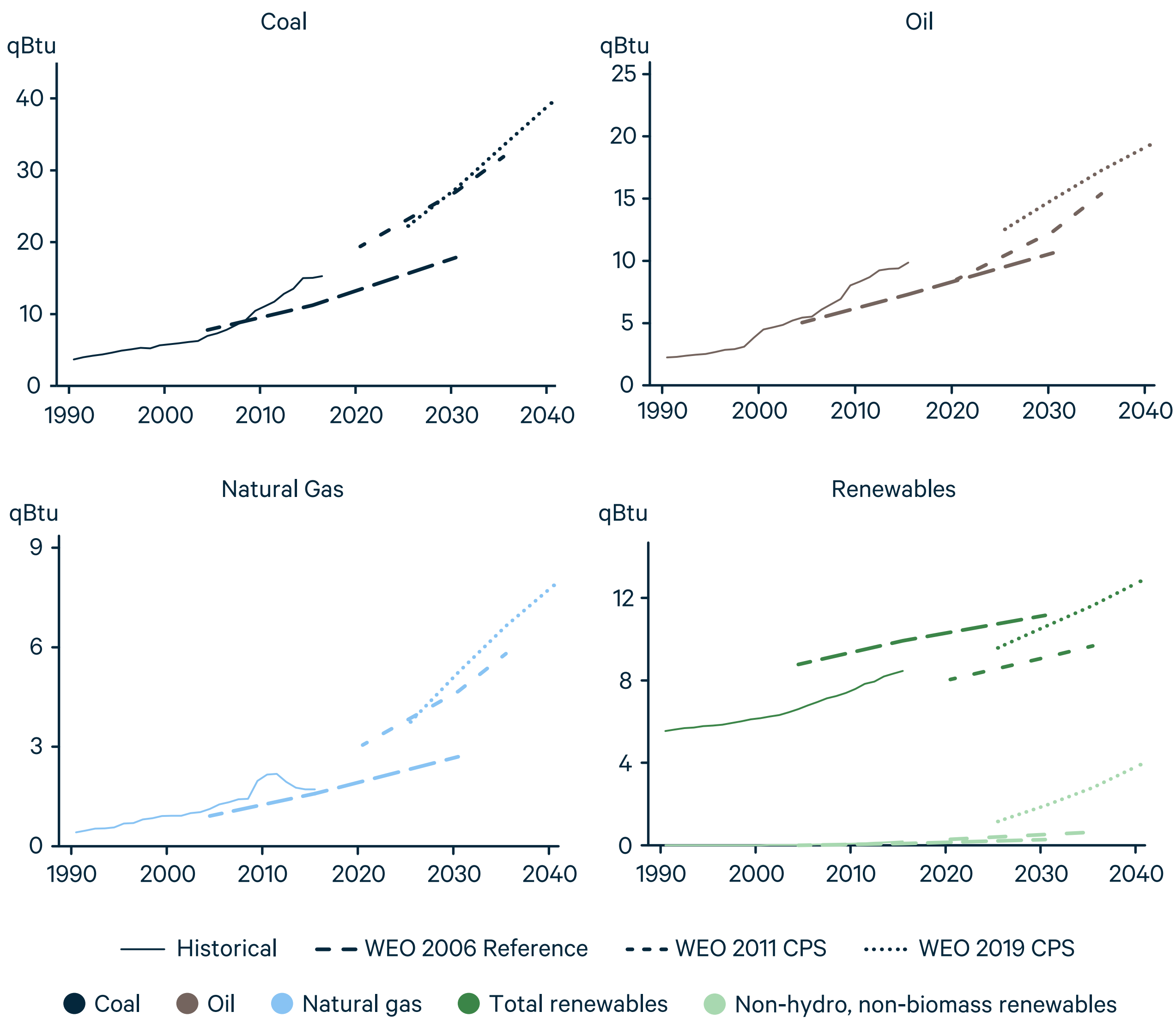
As noted above, oil and natural gas each grow considerably under Reference and Evolving Policies scenarios. Oil demand increases by 36–60% under these scenarios, while natural gas more than doubles under all scenarios and more than triples under the IEA CPS, IEA STEPS, and IEEJ Reference. In percentage terms, renewables are by far the fastest-growing energy source, increasing fourfold under the most bearish scenario (IEEJ Reference) and rising as much as eightfold under the IEA STEPS. Under these scenarios, nuclear energy also grows dramatically, rising from 2 qBtu in 2015 to 6–10 qBtu by 2040.

Under the IEA SDS, both coal and oil decline in absolute terms between 2015 and 2040, falling from 79 to 32 qBtu for coal and from 21 to 18 qBtu for oil, while natural gas grows from 6 to 15 qBtu. Renewables grow more than 12-fold, becoming the second-largest source of primary energy behind coal, while nuclear energy grows more than sixfold.

3.2.2. India

Reminiscent of China's rapid rise during the first decade of the 2000s, India's demand for energy is projected to surge over the next 20–25 years. As shown in Figure 17, IEA has steadily revised upward its projections for coal, oil, and natural gas demand. Projected demand for renewables declined in 2019 relative to 2006, primarily because of a decrease in expected demand for biomass and waste fuels, while projections for more modern renewables, such as wind and solar, have increased dramatically.

Figure 17. Primary Energy Consumption in India



Under the 2019 CPS, coal consumption in India reaches 39 qBtu by 2040, supplying roughly twice as much primary energy as oil, its closest competitor. This surge in coal demand is similar to projections made in 2011 but well above those seen in 2006, when India's prospects for long-term economic growth were less clear.

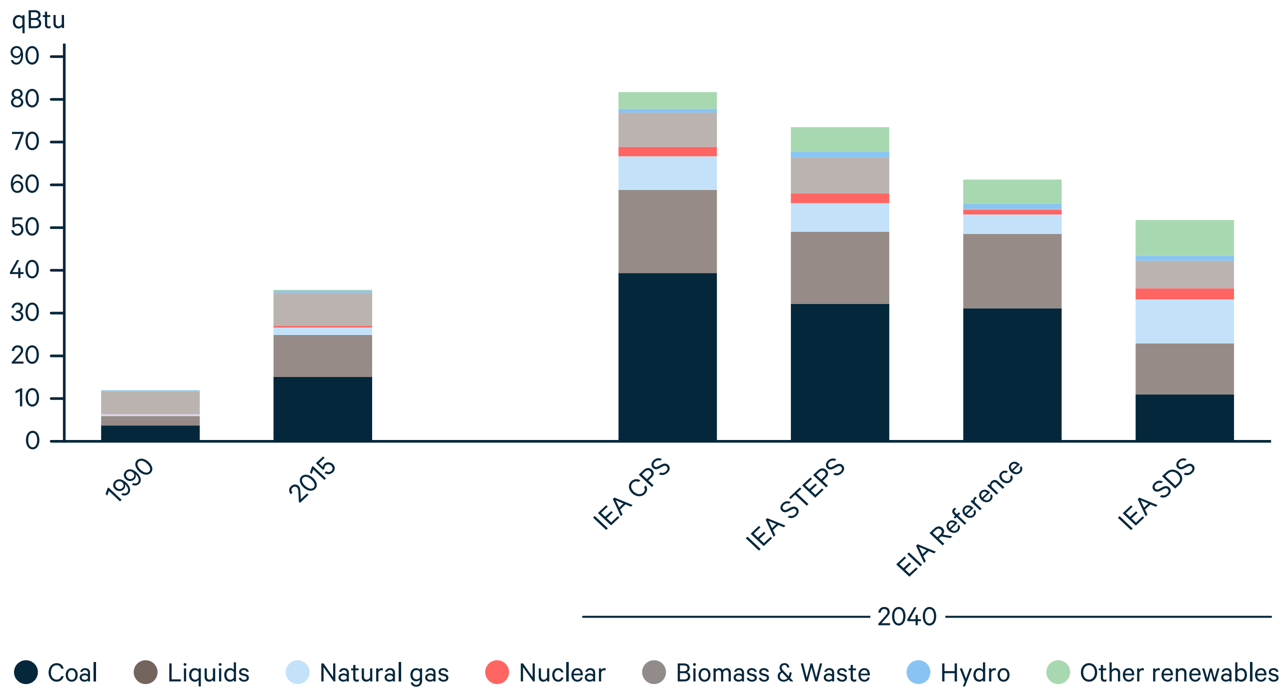
Projections for oil and natural gas demand have also grown. For example, projections for oil demand in 2030 have grown from 11 to 12 to 15 qBtu in projections from 2006, 2011, and 2019, respectively. Projected demand for natural gas in 2030 grew from 3 qBtu in 2006 to 5 qBtu in both 2011 and 2019.

Renewable energy in India is currently dominated by biomass and waste sources, though future growth is largely projected to come from modern renewables, led by solar and, to a lesser extent, wind. Similar to renewables projections across much of the world, today's expectations for the rise of wind and solar have become much more bullish over the past several years. For example, projections for non-hydro non-biomass renewables consumption in India in 2030 have increased from 0.3 to 0.5 to 1.9 qBtu, respectively, in projections from 2006, 2011, and 2019. By 2040, modern renewables grow to 3.9 qBtu under the 2019 IEA CPS and reach even higher under the IEA STEPS and SDS.

Despite the rise of renewables, growth in fossil fuel consumption leads India's CO_2 emissions to rise steadily under the 2019 IEA CPS, growing from 2.3 BMT in 2018 to 5.5 BMT by 2040. Under the IEA STEPS and SDS, CO_2 emissions reach 4.5 and 2.1 BMT, respectively, by 2040. For context, CO_2 emissions for the United States and European Union under the IEA STEPS are 4.0 and 1.6 BMT, respectively, in 2040.

Under Reference and Evolving Policy scenarios, coal consumption more than doubles in India, its share of primary energy rising from 42% in 2015 to 44–51% by 2040 (Figure 18). Oil's market share decreases somewhat under these scenarios, although in absolute terms, it grows by 72–97% by 2040. Natural gas, which accounted for just 5% of primary energy demand in 2015, grows rapidly under these scenarios, accounting for 7–10% of the fuel mix by 2040. Modern renewables, led by solar, also grow rapidly, rising from 0.5% of the mix in 2015 to 5% (IEA CPS) and 9% (US EIA Reference) by 2040.

Figure 18. Primary Energy Consumption in India, by Fuel



Notes: Historical data from IEA. 2040 bars are ordered by declining level of fossil fuels. US EIA excludes non-marketed biomass energy.

The IEA SDS embodies a very different energy future in India. Coal consumption declines in absolute terms by 27%, and its share of the energy mix falls to just 21%. Natural gas plays a major role in displacing coal in the power and heating sectors, growing more than fivefold in absolute terms and rising from 5% of the fuel mix in 2015 to 20% by 2040. Modern renewables also play a major role in displacing coal in the power sector, growing to 16% of the energy mix by 2040, with solar providing almost one-third of India's power generation.

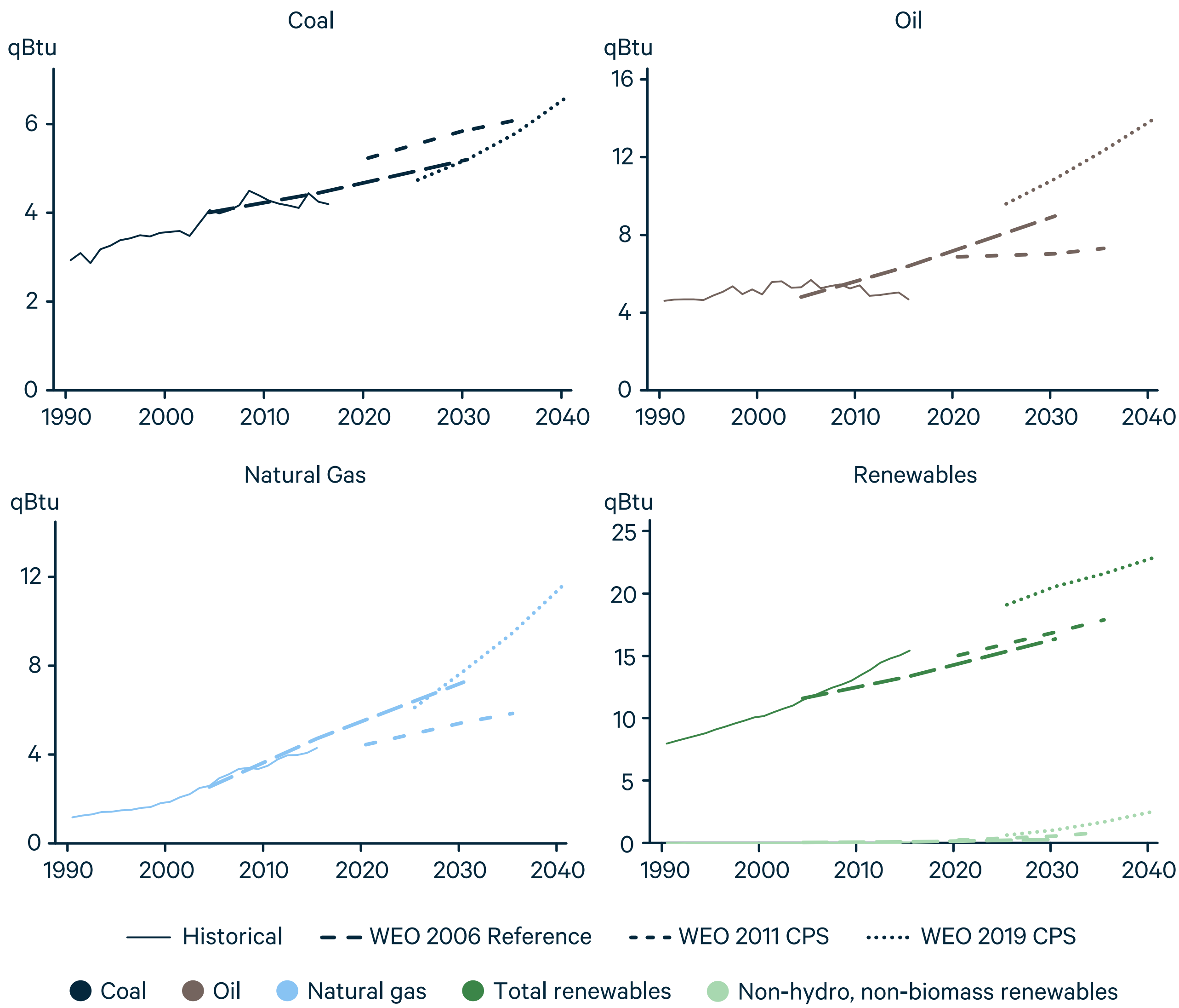
Oil consumption continues to grow under the IEA SDS, but far more slowly than under other scenarios discussed here. Still, oil becomes the largest energy source by 2040, accounting for 23% of the fuel mix. Under Reference and Evolving Policies scenarios, coal remains by far the leading energy source in 2040.

3.2.3. Africa

Africa comprises more than 50 countries, and thus any long-term projection for the continent inevitably masks distinct trends at more local levels. Nonetheless, several notable points emerge when we examine historical and current projections for the continent's energy demand.

In 2015, biomass and waste accounted for more than half of Africa's primary energy demand, indicating the continent's continued reliance on traditional fuels and the ongoing challenge of increasing access to modern energy services. Demand for biomass and waste has grown more rapidly than projected in 2006 or 2011, as shown in the "Renewables" panel of Figure 19.

Figure 19. Primary Energy Consumption in Africa, by Fuel



Note: IEA historical data, which we rely on here, show lower oil demand in Africa than other historical data sets from roughly 2000 through 2015. The reason for this discrepancy is unclear.

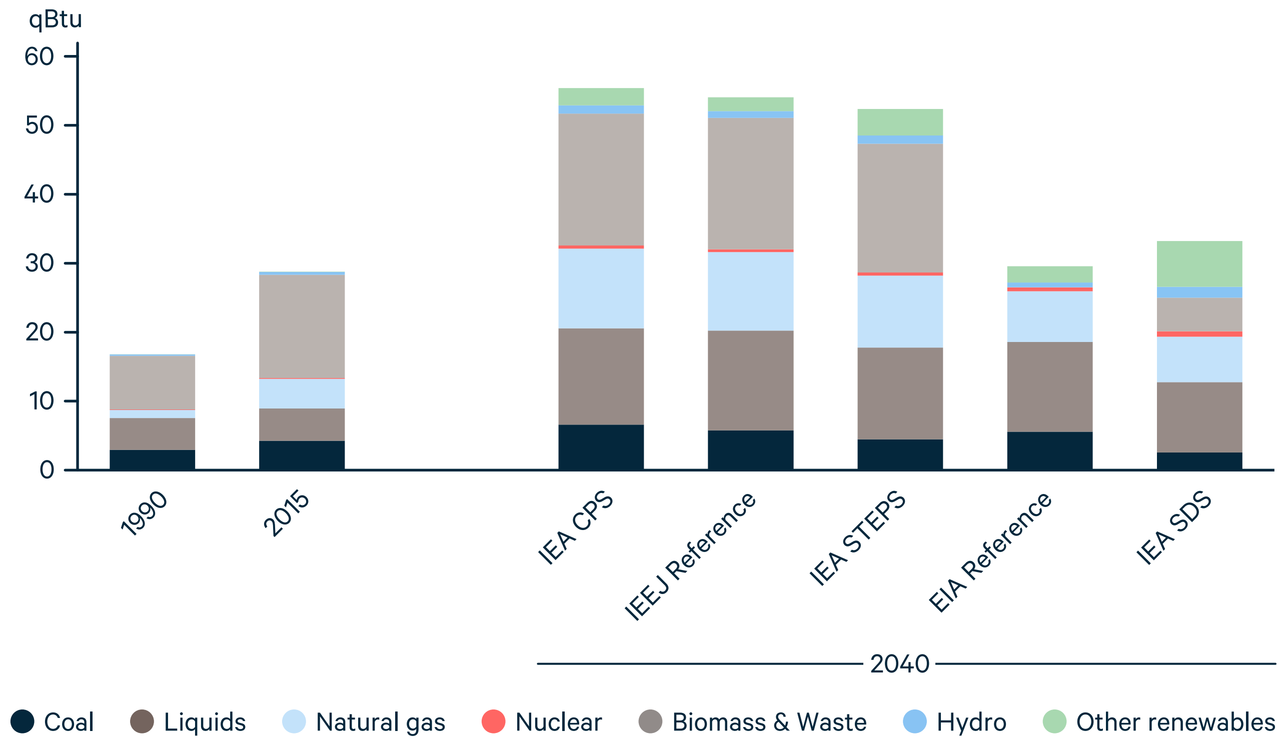
Through 2040, the 2019 IEA CPS projects total renewables will remain at the forefront of Africa's energy consumption, growing from roughly 15 qBtu in 2015 to 23 qBtu by 2040. Biomass and waste grow by 4.2 qBtu during this period, while hydro and other renewables led by wind and solar increase by 3.3 qBtu.

Oil and natural gas demand in Africa are each projected to grow strongly under the most recent IEA CPS, well above the levels projected in 2006 and 2011. By 2035, oil and natural gas demand reach 12 and 9 qBtu, respectively, under the 2019 CPS, compared with just 7 and 6 qBtu under the 2011 projection. Coal demand has grown more slowly than was envisioned in either the 2006 or the 2011 projection, but it accelerates considerably under the 2019 CPS, reaching 7 qBtu by 2040 (coal demand is roughly flat under the 2019 STEPS and declines by roughly half under the SDS).

CO_2 emissions in Africa are nearly 75% higher in 2040 than 2018 levels under the 2019 CPS, reaching 2.1 BMT. This growth is substantial but well below the total emissions projected under the 2019 CPS for India (5.5 BMT) and China (10.4 BMT) in 2040. Under the IEA STEPS, Africa's CO_2 emissions grow by 48% through 2040 and decrease by 9% under the IEA SDS.

As discussed above, biomass and waste are by far Africa's largest primary energy source today. Under Reference and Evolving Policies scenarios, this dynamic continues, and biomass and waste grow considerably in absolute terms (note that US EIA excludes non-marketed biomass). However, this source's share of the energy mix declines from 52% in 2015 to 35–36% by 2040 (Figure 20). Under the IEA SDS, which includes not only ambitious climate change policies but also the fulfillment of other UN Sustainable Development Goals, the use of biomass and waste falls by roughly two thirds as energy poverty challenges are alleviated broadly across the continent.

Figure 20. Primary Energy Consumption in Africa, by Fuel



Notes: Historical data from IEA. 2040 bars are ordered by declining level of fossil fuels. US EIA excludes nonmarketed biomass energy.

Coal demand is projected to increase relatively modestly across Reference and Evolving Policies scenarios, growing by 5–55%. Under the IEA SDS, coal falls by 40%.

Oil and natural gas consumption increase strongly across all scenarios. For oil, demand roughly triples under the IEA and IEEJ Reference scenarios, with growth almost as strong under the IEA STEPS and US EIA Reference scenarios. Oil demand growth is slower under the IEA CPS but still more than doubles by 2040, relative to 2015 levels. Similarly, natural gas consumption more than doubles under the IEA CPS, IEA SDS, and IEEJ Reference scenarios. Natural gas demand rises more modestly under the US EIA Reference scenario and the IEA SDS, rising 71% and 53%, respectively, by 2040.

Modern renewables' contribution to Africa's fuel mix varies widely across scenarios. Whereas wind and solar accounted for just 0.1% of Africa's primary energy mix in 2015, these sources reach roughly 5% of total energy demand by 2040 under the IEA CPS and grow to 20% under the IEA SDS. Energy efficiency also plays a major role in the IEA SDS, as GDP growth is identical to the CPS, yet total primary energy demand is 40% lower by 2040.

3.3. The Kaya Identity: Past, Present, and Future

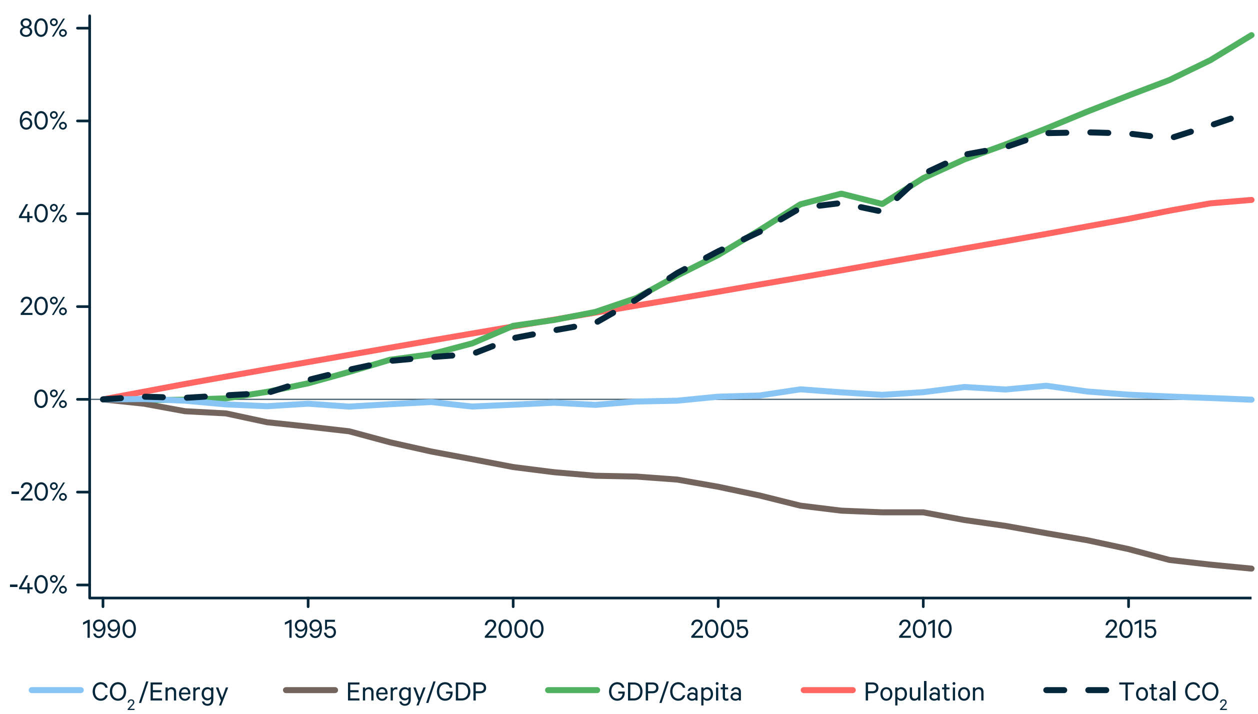
As discussed in Section 2, the Kaya identity is a useful tool to understand key factors underlying changes in CO_2 emissions. In this section, we briefly consider historical trends in the four elements of the identity, then look at the differences among projections in the decades to come.

Since 1990, the world's population has grown by 43% while real GDP per capita has grown by 79%. Higher GDP per capita, in particular, is a cause for celebration, as it largely reflects increased economic opportunity and reductions in global poverty.

However, absent changes in energy intensity and/or carbon intensity, a growing population and rising GDP will tend to result in higher CO_2 emissions. Since 1990, the world has made substantial improvements in energy intensity, reducing the primary energy input per unit of GDP by 36%. This trend has two major drivers: enhanced energy efficiency; and a global economy that has become less reliant on energy-intensive activities such as manufacturing and more reliant on services, which are typically less demanding of energy.

The carbon intensity of energy, however, has seen little change in recent decades. CO_2 emissions per unit of global primary energy consumption in 2018 were just 0.1% lower than they were in 1990, reflecting the continued dominance of fossil fuels in the energy mix (Figure 21).

Figure 21. Kaya Decomposition of Global CO_2 Emissions

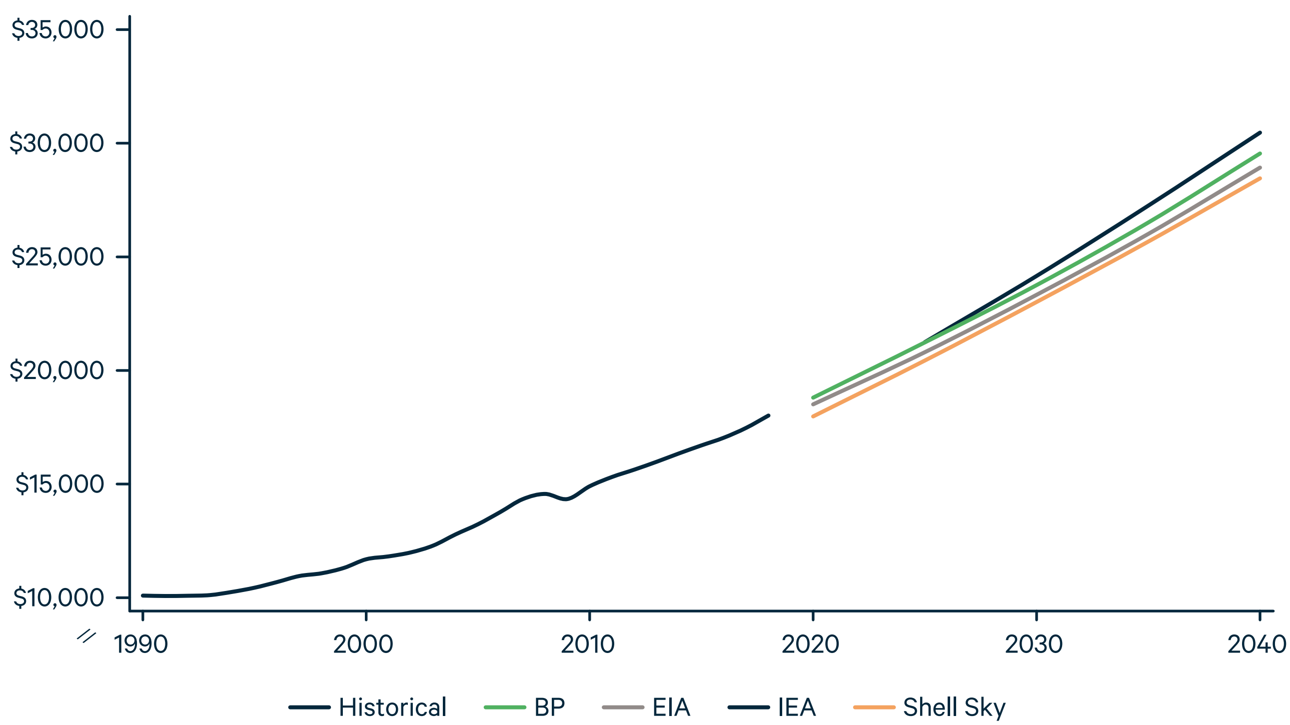


Note: Data from IEA.

Projections for global population vary little among outlooks, with modest variations emerging in estimates for economic growth. For most organizations that produce multiple scenarios, such as BP and IEA, assumptions about population and economic growth are constant across scenarios. For example, all the IEA scenarios assume the same levels of population and income growth over time.

Figure 22 illustrates projected GDP per capita for several outlooks and shows substantial growth over time across scenarios. Because population assumptions vary little across outlooks, these differences primarily reflect varying assumptions about economic growth. IEA, which relies in part on near- and medium-term projections from the International Monetary Fund, assumes that the global economy grows by 3.4% annually, leading to per capita GDP of roughly $30,500 by 2040. BP and US EIA assume slightly slower economic growth (the latter also has slightly lower population assumptions), reaching $29,500 and $29,000 per capita, respectively.

Figure 22. Global Per Capita Income

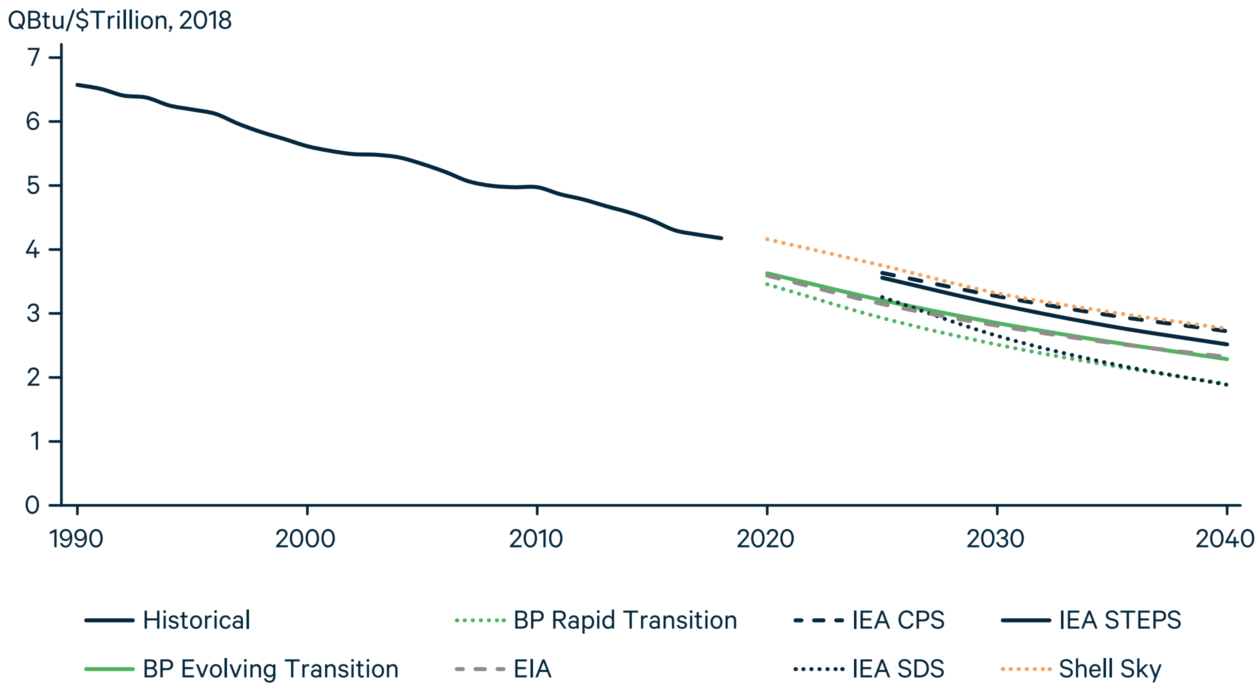


Shell's per capita GDP estimates are lower still, in part because of differing baseline data (Shell's Sky was published in 2018, whereas the other projections were published in 2019). In addition, Shell develops its scenarios through a unique process, generating distinct assumptions about future population and GDP growth.

Wider variation begins to emerge when we turn to energy intensity. Because BP and US EIA exclude nonmarketed biomass from their totals of primary energy consumption, their baseline and projected data tend to be lower than those from other organizations.

Setting aside the issue of baseline data, all scenarios project continued reductions in the energy intensity of GDP (Figure 23). Unsurprisingly, the largest improvements occur in the IEA SDS, which sees energy intensity decrease by almost 50% relative to 2018 as carbon pricing and other factors drive energy efficiency gains across the economy. Under the IEA CPS and STEPS, energy intensity declines by 7% and 14%, respectively. Shell's Sky also sees a relatively modest decline in energy intensity, partly because it relies on older baseline data and partly because the scenario includes energy demand growth that outstrips the growth seen in other Ambitious Climate scenarios.

Figure 23. Global Energy Consumption per Unit of GDP



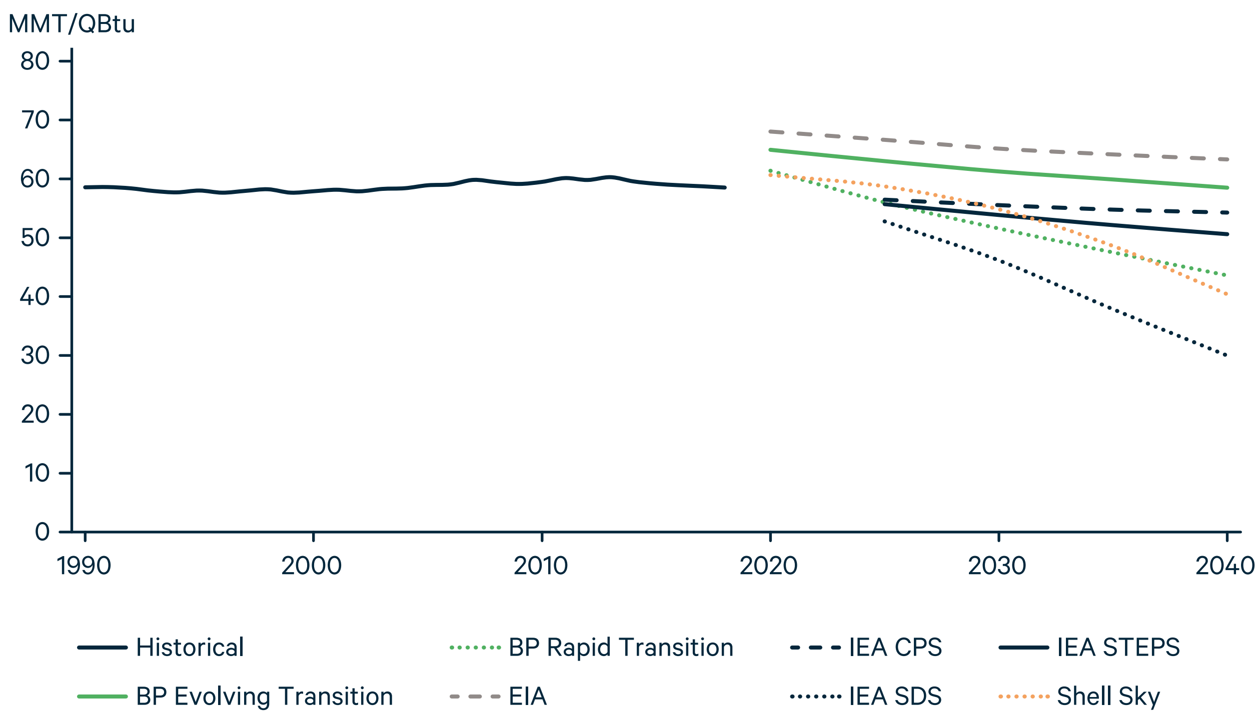
For BP's Evolving Transition scenario and US EIA, energy intensity declines by 12% and 8%, respectively (using comparable 2018 baseline data that excludes non-marketed biomass). Under BP's Rapid Transition scenario, efficiency gains drive energy intensity reductions of 34% by 2040.

The largest differences among scenarios emerge when we turn to the CO_2 intensity of energy. As noted above, the level of CO_2 emitted per unit of primary energy consumption has remained roughly unchanged since 1990. As a result, growing global demand for energy has led to higher global emissions levels. Most outlooks project modest declines in CO_2 intensity, but Ambitious Climate scenarios envision deep reductions.

For Reference and Evolving Policies scenarios, CO_2 intensity declines moderately from current levels. US EIA and IEA's CPS, both Reference scenarios, project declines of 7–8% by 2040, relative to 2018 levels, using comparable baseline data (because US EIA and BP exclude non-marketed biomass, their emissions intensities appear higher than others). For BP and IEA's Evolving Policies scenarios, emissions intensity declines by 12–14% over the same timeframe.

Steep declines in emissions intensity are part of all Ambitious Climate scenarios. For BP, IEA, and Shell, respectively, CO_2 emissions per unit of energy in 2040 are 34%, 31%, and 49% below 2018 levels, as shown in Figure 24 (again, these changes are calculated using comparable baseline data, which for BP excludes non-marketed biomass).

Figure 24. Global CO_2 Emissions per Unit of Energy Consumption



In sum, applying the Kaya identity to this range of scenarios provides a lens through which to observe a widely understood phenomenon: to achieve deep decarbonization goals, the world needs a more efficient energy system in which clean sources play an ever-expanding role.

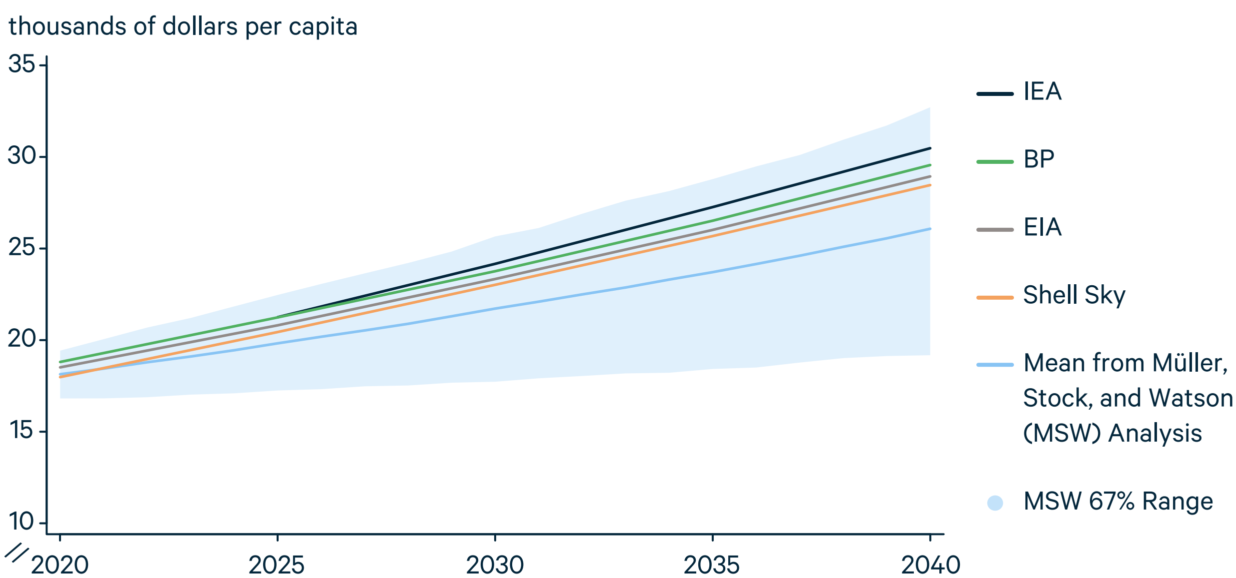
CONSIDERING COVID-19

As long as emitting sources remain a high share of energy use, one of the most important factors that drives CO_2 emissions will be the size of the economy. Moreover, Figure 22 shows that the different outlooks featured here all exhibit very similar projections for economic activity, suggesting this important factor has little uncertainty. The lowest scenario envisions global income per capita of $28,400 on average in 2040, whereas the highest projection is $30,400, only 7% higher.

However, there is significant uncertainty about the future rate of economic growth, as the economic contraction associated with COVID-19 has made clear. From January to April of 2020, the IMF revised its projection of economic growth from positive 3.3% to negative 3.6%—a 6.9% swing. While the IMF anticipates economic activity could rebound in 2021, this large change over such a short period highlights the significant uncertainty about future GDP, which is largely not reflected by the narrow range of projections included in these scenarios. One might reasonably ask, however, whether this hopefully short-lived downturn has long-term relevance for energy projections.

A **recent statistical analysis** by economists Müller, Stock, and Watson sheds light on how uncertain future economic growth is. The study used historical data on economic activity to quantify the uncertainty around future GDP trajectories. Their projections suggest that future global income per capita is far less certain than suggested by the projections in Figure 22. In particular, their projections suggest there is a less than 10% chance that income per capita in 2040 will be within the narrow range of $28,400 to $30,400 considered by the projections in Figure 22. More generally, the projections suggest that there is a two-thirds chance that global per capita incomes in 2040 will fall between $19,200 and $32,700 (see blue area in Figure 25), a much broader range than the GEO projections consider. Holding constant the other components of the Kaya identity, the high end of this range would result in CO_2 emissions more than 70% larger than the low end. We also note that the average growth rate from this statistical analysis is lower than all of the projections included in this report, suggesting an important area for further examination.

Figure 25. GEO Projections versus Likely Range of Global Per Capita Income



4. Data and Methods

In this paper, we have examined projections from the following publications:

- BP: *Energy Outlook 2019*
- BloombergNEF (BNEF): *New Energy Outlook 2019*
- Equinor: *Energy Perspectives 2019*
- ExxonMobil: *Outlook for Energy 2019*
- Institute for Energy Economics, Japan: *Outlook 2020*, published in 2019
- International Energy Agency: *World Energy Outlook 2019*
- OPEC: *World Oil Outlook 2019*
- Shell: *Sky Scenario*, published in 2018
- US Energy Information Administration: *International Energy Outlook 2019*

The outlooks vary because of differences in modeling techniques, different historical data, economic growth assumptions, and 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. We focus in this report on Ambitious Climate scenarios, a major subset of (3). These approaches are summarized in Table 4 (page 35).

4.1. Harmonization

Different scenarios and modeling assumptions produce useful variation among outlooks, allowing analysts to view a wide range of potential energy futures. However, outlooks also have important methodological differences, which can complicate direct comparisons and reduce the ability to draw insights.

One major difference among 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 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 (page 36) presents the reporting units for each outlook examined here, and Table 7 (page 37) provides relevant conversion factors.

A second key difference among 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) and those presented in physical units (e.g., mbd or bcm). Among the outlooks we examine, these assumptions can vary by up to 11%.[1] Although differences in conversion units may appear small, they are amplified when applied across the massive scale of global energy systems, and particularly over long time horizons.

A third major difference results from varying decisions about including nonmarketed biomass, such as locally gathered wood and dung, in historical data and projections for primary energy consumption. BP and 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 8–11% difference in global primary energy consumption.

Yet another difference relates to comparing the energy content of fossil fuels and 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 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 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 those challenges, Newell and Iler[12] 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.[17]

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

Table 4. Sources and Scenarios

Source	Scenario
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: Focus of BP's outlook. Policies, technologies, and social preferences continue to evolve along recent trends. Rapid Transition: Includes variety of policies to reduce emissions from power, transport, buildings, and industrial sectors. Consistent with Paris temperature goals.
Equinor[5]	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 energy system toward limiting warming to 2°C by 2100.
ExxonMobil[6]	Unnamed central scenario: Based on internal views on technology and policy evolution.
IEA[7]	Current Policies Scenario (CPS): No new policies. Stated Policies Scenario (STEPS): Includes existing and announced policies, including climate targets. Sustainable Development Scenario 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.
US EIA[11]	Reference: No new policies.

Table 5. Units of Energy Consumption, by Outlook

	IEA	BP	ExxonMobil	US EIA	OPEC	Equinor	IEEJ	Shell
Primary energy units	mtoe	mtoe	qBtu	qBtu	mboed	Btoe	mtoe	EJ
Fuel- or 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.

Notes: 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[17] for more details.

Table 6. 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: There is no agreed-upon factor for barrels of oil equivalent. 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.

5. Key Statistics

The tables in this section provide a variety of key statistics for global and regional energy projections. IEA historical data, the primary baseline, are available through year 2018, but we use 2015 as a base year to create consistent 25-year increments (i.e., 1940, 1965, 1990, 2015, 2040), for historical context.

Table 7. Global Indicators

	Population	Energy	GDP	Net CO_2	GDP/ capita	Energy/ GDP	Energy/ capita	Net CO_2/ energy
$ in PPP terms	Millions	qBtu	$T, 2018	BMT	$1,000/ person	1,000 Btu/$	1,000 Btu/ person	MMT/ qBtu
1990	5,279	350	53	20.5	10.1	6.6	66.3	58.6
2015	7,358	546	116	32.3	15.7	4.7	74.1	59.2
2018	7,602	568	135	33	17.8	4.2	74.7	58.5
2040								
BP ET	9,161	619	271	35.9	29.6	2.3	67.5	58.5
BP RT	9,161	513	271	18	29.6	1.9	56.0	43.6
US EIA	9,139	613	264	38.8	28.9	2.3	67.1	63.3
IEA CPS	9,172	754	279	41.3	30.4	2.7	82.2	54.8
IEA STEPS	9,172	694	279	35.6	30.4	2.5	75.7	51.3
IEA SDS	9,172	512	279	15.8	30.4	1.8	55.8	30.9
OPEC	9,199	702	267	38	29.0	2.6	76.3	54.4
Shell Sky	9,043	711	257	28.7	28.4	2.8	78.6	40.4
$ in MER terms								
2015	7,358	546	87	32.3	11.8	6.3	74.2	59.2
2040								
Equinor Reform	9,210	639	166	31.1	18.0	3.8	69.3	48.7
Equinor Renewal	9,210	522	168	18.2	18.2	3.1	56.7	34.9
Equinor Rivalry	9,210	685	156	36.2	16.9	4.4	74.4	52.8
ExxonMobil	9,200	669	173	35	18.8	3.9	72.7	52.3
IEEJ	9,176	714	174	40.1	19	4.1	77.8	56.2

Notes: Historical data from IEA. BP and US EIA exclude nonmarketed biomass energy, which is included in all other outlooks. PPP = purchasing power parity. MER = market exchange rate.

Table 8. World Primary Energy Consumption

qBtu	Total	Coal	Liquids	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
2018 (incl. non-marketed biomass)	568	152	182	130	28	14	62
2040 (incl. non-marketed biomass)							
Equinor Reform	639	124	189	153	35	19	119
Equinor Renewal	522	57	135	122	44	21	143
Equinor Rivalry	685	154	218	151	34	18	109
ExxonMobil	675	133	211	177	45	18	91
IEA CPS	760	178	230	192	37	20	104
IEA STEPS	703	150	204	176	36	21	116
IEA SDS	527	58	135	125	46	24	138
IEEJ	714	169	220	186	32	18	88
OPEC	702	152	204	178	43	20	104
Shell Sky	711	123	182	143	61	17	186
2015 (excl. non-marketed biomass)	490	151	175	115	26	13	7
2018 (excl. non-marketed biomass)	511	149	183	123	28	15	13
2040 (excl. non-marketed biomass)							
BP ET	619	147	197	175	35	19	45
BP RT	513	44	160	165	46	21	77
US EIA	613	150	206	156	35	20	47

Notes: Historical data from Grubler (1940, 1965 [interpolated from 1960 and 1970 data]), IEA (1990, 2015, and 2018 including non-marketed biomass), and US EIA (2015 and 2018, excluding non-marketed biomass).

Table 9. Liquids Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	121	—	—	86	—	—	35	—	—
2015	172	2.0	1.4%	90	0.2	0.2%	82	1.9	3.5%
2018	182	3.3	1.9%	93.0	1.0	1.1%	91	3.0	3.5%
2040		2018-2040			2018-2040			2018-2040	
BP ET	197	0.7	0.4%	82	-0.5	-0.6%	115	1.1	1.1%
BP RT	160	-1.0	-0.6%	68	-1.1	-1.4%	92	0.0	0.0%
US EIA	206	1.1	0.6%	88	-0.2	-0.3%	118	1.2	1.2%
Equinor Reform	189	0.3	0.2%	—	—	—	—	—	—
Equinor Renewal	135	-2.1	-1.3%	—	—	—	—	—	—
Equinor Rivalry	218	1.6	0.8%	—	—	—	—	—	—
ExxonMobil	211	1.3	0.7%	94	0.0	0.0%	117	1.2	1.1%
IEA CPS	230	2.2	1.1%	86	-0.3	-0.4%	117	1.2	1.1%
IEA STEPS	204	1.0	0.5%	76	-0.8	-0.9%	105	0.6	0.7%
IEA SDS	135	-2.1	-1.3%	49	-2.0	-2.9%	70	-1.0	-1.2%
IEEJ	220	1.7	0.9%	78	-0.7	-0.8%	118	1.2	1.2%
OPEC	204	1.0	0.5%	—	—	—	—	—	—
Shell Sky	182	0.0	0.0%	64	-1.3	-1.7%	108	0.8	0.8%

Notes: Historical data from IEA. 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 results for Equinor and OPEC are excluded because of insufficient data.

Table 10. Natural Gas Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	66	—	—	55	—	—	9	—	—
2015	117	2.0	2.3%	74.0	0.8	1.2%	43	1.4	6.5%
2018	130	4.3	3.6%	80.4	2.1	2.8%	49	2.2	4.8%
2040		2018-2040			2018-2040			2018-2040	
BP ET	175	2.0	1.4%	89	0.4	0.5%	86	1.7	2.5%
BP RT	165	1.6	1.1%	67	-0.6	-0.8%	98	2.2	3.2%
US EIA	156	1.2	0.8%	85	0.2	0.3%	71	1.0	1.7%
Equinor Reform	153	1.0	0.7%	—	—	—	—	—	—
Equinor Renewal	122	-0.4	-0.3%	—	—	—	—	—	—
Equinor Rivalry	151	1.0	0.7%	—	—	—	—	—	—
ExxonMobil	177	2.1	1.4%	86	0.3	0.3%	92	1.9	2.9%
IEA CPS	192	2.8	1.8%	99	0.8	1.0%	93	2.0	2.9%
IEA STEPS	176	2.1	1.4%	89	0.4	0.5%	86	1.7	2.5%
IEA SDS	125	-0.2	-0.2%	60	-0.9	-1.3%	65	0.7	1.2%
IEEJ	186	2.5	1.6%	93	0.6	0.7%	92	1.9	2.9%
OPEC	178	2.2	1.4%	—	—	—	—	—	—
Shell Sky	143	0.6	0.4%	74	-0.3	-0.4%	67	0.8	1.4%

Notes: Historical data from IEA. Regional results for Equinor and OPEC are excluded because of insufficient data.

Table 11. Coal Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1965	55	—	—	45	—	—	10	—	—
1990	88	1.3	5.3%	52.0	0.3	1.1%	36	1.0	4.2%
2015	152	2.6	2.2%	37.0	-0.6	-1.4%	115	3.2	4.8%
2018	152	2.3	2.0%	33.7	-0.7	-1.5%	118	2.9	4.3%
2040		2018-2040			2018-2040			2018-2040	
BP ET	147	-0.2	-0.2%	18	-0.7	-2.8%	129	0.5	0.4%
BP RT	44	-4.9	-5.5%	3	-1.4	-10.4%	41	-3.5	-4.7%
US EIA	150	-0.1	-0.1%	24	-0.4	-1.5%	126	0.4	0.3%
Equinor Reform	124	-1.3	-0.9%	—	—	—	—	—	—
Equinor Renewal	57	-4.3	-4.4%	—	—	—	—	—	—
Equinor Rivalry	154	0.1	0.1%	—	—	—	—	—	—
ExxonMobil	133	-0.9	-0.6%	15	-0.9	-3.6%	118	0.0	0.0%
IEA CPS	178	1.2	0.7%	26	-0.4	-1.2%	151	1.5	1.1%
IEA STEPS	150	-0.1	-0.1%	20	-0.6	-2.3%	129	0.5	0.4%
IEA SDS	58	-4.3	-4.3%	6	-1.3	-7.5%	52	-3.0	-3.7%
IEEJ	169	0.8	0.5%	20	-0.6	-2.3%	142	1.1	0.9%
OPEC	152	0.0	0.0%	—	—	—	—	—	—
Shell Sky	123	-1.3	-1.0%	14	-0.9	-3.9%	109	-0.4	-0.4%

Notes: Historical data from IEA (1990) and Grubler (1965). Regional results for Equinor and OPEC are excluded because of insufficient data.

Table 12. Nuclear Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	21	—	—	18	—	—	3	—	—
2015	27	0.2	1.0%	22.0	0.2	0.8%	5	0.1	2.1%
2018	28	0.3	1.2%	22.4	0.1	0.6%	6.1	0.4	6.9%
2040		2018-2040			2018-2040			2018-2040	
BP ET	35	0.3	1.0%	15	-0.3	-1.8%	20	0.6	5.5%
BP RT	46	0.8	2.3%	23	0.0	0.1%	23	0.8	6.2%
US EIA	35	0.3	1.0%	19	-0.2	-0.7%	16	0.5	4.5%
Equinor Reform	35	0.3	1.0%	—	—	—	—	—	—
Equinor Renewal	44	0.7	2.1%	—	—	—	—	—	—
Equinor Rivalry	34	0.3	0.9%	—	—	—	—	—	—
ExxonMobil	45	0.8	2.2%	21	-0.1	-0.3%	24	0.8	6.4%
IEA CPS	37	0.4	1.3%	19	-0.2	-0.7%	18	0.5	5.0%
IEA STEPS	18	-0.5	-2.0%	18	-0.2	-1.0%	18	0.5	5.0%
IEA SDS	46	0.8	2.3%	22	0.0	-0.1%	24	0.8	6.4%
IEEJ	32	0.2	0.6%	19	-0.2	-0.7%	14	0.4	3.8%
OPEC	43	0.7	2.0%	—	—	—	—	—	—
Shell Sky	62	1.5	3.7%	23	0.0	0.1%	33	1.2	8.0%

Notes: Historical data from IEA. Regional results for Equinor and OPEC are excluded because of insufficient data.

Table 13. Renewables (Including Hydro) Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	45	—	—	16	—	—	29	—	—
2015 (incl. non-marketed biomass)	74	1.2	2.0%	28	0.5	2.3%	46	0.7	1.9%
2018 (incl. non-marketed biomass)	76	0.7	0.9%	31.3	1.1	3.8%	48.5	0.8	1.8%
2040 (incl. non-marketed biomass)		2018-2040			2018-2040			2018-2040	
Equinor Reform	138	2.9	2.9%	—	—	—	—	—	—
Equinor Renewal	164	4.1	3.7%	—	—	—	—	—	—
Equinor Rivalry	127	2.4	2.5%	—	—	—	—	—	—
ExxonMobil	109	1.6	1.8%	39	0.5	1.5%	70	1.1	1.9%
IEA CPS	124	2.3	2.4%	45	0.8	2.2%	79	1.5	2.5%
IEA STEPS	137	2.9	2.8%	49	1.0	2.6%	88	1.9	3.0%
IEA SDS	162	4.0	3.6%	64	1.6	3.8%	98	2.4	3.5%
IEEJ	106	1.4	1.6%	38	0.5	1.4%	67	1.0	1.8%
OPEC	114	1.8	2.0%	—	—	—	—	—	—
Shell Sky	202	5.8	4.7%	82	2.5	5.0%	121	3.4	4.5%
2015 (excl. non-marketed biomass)	24		46	15			9		
2018 (excl. non-marketed biomass)	28	1.2	4.6%	16	0.2	1.3%	12	1.0	10.1%
2040 (excl. non-marketed biomass)		2018-2040			2018-2040			2018-2040	
BP ET	64	1.8	4.6%	28	0.6	2.9%	35	1.2	6.4%
BP RT	98	3.4	6.6%	39	1.1	4.4%	59	2.3	8.9%
US EIA	66	1.9	4.7%	27	0.6	2.8%	39	1.4	6.9%

Notes: Historical data from IEA (including marketed biomass) and US EIA (excluding marketed biomass). Regional results for Equinor and OPEC are excluded because of insufficient data.

Table 14. Non-Hydro Renewables Consumption, by Region

qBtu	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR	qBtu	qBtu	CAAGR
1990	38	—	—	10	—	—	27	—	—
2015 (incl. non-marketed biomass)	60	0.9	1.8%	21	0.4	3.0%	40	0.5	1.6%
2018 (incl. non-marketed biomass)	62	0.7	1.1%	23	0.8	3.7%	42	0.7	1.6%
2040 (incl. non-marketed biomass)		2018-2040			2018-2040			2018-2040	
Equinor Reform	119	2.6	3.0%	—	—	—	—	—	—
Equinor Renewal	143	3.7	3.9%	—	—	—	—	—	—
Equinor Rivalry	109	2.1	2.6%	—	—	—	—	—	—
ExxonMobil	91	1.3	1.8%	30	0.3	1.1%	61	0.9	1.7%
IEA CPS	104	1.9	2.4%	35	0.5	1.8%	69	1.2	2.3%
IEA STEPS	116	2.5	2.9%	38	0.7	2.2%	78	1.6	2.9%
IEA SDS	138	3.5	3.7%	52	1.3	3.7%	86	2.0	3.3%
IEEJ	88	1.2	1.6%	30	0.3	1.1%	58	0.7	1.5%
OPEC	104	1.9	2.4%	—	—	—	—	—	—
Shell Sky	186	5.6	5.1%	72	2.2	5.2%	114	3.3	4.6%
2015 (excl. non-marketed biomass)	11			7			4		
2018 (excl. non-marketed biomass)	13	0.7	5.7%	7	0.1	0.9%	6	0.5	11.9%
2040 (excl. non-marketed biomass)		2018-2040			2018-2040			2018-2040	
BP ET	45	1.4	5.8%	19	0.5	4.5%	26	0.9	7.2%
BP RT	77	2.9	8.4%	28	1.0	6.4%	49	2.0	10.3%
US EIA	47	1.5	6.0%	17	0.4	4.0%	30	1.1	7.9%

Notes: Historical data from IEA (including marketed biomass) and US EIA (excluding marketed biomass). Regional results for Equinor and OPEC are excluded because of insufficient data.

Table 15. Global Electricity Generation

TWh	Coal	Natural gas	Hydro	Nuclear	Other renewables	Oil	Total
1990	4,403	1,752	2,142	2,013	172	1,242	11,864
2015	9,524	5,543	3,888	2,571	1,720	843	24,255
2018	10,123	6,188	4,203	2,718	2,596	808	26,603
2040							
BNEF	7,896	6,587	5,089	3,190	16,383	187	39,678
BP ET	10,986	7,672	5,504	3,402	11,510	487	39,650
BP RT	1,598	7,818	6,199	4,473	19,858	1	40,258
US EIA[1]	8,601	8,115	5,770	3,281	11,150	190	37,107
Equinor Reform	9,525	11,134	5,638	3,366	12,916	639	43,218
Equinor Renewal	4,004	8,512	6,187	4,233	18,128	317	41,381
Equinor Rivalry	11,339	10,419	5,421	3,282	10,626	864	41,950
IEA CPS	12,923	10,186	5,923	3,597	9,562	603	42,824
IEA STEPS	10,431	8,899	6,098	3,475	11,951	490	41,373
IEA SDS	2,428	5,584	6,934	4,409	19,131	197	38,713
IEEJ	12,954	11,250	5,225	3,136	7,015	787	40,404
Shell Sky	6,261	8,927	4,210	5,287	23,682	418	48,686

Notes: Historical data from IEA. (1) US EIA reports net electricity generation; other organizations report gross generation.

Table 16. 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
2018	4,203	636	1265	604	91	6,799
2040						
BNEF	5,089	646	6,425	9,179	133	21,472
BP ET	5,504	1,118	4,704	5,445	243	17,013
BP RT	6,199	1,544	8,466	9,478	370	26,057
US EIA[2]	4,210	2,471	8,279	12,423	509	27,892
Equinor Reform	6,187	2,355	6,961	7,464	1,348	24,315
Equinor Renewal	6,199	1,544	8,466	9,478	370	26,057
Equinor Rivalry	4,210	2,471	8,279	12,423	509	27,892
ExxonMobil	5,355	—	4,938	—	7,727[3]	18,020
IEA CPS	5,923	1,256	3,762	4,258	285	15,485
IEA STEPS	6,098	1,459	4,901	5,226	365	18,049
IEA SDS	6,934	2,196	8,013	8,295	627	26,065
IEEJ	5,225	1,196	2,228	3,114	477	12,240
Shell Sky	4,210	2,471	8,279	12,423	509	27,892

Notes: (1) includes wind and solar. (2) US EIA reports net electricity generation, while other organizations report gross generation. (3) includes solar and biomass.

Table 17. Global Energy-Related Net Carbon Dioxide Emissions

	World	Average annual growth		West	Average annual growth		East	Average annual growth	
	BMT	BMT	CAAGR	BMT	BMT	CAAGR	BMT	BMT	CAAGR
1990	20.5			13.9			6.0		
2015	32.3	0.47	1.8%	13.0	0.0	−0.3%	18.2	0.5	4.5%
2018	33.2	0.3	1.0%	13.0	0.0	0.0%	18.9	0.2	1.4%
2040		2018-2040			2018-2040			2018-2040	
BP ET	35.9	0.1	0.4%	11.8	-0.1	-0.4%	24.1	0.2	1.1%
BP RT	18	-0.7	-2.7%	6.3	-0.3	-3.2%	11.7	-0.3	-2.2%
US EIA	38.8	0.3	0.7%	13.5	0.0	0.2%	25.4	0.3	1.3%
Equinor Reform	31.1	-0.1	-0.3%	-	-	-	-	-	-
Equinor Renewal	18.2	-0.7	-2.7%	-	-	-	-	-	-
Equinor Rivalry	36.2	0.1	0.4%	-	-	-	-	-	-
ExxonMobil	35	0.1	0.2%	11.6	-0.1	-0.5%	23.5	0.2	1.0%
IEA CPS	41.3	0.4	1.0%	12.9	0.0	0.0%	26.3	0.3	1.5%
IEA STEPS	35.6	0.1	0.3%	10.9	-0.1	-0.8%	22.8	0.2	0.8%
IEA SDS	15.8	-0.8	-3.3%	5.1	-0.4	-4.2%	9.7	-0.4	-3.0%
IEEJ	40.1	0.3	0.9%	12.4	0.0	-0.2%	25.8	0.3	1.4%
OPEC	38.2	0.2	0.6%	-	-	-	-	-	-
Shell Sky	28.7	-0.2	-0.7%	8.6	-0.2	-1.9%	19.3	0.0	0.1%

Notes: Historical data from IEA. Regional results for Equinor and OPEC are excluded because of insufficient data.

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