RESOURCES
for the FUTURE

Global Energy Outlook 2021: Pathways from Paris

Richard Newell, Daniel Raimi, Seth Villanueva, Brian Prest

Report 21-11
June 2021

About the Authors

Richard G. Newell is president and CEO of Resources for the Future (RFF), an independent, nonprofit research institution that improves environmental, energy, and natural resource decisions through impartial economic research and policy engagement. From 2009 to 2011, he served as the administrator of the US Energy Information Administration, the agency responsible for official US government energy statistics and analysis. Dr. Newell is an adjunct professor at Duke University, where he was previously the Gendell Professor of Energy and Environmental Economics and founding director of its Energy Initiative and Energy Data Analytics Lab. He has also served as the senior economist for energy and environment on the President's Councilof Economic Advisers and was previously a senior fellow and a board member at RFF.

Daniel Raimi is a fellow at RFF and a lecturer at the Gerald R. Ford School of Public Policy at the University of Michigan. He works on a range of energy policy issues with a focus on tools to enable an equitable energy transition. He has published in academic journals including *Science*, *Science Advances*, *Environmental Science and Technology*, *Journal of Economic Perspectives*, and more, and in popular outlets including *The New Republic*, *Newsweek*, *Slate*, and *Fortune*. He has presented his research for policymakers, industry and other stakeholders around the United States and internationally, including before the Energy and Mineral Resources Subcommittee of the US House's Natural Resources Committee. **The Fracking Debate**, his first book, combines stories from his travels to dozens of oil and gas producing regions with a detailed examination of key policy issues, and is published by Columbia University Press as part of the Columbia University Center on Global Energy Policy book series.

Seth Villanueva is research analyst at RFF. His current work focuses on energy projection analysis for RFF's annual Global Energy Outlook report as well as research on the regional and distributional effects of clean energy and climate policy. Villanueva graduated from UC Santa Barbara in 2019 with a BA in economics and a minor in mathematics. At UCSB, he was an undergraduate Gretler Fellow research assistant studying the economic impact of scaled wind power generation. Other research that Villanueva has contributed to at RFF includes a pair of value of information studies as part of the VALUABLES Consortium and energy transition policy analysis.

Brian Prest is a fellow at Resources for the Future specializing in climate change, electricity markets, and oil and gas economics. Prest uses economic theory and econometric models to improve energy and environmental policies by assessing their impacts on markets and pollution outcomes. His recent work includes evaluating the impacts of federal tax credits for coal use. He is also working to establish an empirical basis for determining discount rates used in the social cost of carbon. His past work includes econometric analysis of the US oil and gas industry, understanding the economic effects of rising temperatures, modeling the market dynamics of climate change policy under policy uncertainty, and assessing household responses to timevarying electricity pricing. His work has appeared in the *Journal of the Association of Environmental and Resource Economists*, *Energy Economics*, and *The Energy Journal*.

Acknowledgements

We thank Stu Iler, who initially developed the platform for harmonizing outlooks. We also thank those who assisted by providing data and context, including Matthias Kimmel and Seb Henbest at BloombergNEF; Christof van Agt at the International Energy Forum; Will Zimmern at BP; Tord Bjørndal at Equinor; Filip Schittecatte at ExxonMobil; Tim Gould, Laura Cozzi, and Pawel Olejarnik at IEA; Dolph Geilen, Prakash Gayarthi, Francesco La Camera, and Nicholas Wagner at IRENA; and Julius Walker at OPEC. We would also like to thank Massimo Tavoni of the RFF-CMCC European Institute on Economics and the Environment for assistance in incorporating scenarios from the IPCC process. We also thank Zeke Hausfather of the Breakthrough Institute and Julio Friedmann of Columbia University's Center on Global Energy Policy for help with technical questions related to carbon budgets and carbon capture.

Photos: Simeonn / Shutterstock (cover); Marek Piwnicki / Unsplash.com (page 14); Matthew Henry / Unsplash.com (page 19); Andreas Gücklhorn / Unsplash.com (page 22).

About RFF

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

Sharing Our Work

Abstract

As parts of the world begin to recover from the COVID-19 pandemic, a fundamental shift in the global energy system is needed to avoid the worst impacts of climate change. Despite efforts by policymakers in some nations to stimulate a “green” recovery, far greater effort will be required to spur the scale and speed of technological change necessary to limit warming to 1.5° or 2° Celsius by 2100. 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 range widely from those that assume little to no change in energy and climate policies to those that lay out technological feasible yet politically challenging pathways to limit climate change, improve energy access, and reduce air pollution. This year’s report provides particular insight into the differences between pathways aligned with the 1.5° and 2° Celsius climate targets; the effects of COVID-19 on future population, GDP, and energy demand; and the energy intensity of the global economy.

Contents

1. Introduction

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. Table 1 shows the historical datasets, outlooks, and scenarios.

Table 1. Outlooks and scenarios examined in this report

Source	Dataset or Outlook	Scenario(s)	Years
Grubler (2008)	Historical	—	1800–1970
IEA (2018)	Historical	—	1970–2015
IEA (2021)	Historical	—	2020
BloombergNEF (2020)	New Energy Outlook 2020	Economic Transition Scenario	To 2050
BP (2020)	Energy Outlook 2020	Business as Usual (BAU), Rapid Transition (RT), Net Zero (NZ)	To 2040
Equinor (2020)	Energy Perspectives 2020	Reform, Renewal, Rivalry	To 2050
IEA (2020)	World Energy Outlook 2020	Stated Policies (STEPS), Sustainable Development (SDS)	To 2040
IPCC (Rogelj et al. 2018)	Special Report on 1.5°C	Illustrative pathways 1–4 (IP1, IP2, IP3, IP4)	To 2100
IRENA (2020)	Global Renewables Outlook	Planned Energy Scenario, Transforming Energy Scenario	To 2050
OPEC (2020)	World Oil Outlook 2020	Reference	To 2045

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**.

We include 2020 energy demand and emissions figures based on estimates provided in the IEA's Global Energy Review 2021. However, most of our analysis compares future energy and emissions levels with those seen in 2019, which we choose as a baseline because it was relatively unaffected by the COVID-19 pandemic.

We use a consistent labeling system that distinguishes among the different scenarios (see Table 2):

- For “Reference” scenarios, which assume limited or no new policies, and for Equinor’s Rivalry scenario, which assumes continued geopolitical challenges, we use a long-dashed line: this set comprises Equinor’s Rivalry, IRENA’s Planned Energy Scenario, and OPEC’s Reference.
- 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, BP BAU, Equinor Reform, and IEA STEPS.
- For “Ambitious Climate” scenarios, which are built around limiting global mean temperature rise to 2°C by 2100, we use short-dashed lines: this set comprises BP’s Rapid Transition, Equinor’s Rebalance, IEA’s SDS, and IRENA’s Transforming Energy Scenario.
- Finally, we include an additional set of Ambitious Climate scenarios designed to limit global mean temperature rise to 1.5°C by 2100, which we illustrate with a dotted line: BP’s Net Zero and the four Illustrative Pathways (IPs) published in the IPCC’s 2018 Special Report on 1.5°C. For additional detail on scenarios, see Table 5.

Table 2. Legend for Different Scenario Types

Reference	Evolving Policies	Ambitious Climate (2°C)	Ambitious Climate (1.5°C)
Equinor Rivalry	BNEF	BP Rapid Transition	BP Net Zero
IRENA Planned	BP BAU	Equinor Rebalance	IPCC IP1
OPEC	Equinor Reform	IEA SDS	IPCC IP2
	IEA STEPS	IRENA Transforming	IPCC IP3
			IPCC IP4

Figures and tables in this report frequently refer to regional groupings of “East” and “West.”[1] Table 3 provides those regional groupings.

Table 3. Regional definitions for “East” and “West”

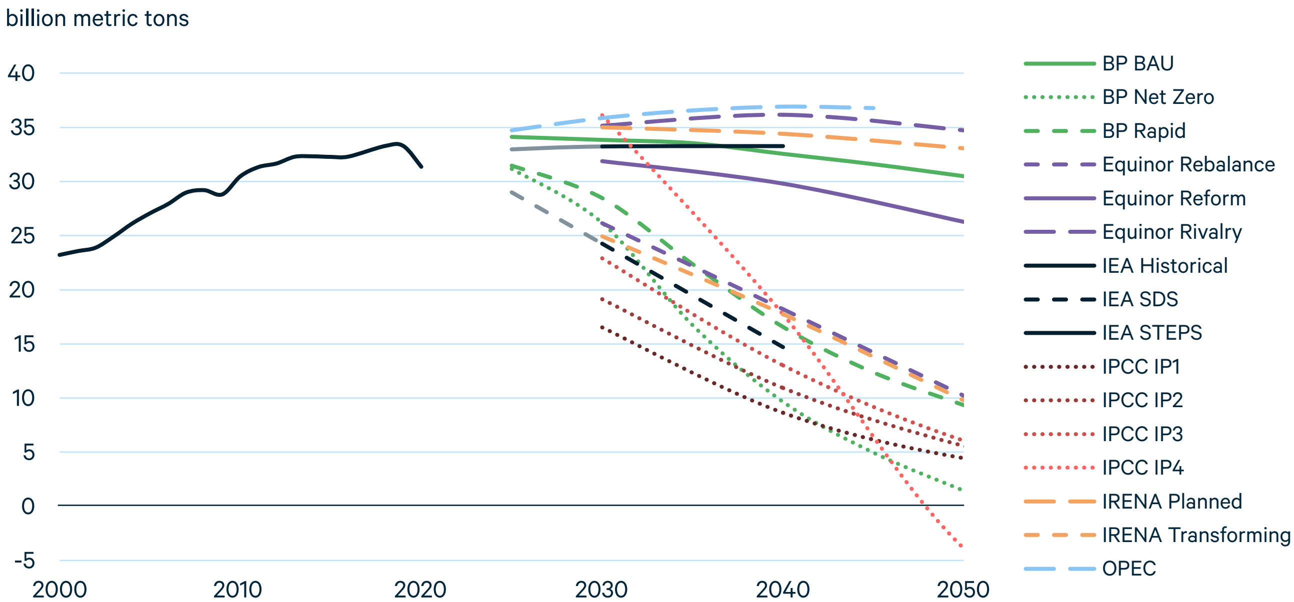
“East”	Africa, Asia-Pacific, Middle East
“West”	Americas, Europe, Eurasia

1 In the figures and tables that follow, we aggregate these regional groupings for all scenarios that provide sufficient data to do so.

2. Key findings

The global energy system lies at an inflection point. To achieve the long-term climate targets articulated in the 2015 Paris Agreement, energy-related **carbon dioxide** (CO_2) emissions will need to decline dramatically. Reference and Evolving Policies scenarios show that current efforts fall well short of the reductions needed to achieve stated targets.

Figure 1. Global carbon dioxide emissions

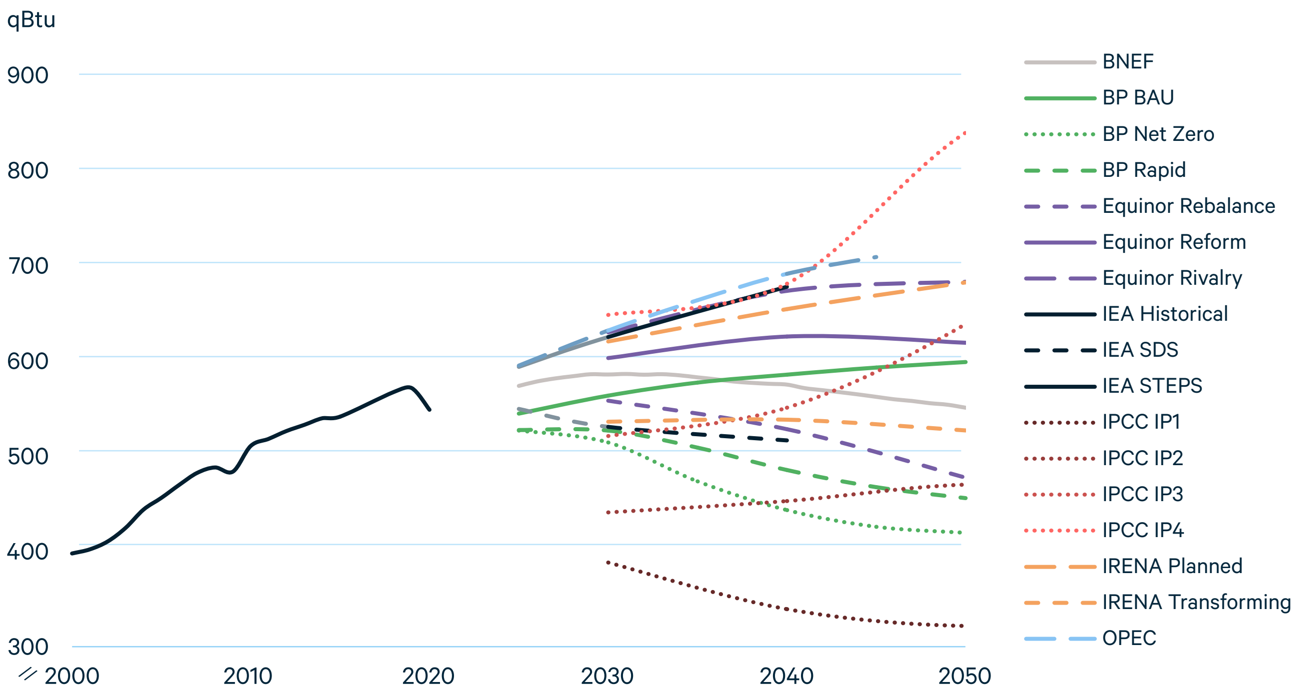


While 2020 saw roughly a 6 percent decrease in global CO_2 emissions, the IEA projects that 2021 will see a rebound to 2019 levels or above. Emissions roughly plateau over the next 2–3 decades under most Reference and Evolving Policies scenarios, and global **CO_2 emissions** range from 4 percent above to 21 percent below 2019 levels by 2050.

Ambitious Climate scenarios that target limiting the 2100 temperature rise to “well below 2°C” project **CO_2 emissions** falling to roughly 10 billion metric tons (BMT) by 2050, or about 70 percent lower than 2019 emissions. For scenarios that seek to limit global temperature rise to 1.5°C by 2100, emissions fall to 5 BMT or lower by 2050. In one scenario, IPCC’s IP4, global emissions rise considerably from 2018 levels (when the scenario was published), then fall below zero by 2050, as negative emissions technologies reduce atmospheric CO_2 concentrations to limit temperature rise by 2100.

Scenarios envision a wide range of potential future growth of global **primary energy** demand, even within scenario types. Compared with 2019, energy consumption increases by as much as 47 percent under the highest-growth scenario (IPCC IP4) and decreases by as much as 44 percent under the lowest-growth scenario (IPCC IP1) by 2050.

Figure 2. Global primary energy consumption

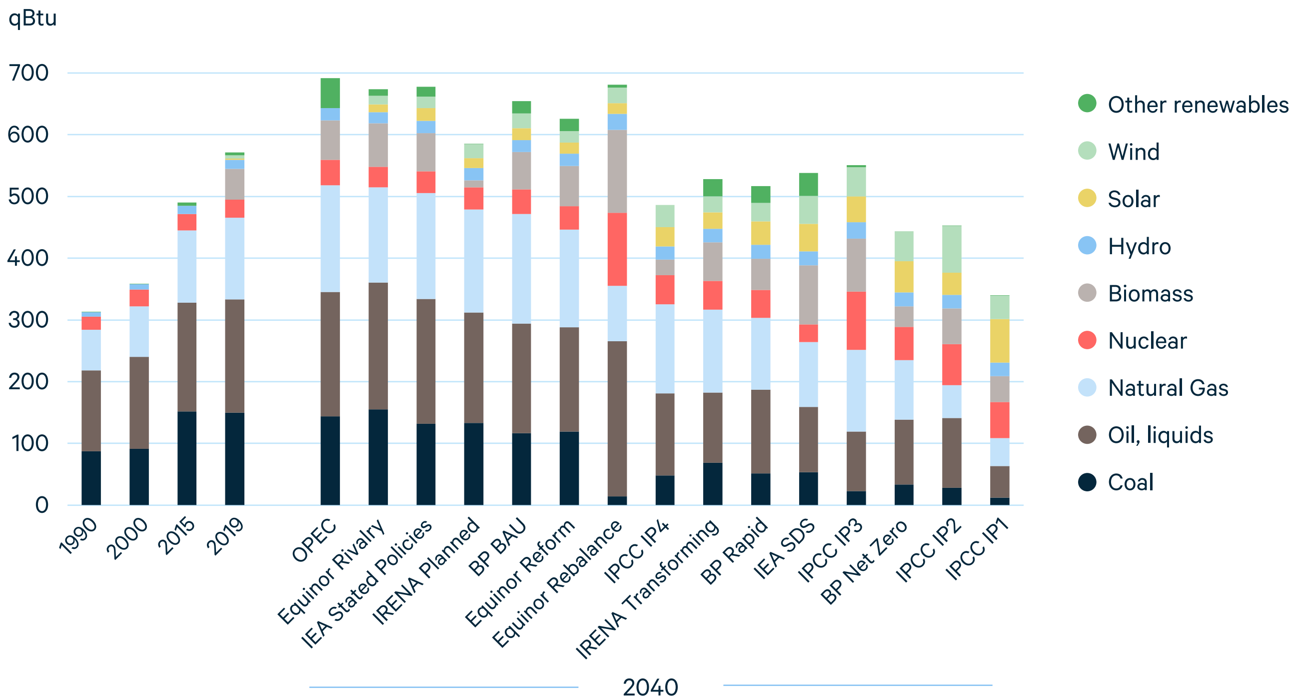


The majority of Reference and Evolving Policies scenarios project that global energy demand will grow more modestly than the increases seen since 2000 and begin to level off toward midcentury. However, projections vary across these scenarios. In 2019, global **primary energy** demand totaled 572 quadrillion (10^{15}) British thermal units (QBtu). BNEF projects that by 2050 demand falls modestly to 551 QBtu, whereas OPEC's Reference Case reaches as high as 709 QBtu by 2045.

Ambitious Climate scenarios vary more widely, largely due to the high-energy-demand scenarios from the IPCC: under IP3 and IP4, energy consumption accelerates in the next several decades as the **carbon intensity** of the energy mix declines, allowing for emissions to fall even as energy consumption grows. Most other Ambitious Climate scenarios, however, anticipate a decline in global energy consumption as **energy efficiency** measures reduce the **energy intensity** of the economy. Under BP's Net Zero scenario, for example, global demand falls to 420 QBtu by 2050, and IPCC IP1 decreases to 322 QBtu.

Under most Reference and Evolving Policies scenarios, aggregate **fossil fuel** consumption in 2040 is similar to, and in some cases substantially higher than, 2019 levels. Under Ambitious Climate scenarios, fossil fuel use declines dramatically, with the possible exception of **natural gas**, which is the only fossil fuel that grows across the majority of scenarios, including some Ambitious Climate scenarios. **Renewable energy resources** see substantial growth in all scenarios, particularly in deep decarbonization scenarios (Figure 3).

Figure 3. Global primary energy fuel shares in 2040



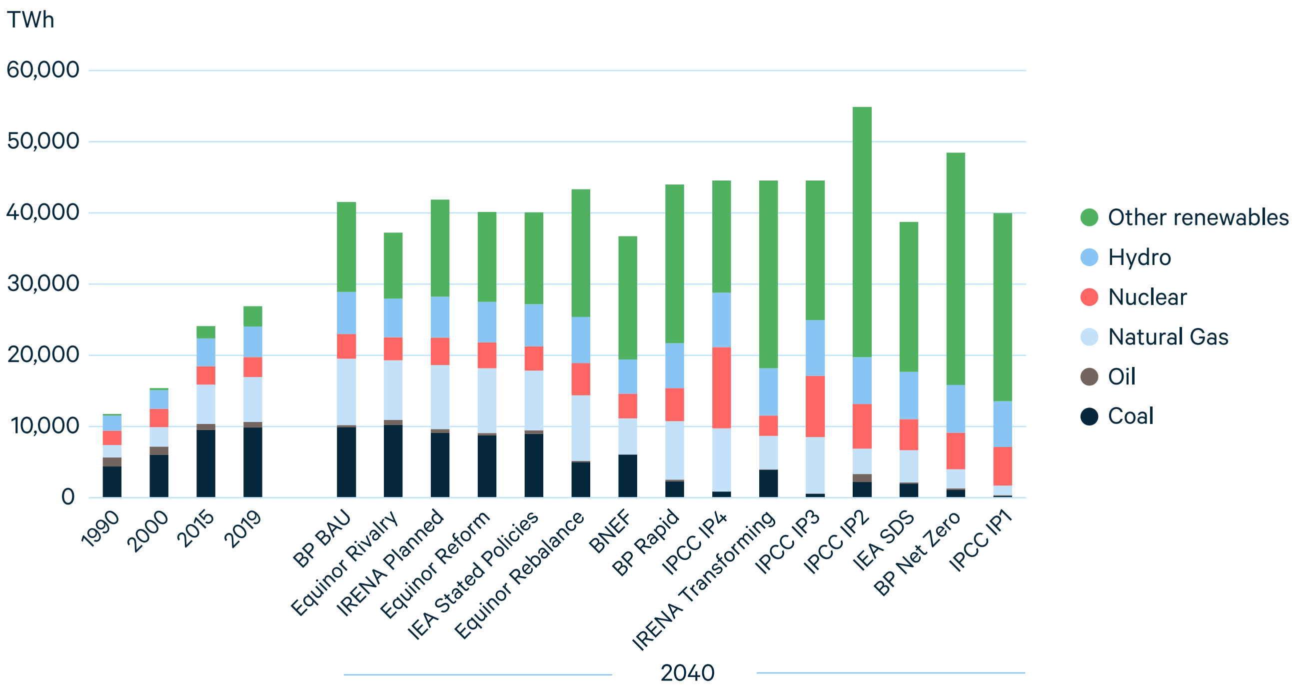
Note: "Other renewables" includes wind and solar for OPEC.

While varying regionally, global **coal** use declines in the coming decades across almost all scenarios. Under IPCC 1.5 scenarios, it approaches zero in 2040. **Natural gas** use grows by 35–52 percent under Evolving Policies and Reference scenarios, but under Ambitious Climate scenarios, 2040 demand ranges widely: stable at 2019 levels under the IEA's SDS and falling by more than 60 percent under IPCC IP1. **Liquids** (which includes oil) use grows more modestly in central scenarios, by just 2 percent under BP's BAU and as much as 17 percent under Equinor's Rivalry. Most Ambitious Climate scenarios show liquids demand falling by 20 percent or more by 2040, although IPCC IP4 has growth of more than 40 percent.

Nuclear and **hydropower** both rise under all scenarios, but with wide variation. Nuclear more than doubles under all IPCC 1.5 scenarios and ranges from 85 percent growth under BP Net Zero to just 1 percent under IRENA Transforming. Hydropower grows by 48–81 percent under Ambitious Climate scenarios, with a range of 26–38 percent growth under Reference and Evolving Policies scenarios.

The full range of outlooks project global **electricity** generation to increase through 2040 by between 37 percent (BNEF) and 104 percent (IP2) over 2019 generation. In some Ambitious Climate scenarios (e.g., BP Net Zero, IPCC IP2) the electrification of new sectors, such as transportation and heating, lead to higher levels of overall electricity generation. In others (e.g., IEA SDS, IPCC IP1), **energy efficiency** gains play a larger role, leading to relatively low levels of electricity demand (Figure 4).

Figure 4. Global electricity mix in 2040

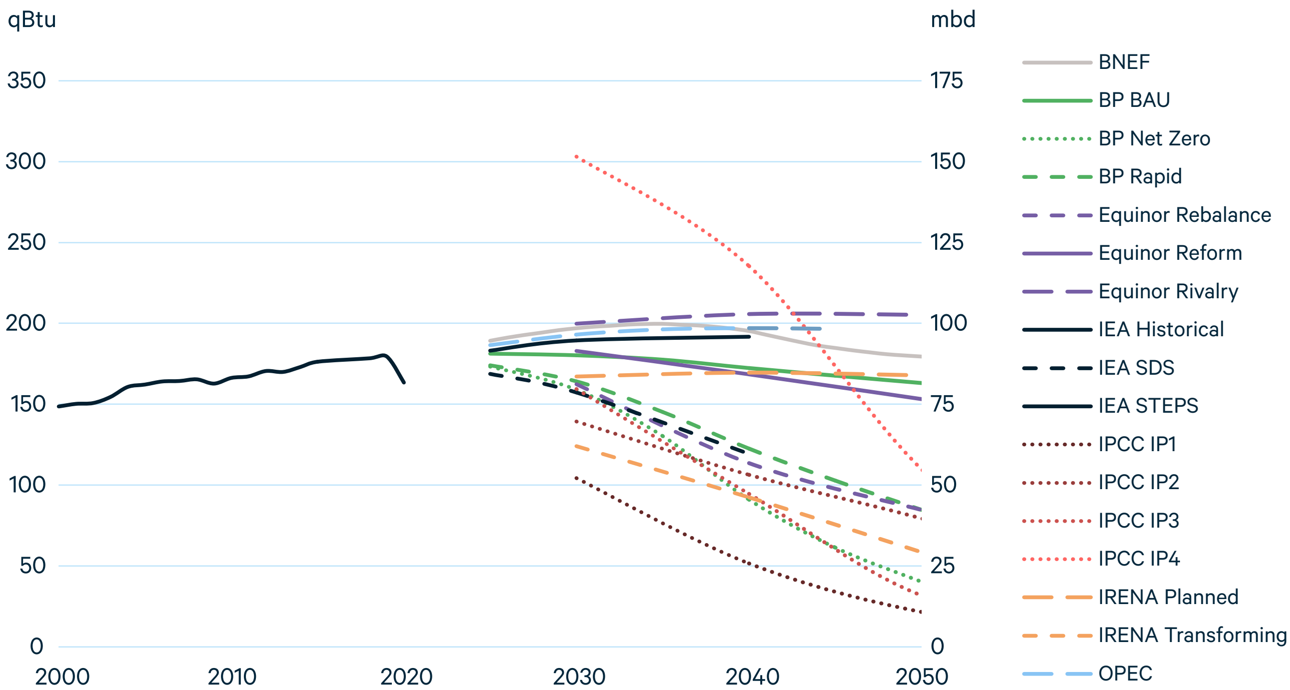


Fossils fuels continue to produce a significant portion of global electricity in Reference and Evolving Policies scenarios; between 30 (BNEF) and 52 (Equinor Rivalry) percent in 2040. **Coal** use remains virtually constant in these scenarios, whereas oil use approaches zero across the board. **Natural gas** use grows substantially in most Reference and Evolving Policies scenarios, by as much as 48 percent (BP BAU) between 2019 and 2040, with only BNEF projecting a decrease of 20 percent. Ambitious Climate scenarios see overall fossil fuels, particularly coal, significantly diminish through 2040, though some predict a persistent use of natural gas.

Both **nuclear** and **hydro** see growth in all projections, with 1.5°C scenarios having the largest. **Non-hydro renewable** energy resources vary dramatically across the spectrum of scenarios, yet all involve substantial growth. Other renewables can grow as much as 10–11 times from 2019 to 2040 in the 1.5°C scenarios BP Net Zero and IP2, respectively, but Reference and Evolving Policies estimates do not exceed 3.7 (IRENA Planned) or 5.0 (BNEF) times 2019 levels.

The volatility and declines of 2020 in global **oil** markets are expected to be short-lived, and as we look forward, the current suite of energy projections are split on future oil demand. Reference and Evolving Policies scenarios cast a fairly narrow band of long-term oil demand futures: IEA STEPS lies near the center of these projections, showing oil demand in 2040 roughly 7 percent above 2019 levels. Ambitious Climate scenarios all show contraction in oil demand by midcentury, ranging from a decrease of 39 (IPCC IP4) to 88 (IPCC IP1) percent by 2050 (Figure 5).

Figure 5. Global oil demand



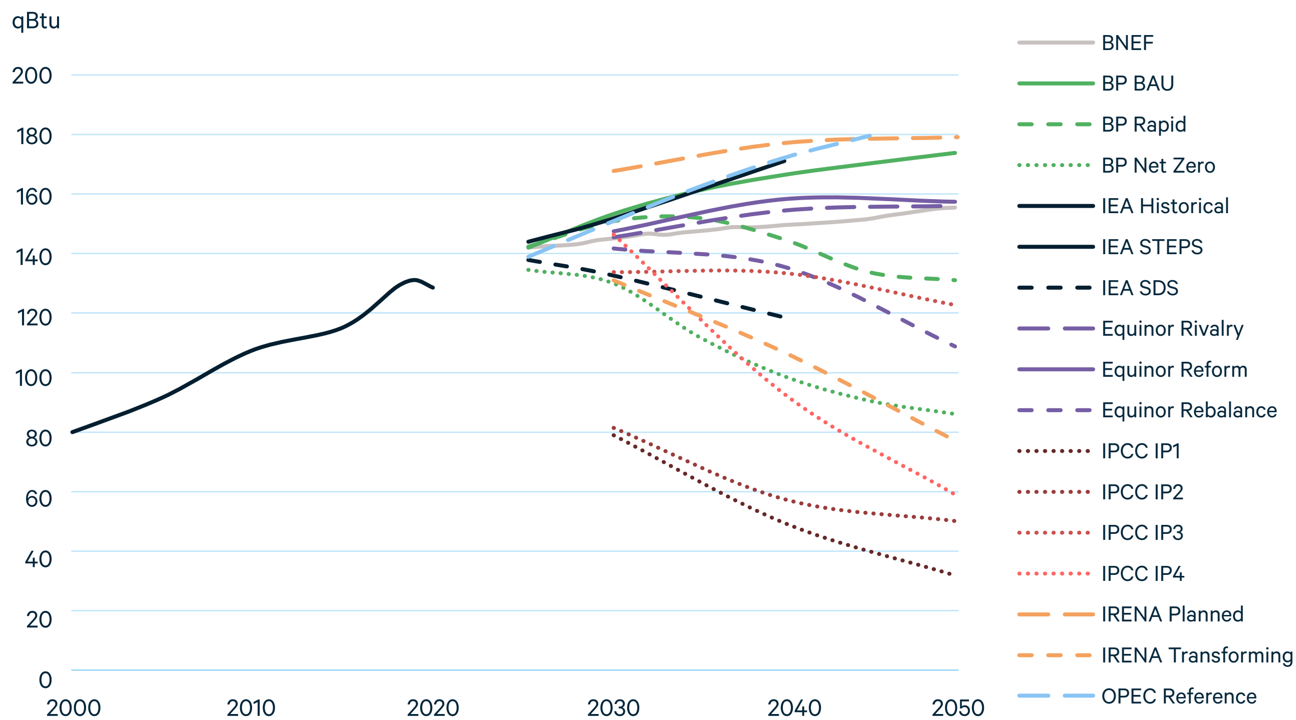
Note: Right-hand y-axis assumes a constant conversion factor of 1.976 QBtu per mbd.

Globally, **oil** demand growth has been driven primarily by the transportation sector. If public policies and continued technological advancements accelerate the electrification of transportation, oil will become less significant, particularly for light-duty transportation. However, considerable demand for oil will likely persist for the foreseeable future due to its comparative advantages for heavy-duty and long-distance transportation and the petrochemicals sector.

This growth continues to be concentrated in the Global East, where expansion is projected through at least the next decade. Under Reference and Evolving Policies scenarios, India and Africa are projected to see sustained growth, and Ambitious Climate scenarios would see this trend reverse in the long run.

Demand for **natural gas** varies widely across scenarios. Even within the subset of Ambitious Climate scenarios, demand in 2050 ranges from a high of 130 (BP Rapid) to a low of 27 (IPCC IP1) QBtu. All Reference and Evolving Policies scenarios project global growth to continue through 2040, although several of them envision a plateau or modest decline for 2040–2050 (Figure 6).

Figure 6. Global natural gas demand

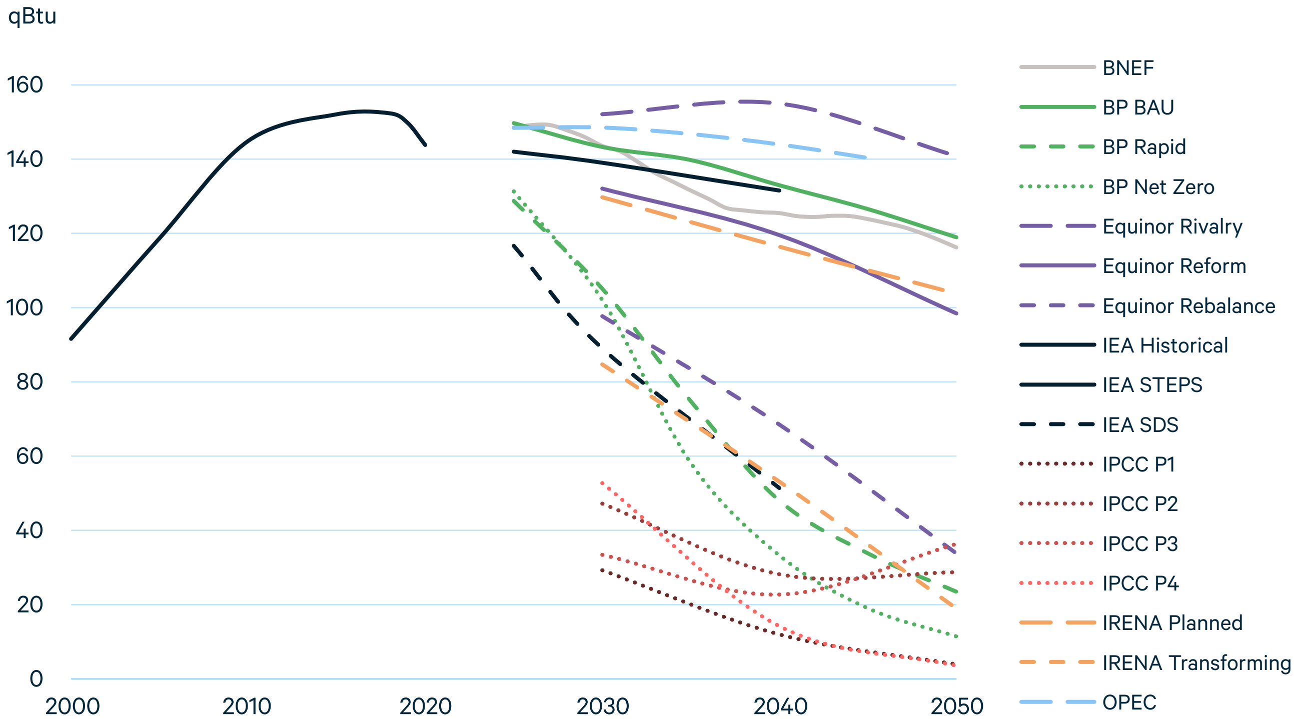


Natural gas demand has grown dramatically in recent decades, displacing **coal** in the power sector and becoming more widely used in buildings and industry around the world. Looking forward, global gas demand will need to decline to achieve the 1.5°C or 2°C goals of the Paris Agreement, but with wide variation across regions. For example, gas consumption grows dramatically across Africa, China, and India under Ambitious Climate scenarios, pushing coal out of the power sector, but falls by 40–50 percent by 2050 relative to 2019 levels in Europe and North America as **renewables** and **energy efficiency** displace gas.

Reducing **methane** emissions from **oil and natural gas** supply chains will also be a critical piece of limiting global temperature rise, especially in the near and medium terms. For example, the IEA's World Energy Outlook highlights the wide variation in methane emissions per unit of oil produced around the world and notes that "huge and rapid improvements" are likely achievable. Some outlooks also highlight the potential for **biogases**, including **biomethane**, to play a more substantial role in the future energy system.

Global **coal** demand fell dramatically in 2019 and 2020, and all scenarios project a mostly downward trend in the years ahead. In 2020, coal use dropped by an estimated 4 percent, and under most Ambitious Climate scenarios, a similar rate of decline continues for the foreseeable future. However, the IEA projects that coal demand in 2021 will exceed its 2019 levels. Reflecting this potential return to "business as usual," all Reference and Evolving Policies scenarios envision a slower contraction, with coal remaining at or above 100 QBtu through 2050. In some IPCC scenarios, demand stabilizes and begins to rise around 2040 as CCUS technologies become deployed widely (Figure 7)

Figure 7. Global coal demand

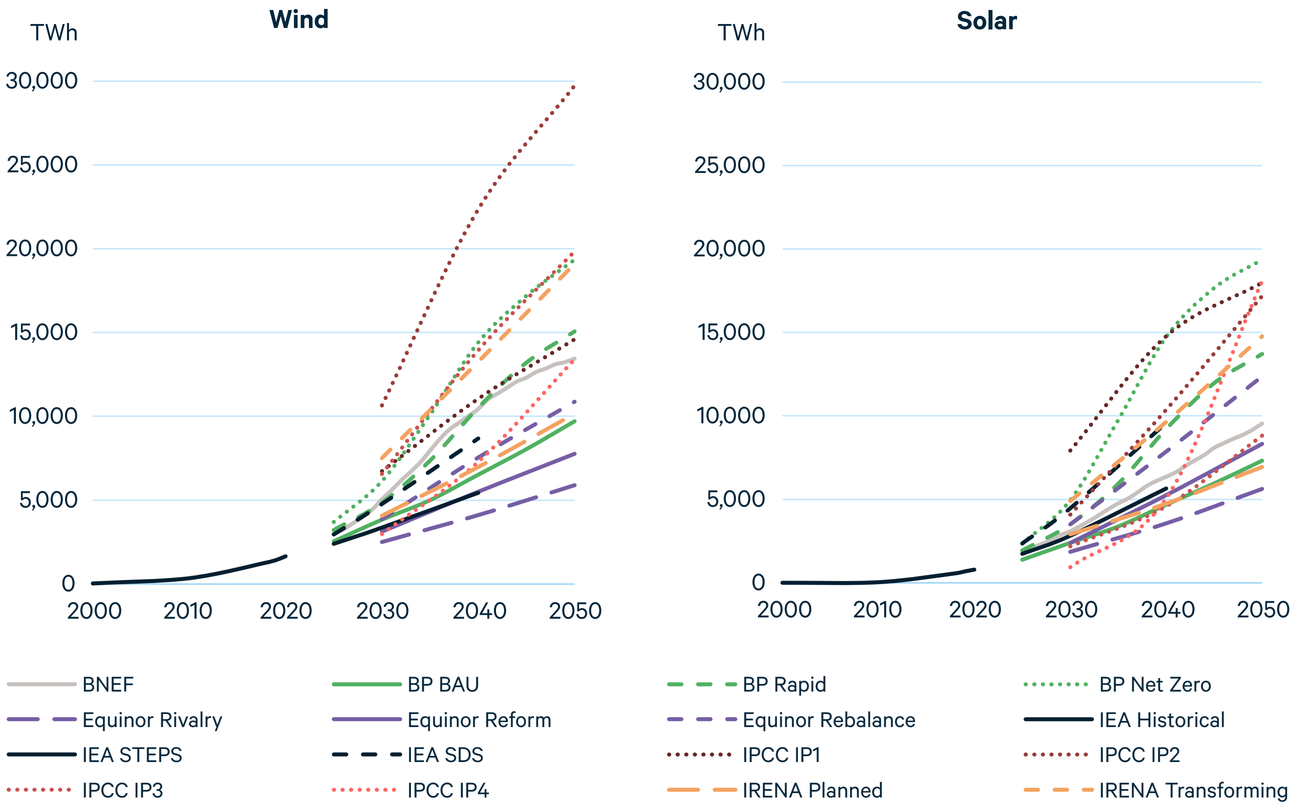


At a regional level, driven by a combination of public policies and increasingly competitive alternatives, **coal** consumption is projected to decline in most regions. By 2050, in North America and Europe, it falls by 93–99 percent under Ambitious Climate scenarios and 71–77 percent under most Evolving Policies scenarios.

However, a much wider range of outcomes emerges in the Global East. Under Evolving Policies from BP and the IEA, **coal** demand falls by just 1–2 percent by 2040. Under Ambitious Climate scenarios, it falls by 62–75 percent by 2040, then further by 2050. A considerable share of this variation is driven by India. Under Evolving Policies scenarios, coal demand in India grows by between 31 percent (IEA STEPS) and 95 percent (BP BAU) by 2040. Under Ambitious Climate scenarios, projections range from a decline of 1 percent by 2040 (Equinor Rebalance) to more than 50 percent (BP Net Zero and IEA SDS).

Driven by the interconnected trends of plunging costs and policy support, **wind** and **solar** are on track to play a central role in a net-zero emissions energy system. However, the speed of future deployment varies by a factor of six for wind and a factor of four for solar across scenarios, with Ambitious Climate scenarios typically showing the strongest growth (Figure 8).

Figure 8. Global solar and wind electricity generation



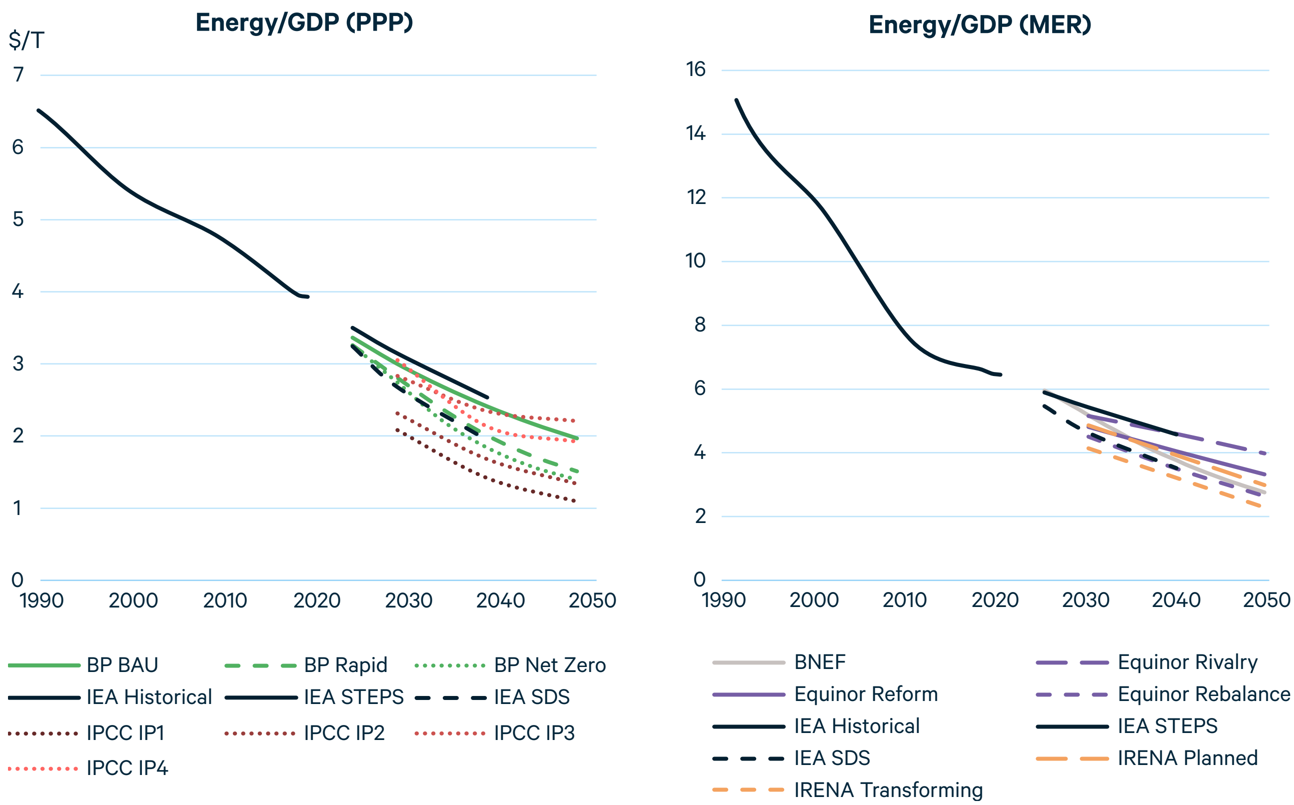
Note: Includes onshore and offshore wind, solar photovoltaic, and solar thermal technologies.

Global **wind** power generation more than triples by 2050 under the most conservative scenario (Equinor Rivalry) and grows by a factor of 12 under the least conservative (IPCC IP2). Among Evolving Policies scenarios, BNEF stands out with the most bullish projection, showing faster growth than Ambitious Climate scenarios from the IEA and Equinor. Regionally, most outlooks project that roughly 50–60 percent of wind generation will come from the Global East in 2040 and 2050, though IRENA's scenarios project that it will account for 61–78 percent by 2050.

In percentage terms, **solar** grows much faster than wind under all scenarios, more than 8-fold by 2050 under the most bearish scenario (Equinor Rivalry) and more than 28-fold under the most bullish (BP Net Zero). As with wind energy, scenarios envision the Global East to lead solar deployment. In 2019, the East accounted for 58 percent of global solar electricity generation, but it grows to 65–75 percent by 2050 under scenarios for which regional data are available.

Over the last three decades, the **energy intensity** of the global economy has declined dramatically, reflecting improvements in energy efficiency and, in many nations, a shift away from energy-intensive manufacturing and toward a service-based economy. In the next several decades, energy intensity continues to decline in all scenarios, falling fastest under Ambitious Climate scenarios (Figure 9).

Figure 9. Global energy consumption per unit of GDP



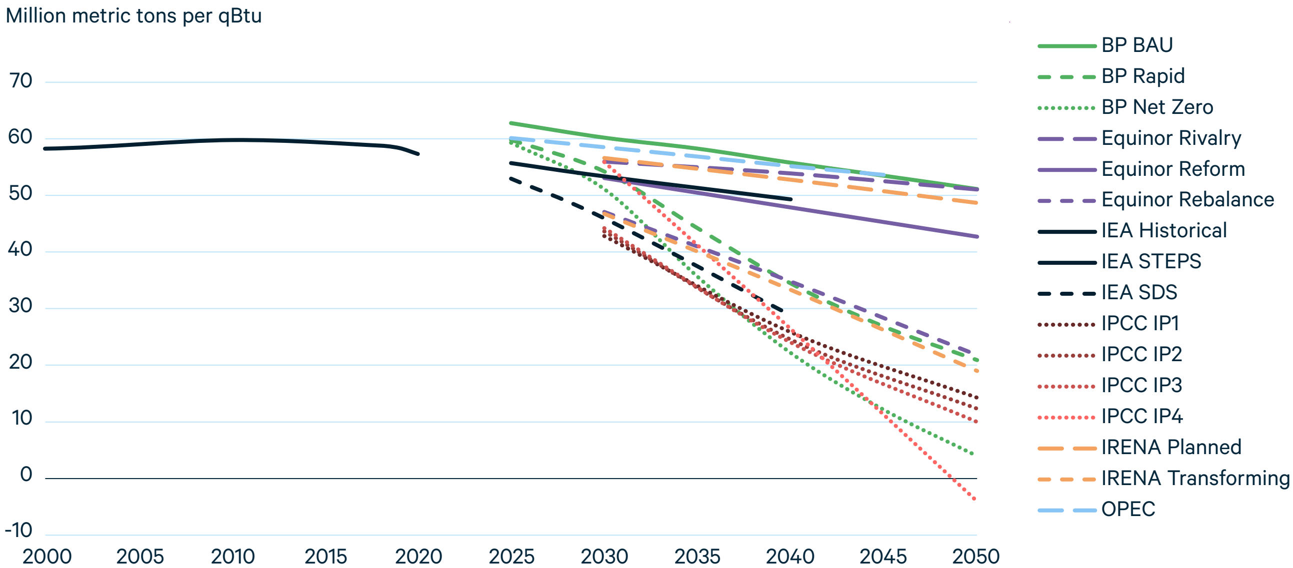
Note: BP excludes nonmarketed biomass, which results in lower primary energy demand and therefore a relatively low rate of energy demand per unit of GDP.

In Purchasing Power Parity (PPP) terms, global **energy intensity** falls to two QBtu per trillion US dollars (real $2019) or lower by 2040 under most Ambitious Climate scenarios, except the relatively high-energy-intensity IPCC IP3. Under Evolving Policies scenarios, energy intensity falls to roughly 2.5 QBtu/$T by 2040. Similar trends emerge when calculating in Market Exchange Rate terms.

Energy intensity varies considerably across nations and regions. In 2019, the Global West consumed roughly 3.7 QBtu/$T (at PPP) and the Global East roughly 4.1 QBtu/$T, reflecting the relatively high concentration of energy-intensive manufacturing in China and other parts of Asia. The IEA projects energy intensity in the West and East to fall by 32 and 40 percent, respectively, under its Evolving Policies Scenario (STEPS) and by 46 and 55 percent, respectively, under its Ambitious Climate Scenario (SDS). Under the SDS, the energy intensity of the East and West roughly converge by 2040.

Unlike the rapid declines in **energy intensity** over the last several decades, the **carbon intensity** of energy, measured as the volume of **CO_2** emissions per unit of **primary energy** demand, has remained roughly flat. Under Reference and Evolving Policies scenarios, carbon intensity declines over the next three decades but does not approach the rates of decline needed to limit temperature rise to 1.5°C or 2°C (Figure 10)

Figure 10. Global CO_2 emissions per unit of energy



Note: BP excludes nonmarketed biomass, which results in lower primary energy demand and therefore a relatively high rate of CO_2 emissions per unit of energy demand.

Under Reference and Evolving Policies scenarios, the **carbon intensity** of the energy system declines by 10–18 percent through 2040, then further through 2050. Under Ambitious Climate scenarios, the decline is 41–63 percent by 2040. This rate of change would be unprecedented; it reinforces the magnitude of fossil fuels transition required for the global **primary energy** mix, which will need to decline well below its roughly 80 percent share in 2019.

Because net **CO_2** emissions fall below zero in the second half of the twenty-first century for many Ambitious Climate scenarios, the **CO_2 intensity** of energy enters negative territory as early as 2050 under the IPCC IP4 scenario.

3. In focus

3.1. “Paris”: What’s in a name?

In the 2015 Paris Climate Agreement, under the United Nations Framework Convention on Climate Change, virtually all countries agreed to take action to limit global temperature rise to “well below 2°C above preindustrial levels” (UNFCCC 2015). The Agreement also states that nations will pursue “efforts to limit the temperature increase to 1.5°C.” Including two different targets —1.5°C and 2°C—has led to some confusion about what individuals, companies, and governments mean when they refer to the goals of “Paris.”

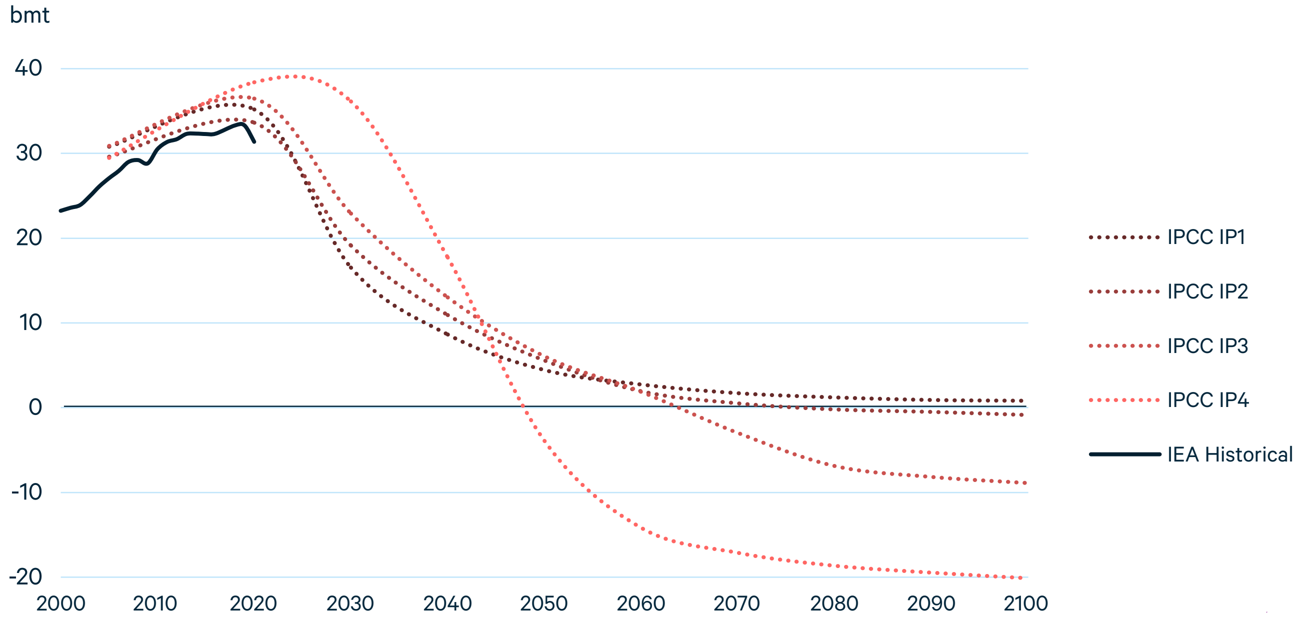
As discussed briefly in our Key Findings (see Figures 1 and 2), the energy and emissions trajectories needed to limit the global average temperature rise to 1.5°C differ substantially compared with 2°C. In a recent analysis of the remaining “carbon budget,” researchers estimated that emitting 440 BMT of CO_2 would result in a 50 percent chance of limiting temperature rise to 1.5°C by the end of the century, and the equivalent figure for 2°C would be 1,374 BMT (about three times as high).

3.1.1. The IPCC’s Illustrative Pathways to 1.5°C

Modeling teams working as part of the IPCC process published a range of scenarios compatible with 1.5°C in 2018 (Rogelj et al. 2018), represented in this GEO report by four IPs. Each IP illustrates the energy and emissions implications associated with distinct assumptions on the rate of social, economic, and technological change through 2100. IP1 is a scenario of low global energy demand, IP2 represents a push for sustainability, IP3 embodies societal and technological evolution at similar rates to historical trends, and IP4 assumes high fossil fuel energy demand and energy-intensive economic growth.

These IPs differ considerably, most notably in their inclusion of negative emissions technologies, such as biomass with carbon capture and sequestration (BECCS), direct air capture, and reforestation and afforestation. When these scenarios reach net zero emissions also varies greatly to reflect their differences in energy consumption, technology deployment, and mitigation timing.

Figure 11. Global CO_2 emissions trends of the IPCC Illustrative Pathways

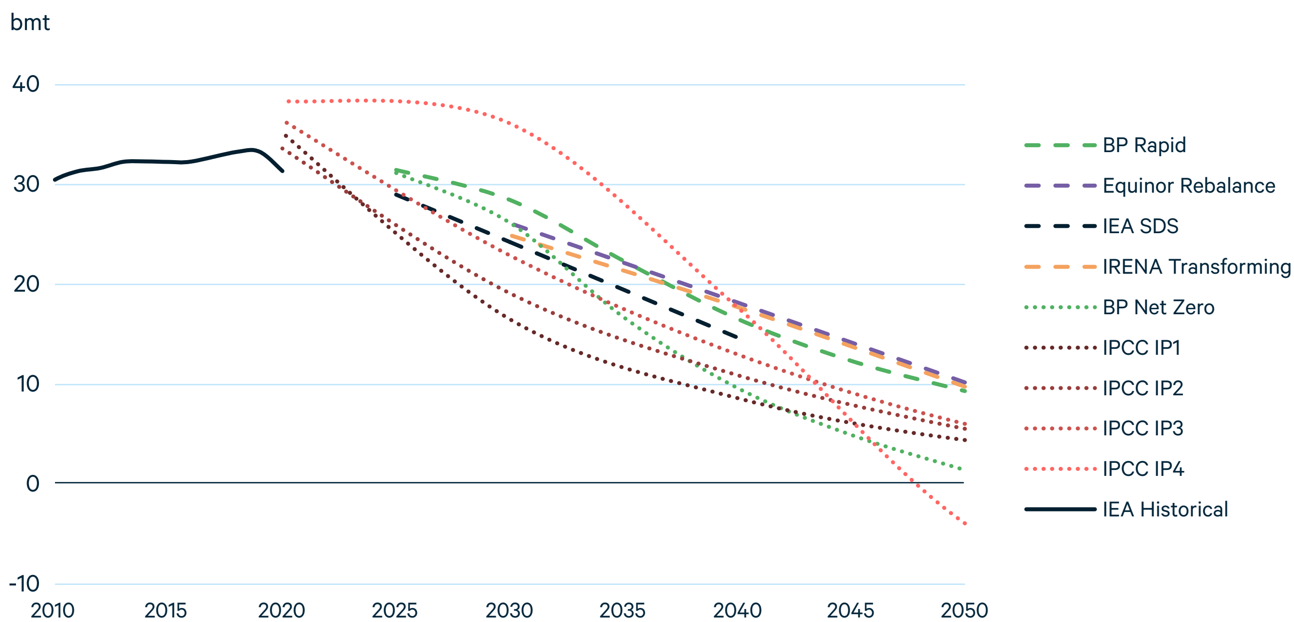


One key observation of the emissions trajectories of the IPs is that because they share the same warming goal of 1.5°C, a longer deferment of emissions reductions necessitates a significantly more aggressive "net-negative" abatement strategy down the road. Figure 11 illustrates this: continued emissions growth over the next decade (as seen in IP4) necessitates a steeper decline in emissions later in the century in addition to large-scale net-negative emissions starting around 2050. In other IP scenarios, emissions peak in 2020 and decline steeply over the next decade, a trend that appears unlikely based on early estimates for strong emissions growth in 2021 (International Energy Agency 2021).

3.1.2. Comparing 1.5°C and 2°C scenarios

In addition to the IPCC 1.5°C scenarios, BP's Net Zero also aligns with a 1.5°C target by achieving net zero global emissions by midcentury. Other Ambitious Climate scenarios from BP, Equinor, the IEA, and IRENA align more closely with the "well below 2°C" target, reaching net zero global emissions later in the second half of the twenty-first century. For simplicity, we refer to these as "2°C scenarios." Figure 12 illustrates the different emissions trajectories associated with the 1.5°C and 2°C scenarios; the 2°C projections all remain higher to 2050.

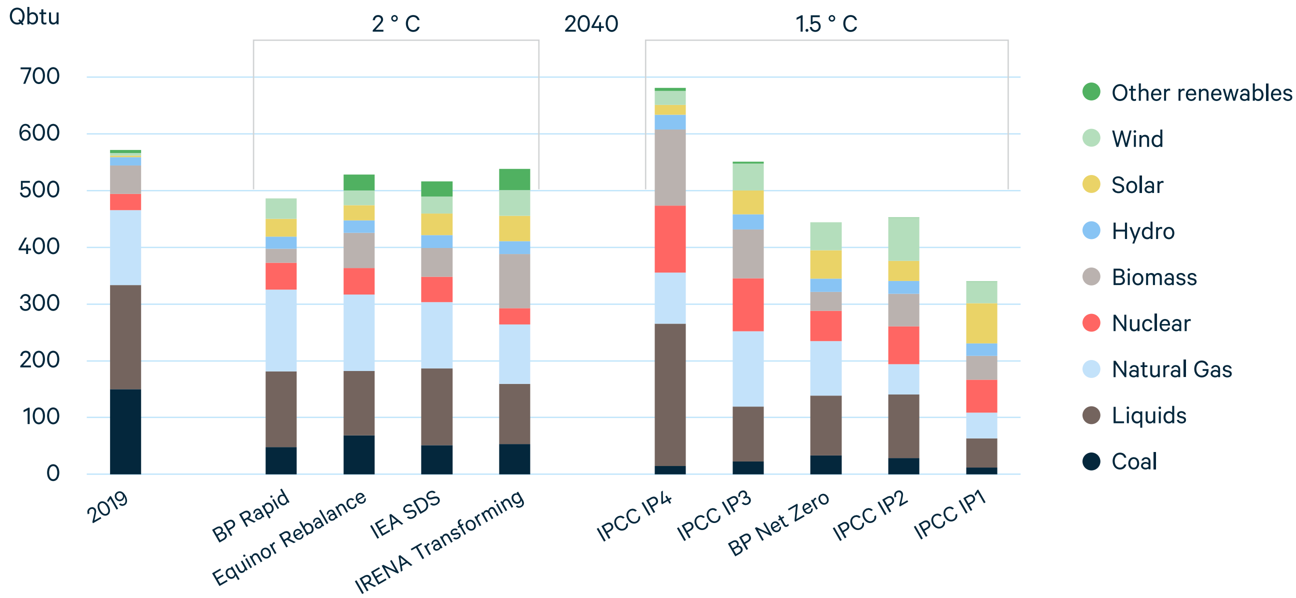
Figure 12. Global emissions trends in 1.5°C scenarios and 2°C scenarios



Excluding the high-energy IPCC IP4 scenario, 1.5°C scenarios reduce CO_2 emissions by 81–95 percent between 2019 and 2050, whereas 2°C scenarios see reductions of 67–70 percent. IP4 reaches net zero before 2050, and BP Net Zero looks to be the second outlook to see negative emissions just beyond the century's midpoint. IP1 is the only IP that does not include negative emissions later in the century due to its assumptions of low global energy demand and rapid deployment of clean energy technologies.

All 1.5°C and 2°C scenarios other than IP3 and IP4 envision lower global energy demand in 2040 relative to 2019. The energy mix of these models is quite heterogenous but also shows clear areas of agreement. As Figure 13 presents, renewables expansion and fossil fuel retirement are by and large the primary modes of emissions abatement. Even in high-energy-demand scenarios, such as IP3 and IP4, a significant portion of emissions reductions come from a shift away from fossil fuels, particularly coal.

Figure 13. Global primary energy mix in 2040 under 1.5°C and 2°C scenarios



Fossil fuel consumption decreases in both 1.5°C and 2°C scenarios by 2040. Coal falls from 150 QBtu in 2019 to 68 QBtu or less in 2°C scenarios and half that level again to below 34 QBtu in 1.5°C scenarios in 2040. Under 2°C scenarios, liquids see a slight reduction in consumption from 183 QBtu to between 106 (IRENA Transforming) and 136 (IEA SDS) QBtu. Liquids in 1.5°C scenarios (excluding IP4) see sizable reductions, from 113 QBtu in IP2 to just 52 QBtu in IP1. In many 2°C and 1.5°C scenarios, natural gas consumption remains at a similar level, though IP1 and IP2 would see 133 QBtu demand in 2019 fall to 45 or 53 QBtu in 2040, respectively.

Nuclear grows in all Ambitious Climate scenarios, but in particular, the 1.5°C scenarios use nuclear as a major source of energy. From 29 QBtu of demand in 2019, nuclear grows to between 53 (BP Net Zero) and 118 (IP4) QBtu among 1.5°C scenarios.

Solar and wind become major sources of energy by 2040, with biomass also used, particularly in high-energy-demand scenarios. Solar grows to as much as 45 QBtu (IRENA Transforming) in 2°C scenarios or 70 QBtu (IP1) in 1.5°C scenarios. Wind has a similar story in 2040, reaching 45 QBtu under IRENA Transforming in 2°C scenarios and 76 QBtu under IP2 for 1.5°C.

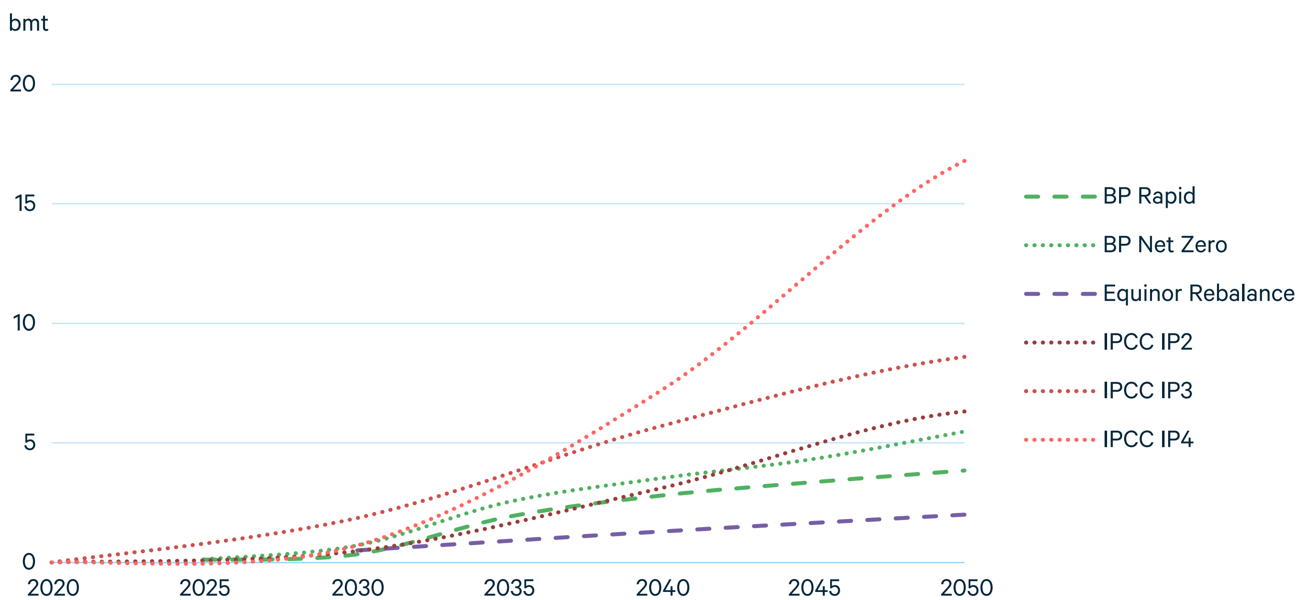
IP4 differs from the other Ambitious Climate scenarios in its high-energy pathway and its particularly heavy reliance on negative emissions. While coal falls close to zero by 2040 and natural gas is lower than most other scenarios, liquids demand grows by 37 percent above 2019 levels. Similarly, nuclear grows the strongest under IP4—more than tripling. IP4 also sees a large rollout of solar and wind, but biomass becomes the largest renewable energy source.

Biomass energy, in some cases paired with CCS, plays a major role in some IPCC 1.5 scenarios. From roughly 50 QBtu in 2019 (a majority of which is traditional biomass), biomass in 2040 falls to 42 QBtu in IP1 and grows slightly to 57 QBtu under IP2. Under IP3 and IP4, however, it becomes one of the largest primary energy sources, growing to 86 and 135 QBtu, respectively. By 2100, biomass grows further under all scenarios, ranging from a low of 71 QBtu under IP1 to 407 QBtu under IP4, accounting for 33 percent of global primary energy demand and rivaled only by solar, which provides 28 percent in 2100.

3.1.3. The role of large-scale CCS

Most pathways to 1.5°C and, to a lesser extent, 2°C climate goals are heavily reliant on large-scale deployment of CCS technologies. In particular, the IPCC 1.5 scenarios other than IP1 depend on BECCS (Figure 14). The enormous scale of BECCS required, particularly in IP3 and IP4, raise questions about sustainable forestry practices, land-use competition, the build-out of CO_2 infrastructure, and a variety of other issues beyond the scope of this report (Butnar et al. 2020).

Figure 14. Global CCS trends in 1.5°C scenarios and 2°C scenarios



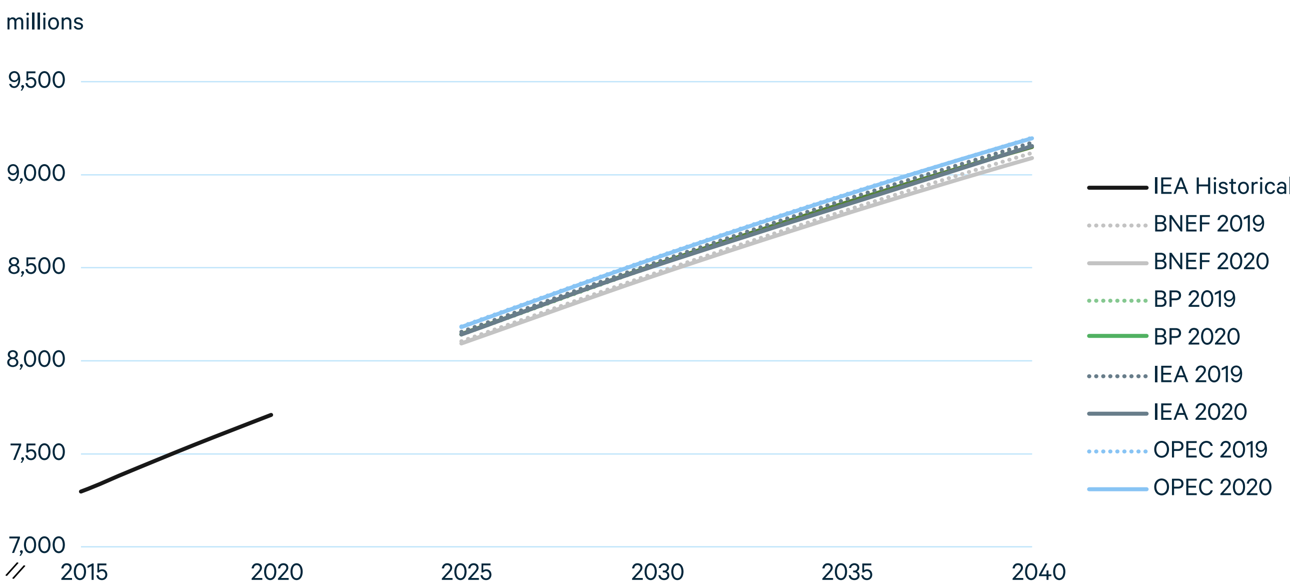
Comparing to BP historical data that show global CCS at 38 million metric tons in 2018, the highest 2050 projection reaches 17 BMT per year in IP4, with 96 percent coming from BECCS. Less energy-intensive scenarios estimate CCS use at half or less that of IP4, though their levels remain over 50 times greater than 2018. BP Net Zero includes CCS of roughly 5 BMT in 2050, whereas 2°C scenarios from Equinor and BP show CCS of roughly 2 BMT and 4 BMT in 2050, respectively.

3.2. Global population and economic growth post-COVID

As of early May 2021, the COVID-19 pandemic had killed an estimated 3.2 million people worldwide (Johns Hopkins University 2021), resulting in immense suffering. As the virus continues to spread uncontrolled in some parts of the world and vaccine distribution accelerates along with new variants of the disease, the ultimate human toll of the virus is currently unknown.

Nevertheless, 3.2 million deaths represents just 0.04 percent of the global population of 7.8 billion, suggesting that the virus' implications for long-term population growth are likely to be small. Reflecting this dynamic, population growth assumptions changed little from 2019 and 2020. However, they declined slightly for each of the four models where comparable data are available (Figure 15). 2020 outlooks assume that global population will be 0.3 percent (BNEF), 0.2 percent (IEA), 0.1 percent (BP), and 0.03 percent (OPEC) lower in 2040 than assumed in outlooks published in 2019 (International Energy Agency 2018).

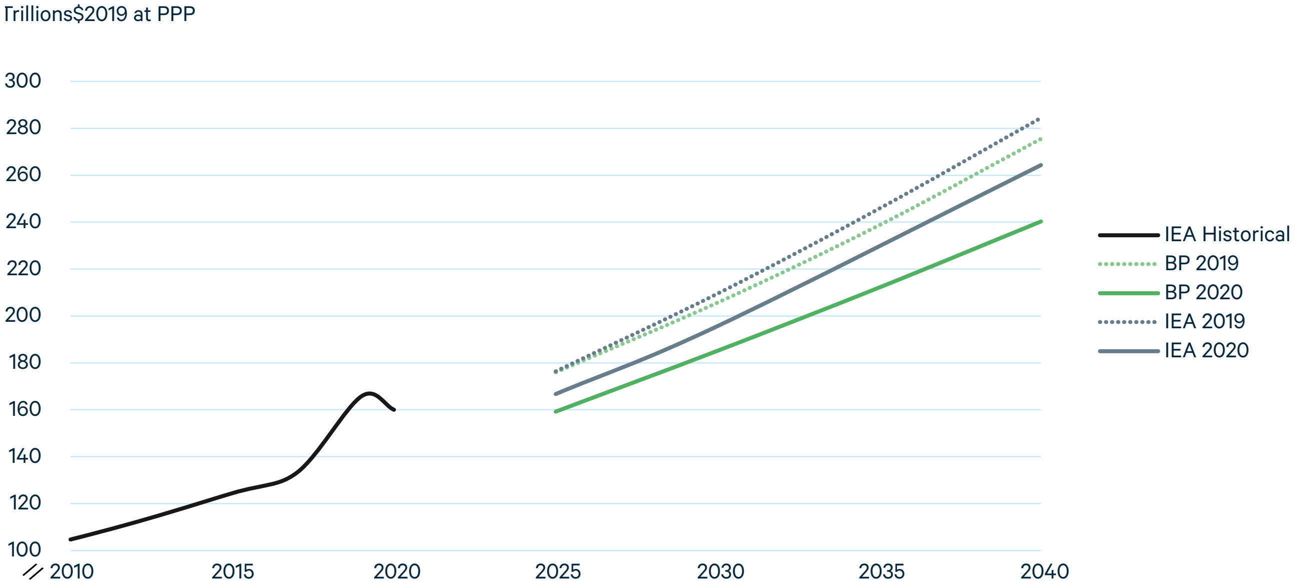
Figure 15. World population assumptions in 2019 and 2020



Compounding the loss of life, the pandemic produced an economic shock unlike any witnessed in most of our lifetimes. The lockdowns that attempted to control virus spread, and which proliferated across the world during 2020, restricted travel and commerce in unprecedented ways. As a result, global GDP fell by 3.3 percent in 2020, one of the largest contractions on record. However, the global economy appears to be bouncing back relatively quickly. In April 2021, the IMF projected 2021 world GDP growth forecast of 6 percent, exceeding 2019 levels (IMF 2021).

Despite the potential for a relatively swift economic recovery, outlooks produced in 2020 assumed substantially lower future GDP relative to 2019. For example, BP's 2020 GDP assumption for the year 2040 is 13 percent lower than that in 2019's outlook, and the IEA's assumptions were 7 percent lower, as illustrated in Figure 16.

Figure 16. Global GDP assumptions in 2019 and 2020



As we discussed in last year's Global Energy Outlook, energy projections tend to assume that a consistent long-term GDP growth rate is on the high end of the historically observed range (Newell et al. 2020). These downward revisions to global GDP assumptions are not particularly surprising and highlight the potential benefit for outlook-producing organizations to consider a wider range of GDP scenarios in their modeling exercises.

3.3. Energy intensity: historical trends and future pathways

The Kaya identity decomposes total CO_2 emissions into four factors: human population, GDP per capita, energy use per unit of GDP (i.e., energy intensity), and CO_2 emissions per unit of energy use (i.e., carbon intensity). Estimating future energy consumption and CO_2 levels depends heavily on assumptions regarding each of these four factors, and as discussed earlier in this report, there is a range of future possibilities for each.

Figure 17 demonstrates that the energy intensity of the global economy has declined reliably over the past several decades. As a result, the economy is slightly more than half as energy intense as it was in 1980. As of 2020, each trillion dollars of global GDP entailed four QBtu of primary energy consumption.

Figure 17. IEA Historical global energy intensity

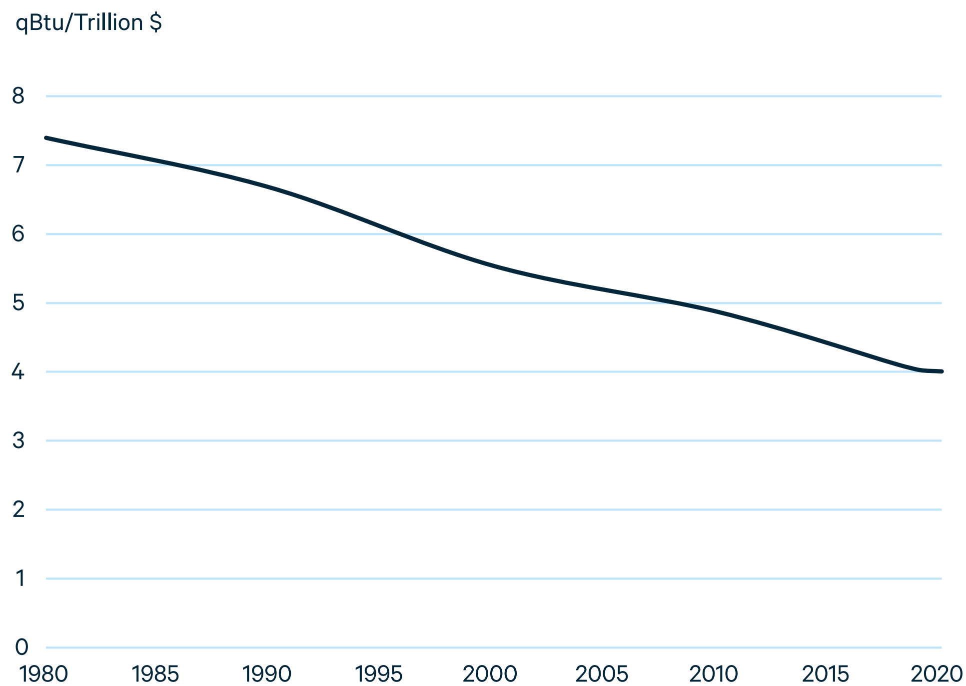
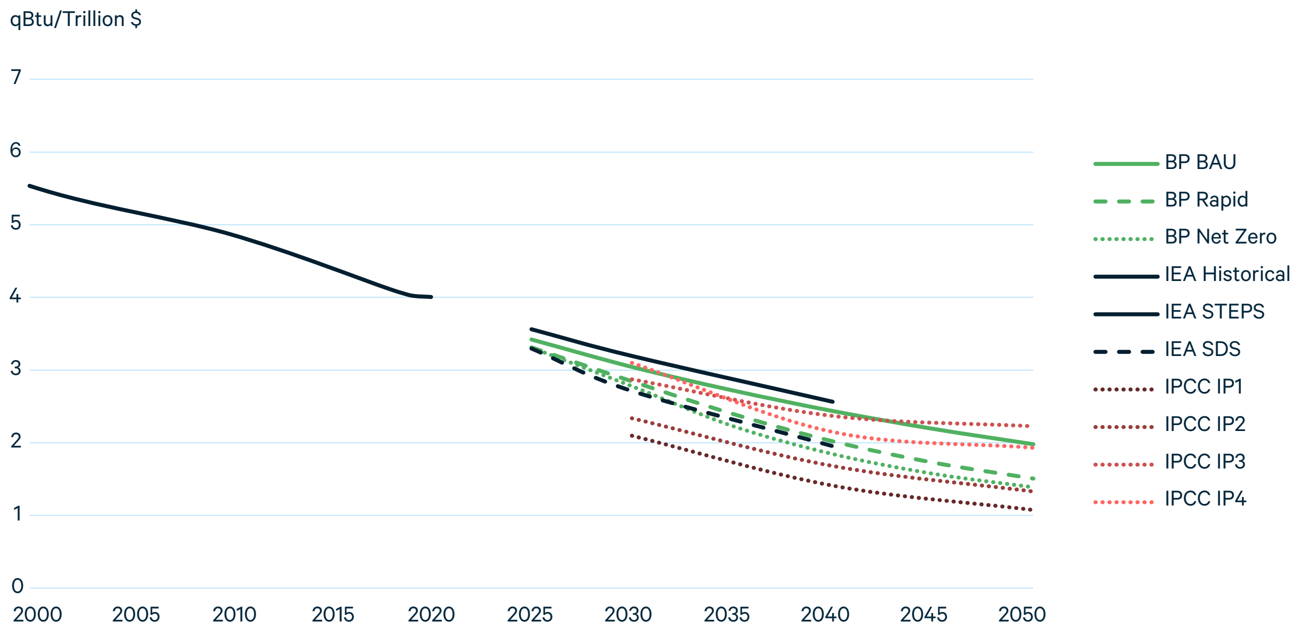


Figure 18 shows more recent historical trends alongside projections from the outlooks in this year's GEO. Improving energy intensity is one way of reducing future CO_2 emissions. The scenarios with less aggressive emissions reductions, such as BP BAU and IEA STEPS, feature declining energy at rates roughly consistent with historical experience. By contrast, the outlooks that are consistent with more aggressive emissions reductions, such as the IEA's SDS, BP's Rapid and Net Zero, and IP1-2, feature accelerated reductions in energy intensity.

Figure 18. Historical and projected future global energy intensity



4. Data and methods

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

- BP: Energy Outlook 2020
- BNEF: New Energy Outlook 2020
- Equinor: Energy Perspectives 2020
- Intergovernmental Panel on Climate Change: Special Report on 1.5°Celsius (2018)
- International Energy Agency: World Energy Outlook 2020
- International Renewable Energy Agency: Global Renewables Outlook 2020
- OPEC: World Oil Outlook 2020

The outlooks vary because of differences in modeling techniques, different historical data, economic growth assumptions, and policy scenarios. Generally, scenarios can be grouped into three categories: (1) Reference, which assume no major policy changes; (2) Evolving Policies, which incorporate the modeling team's expectations of policy trends; and (3) alternatives, which are typically based on certain policy targets or technology assumptions. We focus on Ambitious Climate scenarios, a major subset of (3). Table 4 summarizes these approaches.

Table 4. Sources and scenarios

Source	Scenario
Grubler (2008)	Historical data
IEA (2018)	Historical data
BloombergNEF (2020)	Economic Transition Scenario: Based on internal views on technological change, which drives the development of markets and business models. Consistent with 3.3°C of warming by 2100.
BP (2020)	Business as Usual (BAU): Assumes that policies, technologies, and consumer preferences evolve similarly to recent trends. Rapid Transition: Includes variety of policies to reduce emissions from power, transport, buildings, and industrial sectors. Consistent with limiting warming to “well below” 2°C by 2100. Net Zero: Trends from the Rapid Transition scenario are enhanced by substantial societal changes, limiting warming to 1.5°C by 2100.
Equinor (2020)	Rivalry: “The energy transition does not take off.” Geopolitical disputes and conflict continue to grow, slowing economic growth, technology development, and efforts to reduce emissions. Rebalance: Ambitious policies push energy system toward limiting warming to “well below” 2°C by 2100 and global inequality declines. Reform: Market, technology, and policy trends evolve similarly to recent trends.
IEA (2020)	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.
IPCC (Rogelj et al. 2018)	All scenarios limit warming to 1.5°C by 2100: Illustrative Pathway 1 (IP1): A low-energy-demand scenario that includes substantial reductions in end-use energy demand. Illustrative Pathway 2 (IP2): A sustainability-oriented scenario based on Shared Socioeconomic Pathway 1 (O’Neill, et al. 2014; Riahi, et al. 2017) developed with the AIM model. Illustrative Pathway 3 (IP3): A “middle-of-the-road” scenario based on Shared Socioeconomic Pathway 2 developed with the MESSAGE-GLOBIOM model. Illustrative Pathway 4 (IP4): A high-energy-demand scenario developed with the REMIND-MAgPIE model.
IRENA (2020)	Planned Energy Scenario: Based on current and announced policies, including NDCs and long-term emissions reduction targets Transforming Energy Scenario: An “ambitious, yet realistic” scenario with improved energy efficiency and large-scale renewables deployment that limits warming to “well below” 2°C by 2100.
OPEC (2020)	Reference: Incorporates policies that have been enacted. Assumes some future policy changes.

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 is the choice of reporting units. For primary energy, outlooks use different energy units, such as QBtu, million tonnes of oil equivalent (mtoe), or terajoules. 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 5 presents the reporting units for each outlook, and Table 6 provides relevant conversion factors.

Table 5. Units of energy consumption, by outlook

	IEA	BP	BNEF	Equinor	IPCC	IRENA	OPEC
Primary energy units	mtoe	mtoe	PJ	Btoe	EJ	EJ	mboed
Fuel- or sector-specific units							
Liquids	mbd	mbd	PJ	mbd	EJ	EJ	mbd
Oil	mbd	mbd	PJ	N.A.	EJ	EJ	mbd
Biofuels	mboed	mboed	PJ	N.A.	EJ	EJ	mbd
Natural gas	bcm	bcfd	PJ	bcm	EJ	EJ	mboed
Coal	mtce	btoe	PJ	btoe	EJ	EJ	mboed
Electricity	TWh	TWh	TWh	TWh	EJ	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 (2020) 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 boe. 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 among outlooks is that 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 percent (International Energy Agency 2018). Although conversion unit variations may appear small, they are amplified when applied across the massive scale of global energy systems, 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 it in their outlooks, unlike all other organizations examined in this report. Including these fuels can yield an 8–11 percent difference in global primary energy consumption.

Yet another difference relates to comparing the energy content of fossil 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 (1) different categorizations for liquids fuels and renewable energy, (2) different regional groupings for aggregated data and projections, (3) using net versus gross calorific values when reporting energy content of fossil fuels, (4) using 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 and allow for a more accurate comparison across outlooks, Newell and Iler (2013) apply a harmonization process. We update and use it here. For details, see Newell and Raimi (2020).

5. Statistics

Table 7. Global indicators

	Population	Energy	GDP	Net CO_2	GDP/ Capita	Energy/ GDP	Energy/ Capita	Net CO_2
$ in PPP terms	Millions	qBtu	$T, 2019	BMT	$1,000/ person	1,000 Btu/$	1,000 Btu/ person	MMT/ qBtu
1990	5,279	350	53	21	10.0	6.6	66.3	58.6
2015	7,358	546	116	32	15.8	4.7	74.2	59.2
2019	7,672	572	142	33	18.5	4.0	74.5	58.2
2040								
BP BAU	9,149	586	240	33	26.3	2.4	64.0	55.6
BP RT	9,149	486	240	17	26.3	2.0	53.1	34.1
BP NZ	9,149	443	240	10	26.3	1.8	48.5	21.8
IEA STEPS	9,154	678	264	33	28.9	2.6	74.1	49.1
IEA SDS	9,154	517	264	15	28.9	2.0	56.4	28.5
IPCC SR 1.5 IP1	8,787	339	241	9	27.4	1.4	38.6	25.5
IPCC SR 1.5 IP2	8,332	453	269	11	32.3	1.7	54.4	24.1
IPCC SR 1.5 IP3	8,787	551	233	13	26.5	2.4	62.7	23.6
IPCC SR 1.5 IP4	8,403	681	317	18	37.7	2.1	81.1	26.0
OPEC	9,196	671	—	37	—	—	73.0	55.0
$ in MER terms								
2015	7,358	546	73	32	9.9	7.5	74.2	59.2
2019	7,672	572	87	33	11.3	6.6	74.5	58.2
2040								
BNEF	9,090	575	152	28	16.8	3.8	63.3	48.4
Equinor Reform	9,154	626	154	30	16.8	4.1	68.3	47.6
Equinor Rebalance	9,154	528	151	18	16.5	3.5	57.7	34.4
Equinor Rivalry	8,787	674	145	36	16.5	4.6	76.7	53.7
IRENA Planned	8,869	594	211	34	23.8	2.8	67.0	57.9
IRENA Transforming	8,869	443	216	18	24.3	2.1	50.0	40.1

Notes: Historical data from IEA. Equinor does not publish 2040 population assumptions. We show IEA population assumptions above.

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
2019 (incl. non-marketed biomass)	572	150	183	133	29	15	62
2040 (incl. non-marketed biomass)							
BNEF	575	125	195	149	39	—	—
Equinor Reform	626	119	168	158	38	20	122
Equinor Rebalance	528	68	114	134	47	22	143
Equinor Rivalry	674	155	206	154	33	18	107
IEA STEPS	678	132	202	171	36	20	117
IEA SDS	517	51	136	117	45	23	145
IPCC SR1.5 IP1	339	12	52	45	58	22	151
IPCC SR1.5 IP2	453	28	113	53	67	23	169
IPCC SR1.5 IP3	551	23	97	132	94	27	179
IPCC SR1.5 IP4	681	14	251	90	118	26	182
OPEC	671	144	202	173	41	—	112
2015 (excl. non-marketed biomass)	490	151	175	115	26	13	7
2019 (excl. non-marketed biomass)	518	150	183	133	29	15	9
2040 (excl. non-marketed biomass)							
BP BAU	586	133	179	167	36	20	51
BP RT	486	48	133	144	48	22	91
BP NZ	443	33	105	96	53	23	132
IRENA Planned	594	116	178	178	40	20	63
IRENA Transforming	443	53	106	105	29	23	127

Notes: "Liquids" only includes oil for BNEF, Equinor, and IPCC, as biofuels data were not available.

Table 9. Liquids consumption, by region

	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	2.0	1.4%	90	0.2	0.2%	82	1.9	3.5%
2019	183	2.9	1.6%	85	-1.4	-1.6%	82	0.0	0.0%
2040		2019-2040			2019-2040			2019-2040	
BNEF	195	0.6	0.3%	—	—	—	—	—	—
BP BAU	179	-0.2	-0.1%	79	-0.3	-0.3%	100	0.9	1.0%
BP RT	133	-2.4	-1.5%	56	-1.3	-1.9%	77	-0.2	-0.3%
BP NZ	105	-3.7	-2.6%	44	-1.9	-3.1%	62	-1.0	-1.3%
Eq Reform	168	-0.7	-0.4%	—	—	—	—	—	—
Eq Rebalance	114	-3.3	-2.3%	—	—	—	—	—	—
Eq Rivalry	206	1.1	0.5%	—	—	—	—	—	—
IEA STEPS	202	0.9	0.5%	76	-0.4	-0.5%	104	1.0	1.1%
IEA SDS	136	-2.3	-1.4%	48	-1.7	-2.6%	72	-0.5	-0.6%
IPCC SR1.5 IP1	52	-6.3	-5.9%	—	—	—	—	—	—
IPCC SR1.5 IP2	113	-3.4	-2.3%	—	—	—	—	—	—
IPCC SR1.5 IP3	97	-4.1	-3.0%	—	—	—	—	—	—
IPCC SR1.5 IP4	251	3.2	1.5%	—	—	—	—	—	—
IRENA Planned	178	-0.3	-0.1%	72	-0.6	-0.7%	100	0.9	1.0%
IRENA Transforming	106	-3.7	-2.6%	33	-2.5	-4.4%	59	-1.1	-1.6%
OPEC	202	0.9	0.5%	—	—	—	—	—	—

Notes: "Liquids" only includes oil for BNEF, Equinor, and IPCC, as biofuels data were not available. Regional totals may not sum because of different treatment of international aviation and bunker fuels.

Table 10. Natural gas consumption, by region

	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	1.4	6.5%
2019	133	3.9	3.2%	81	1.7	2.2%	52	2.2	4.8%
2040		2019-2040			2019-2040			2019-2040	
BNEF	149	0.8	0.6%	—	—	—	—	—	—
BP BAU	167	1.6	1.1%	85	0.2	0.3%	81	1.4	2.2%
BP RT	144	0.5	0.4%	62	-0.9	-1.2%	82	1.4	2.2%
BP NZ	96	-1.7	-1.5%	43	-1.8	-2.9%	53	0.1	0.1%
Eq Reform	158	1.2	0.8%	—	—	—	—	—	—
Eq Rebalance	134	0.1	0.1%	—	—	—	—	—	—
Eq Rivalry	154	1.0	0.7%	—	—	—	—	—	—
IEA STEPS	171	1.9	1.2%	85	0.2	0.3%	85	1.6	2.4%
IEA SDS	117	-0.8	-0.6%	52	-1.4	-2.1%	64	0.6	1.0%
IPCC SR1.5 IP1	45	-4.2	-5.0%	—	—	—	—	—	—
IPCC SR1.5 IP2	53	-3.8	-4.2%	—	—	—	—	—	—
IPCC SR1.5 IP3	132	0.0	0.0%	—	—	—	—	—	—
IPCC SR1.5 IP4	90	-2.0	-1.8%	—	—	—	—	—	—
IRENA Planned	178	2.2	1.4%	81	0.0	0.0%	96	2.1	3.0%
IRENA Transforming	105	-1.3	-1.1%	47	-1.6	-2.6%	58	0.3	0.5%
OPEC	173	1.9	1.3%	—	—	—	—	—	—

Table 11. Coal consumption, by region

	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	5.3%	52	0.3	1.1%	36	1.0	4.2%
2015	152	2.6	2.2%	37	-0.6	-1.4%	115	3.2	4.8%
2019	150	2.1	1.9%	30	-0.8	-1.9%	120	2.9	4.2%
2040		2019-2040			2019-2040			2019-2040	
BNEF	125	-6.6	-4.7%	—	—	—	—	—	—
BP BAU	133	-4.8	-3.3%	15	-5.5	-20.2%	118	0.7	0.6%
BP RT	48	-26.0	-25.0%	4	-8.3	-42.7%	44	-17.8	-21.4%
BP NZ	33	-29.7	-31.6%	3	-8.5	-46.5%	30	-21.2	-28.4%
Eq Reform	119	-8.1	-5.8%	—	—	—	—	—	—
Eq Rebalance	68	-20.9	-18.1%	—	—	—	—	—	—
Eq Rivalry	155	0.7	0.5%	—	—	—	—	—	—
IEA STEPS	132	-5.1	-3.6%	15	-5.6	-20.6%	117	0.5	0.4%
IEA SDS	51	-25.2	-23.7%	6	-7.8	-37.6%	46	-17.3	-20.6%
IPCC SR1.5 IP1	12	-35.0	-47.0%	—	—	—	—	—	—
IPCC SR1.5 IP2	28	-31.0	-34.4%	—	—	—	—	—	—
IPCC SR1.5 IP3	23	-32.3	-37.8%	—	—	—	—	—	—
IPCC SR1.5 IP4	14	-34.5	-44.7%	—	—	—	—	—	—
IRENA Planned	116	-8.9	-6.5%	25	-3.1	-9.5%	92	-5.8	-5.5%
IRENA Transforming	53	-24.7	-23.1%	6	-7.7	-36.4%	47	-17.0	-20.0%
OPEC	144	-2.0	-1.4%	—	—	—	—	—	—

Table 12. Nuclear consumption, by region

	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	1.0%	22	0.2	0.8%	5	0.1	2.1%
2019	29	0.5	1.7%	22	0.0	-0.2%	7	0.5	8.8%
2040		2019-2040			2019-2040			2019-2040	
BNEF	39	0.5	1.5%	—	—	—	—	—	—
BP BAU	36	0.3	1.0%	15	-0.3	-1.9%	21	0.7	5.4%
BP RT	48	0.9	2.4%	22	0.0	0.1%	28	1.0	6.9%
BP NZ	53	1.2	3.0%	25	0.2	0.7%	25	0.9	6.3%
Eq Reform	38	0.4	1.3%	—	—	—	—	—	—
Eq Rebalance	47	0.9	2.3%	—	—	—	—	—	—
Eq Rivalry	33	0.2	0.7%	—	—	—	—	—	—
IEA STEPS	36	0.3	1.0%	18	-0.2	-1.0%	18	0.5	4.5%
IEA SDS	45	0.8	2.1%	21	0.0	-0.1%	23	0.8	5.9%
IPCC SR1.5 IP1	58	1.4	3.4%	—	—	—	—	—	—
IPCC SR1.5 IP2	67	1.8	4.1%	—	—	—	—	—	—
IPCC SR1.5 IP3	94	3.1	5.8%	—	—	—	—	—	—
IPCC SR1.5 IP4	118	4.2	6.9%	—	—	—	—	—	—
IRENA Planned	40	0.5	1.5%	20	-0.1	-0.4%	20	0.6	5.0%
IRENA Transforming	29	0.0	0.0%	12	-0.4	-2.6%	17	0.5	4.2%
OPEC	41	0.6	1.7%	—	—	—	—	—	—

Table 13. Wind consumption, by region

	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	QBtu	QBtu	CAAGR	QBtu	QBtu	CAAGR	QBtu	QBtu	CAAGR
1990	0	—	—	0	—	—	0	—	—
2015	2.8	0.11	—	2.0	0.08	—	0.9	0.03	—
2019	4.9	0.5	14.3%	3.0	0.3	11.3%	1.8	0.2	20.5%
2040		2019-2040			2019-2040			2019-2040	
BNEF	—	—	—	—	—	—	—	—	—
BP BAU	22	0.8	7.5%	11	0.4	6.3%	11	0.4	9.0%
BP RT	36	1.5	10.0%	14	0.5	7.6%	22	0.9	12.6%
BP NZ	49	2.1	11.6%	20	0.8	9.4%	29	1.3	14.1%
Eq Reform	19	0.7	6.7%	—	—	—	—	—	—
Eq Rebalance	26	1.0	8.3%	—	—	—	—	—	—
Eq Rivalry	14	0.4	5.2%	—	—	—	—	—	—
IEA STEPS	19	0.7	6.6%	9	0.3	5.4%	9	0.4	8.1%
IEA SDS	30	1.2	9.0%	14	0.5	7.5%	16	0.7	10.8%
IPCC SR1.5 IP1	38	1.6	10.3%	—	—	—	—	—	—
IPCC SR1.5 IP2	76	3.4	14.0%	—	—	—	—	—	—
IPCC SR1.5 IP3	48	2.0	11.5%	—	—	—	—	—	—
IPCC SR1.5 IP4	25	1.0	8.1%	—	—	—	—	—	—
IRENA Planned	24	0.9	7.9%	6	0.1	3.3%	18	0.8	11.5%
IRENA Transforming	45	1.9	11.2%	18	0.7	8.8%	27	1.2	13.8%
OPEC	—	—	—	—	—	—	—	—	—

Table 14. Solar consumption, by region

	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	QBtu	QBtu	CAAGR	QBtu	QBtu	CAAGR	QBtu	QBtu	CAAGR
1990	—	—	—		—	—		—	—
2015	0.9	0.04	—	0.5	0.02	—	0.4	0.01	—
2019	2.4	0.4	28.4%	1.0	0.1	17.2%	1.4	0.3	40.2%
2040		2019-2040			2019-2040			2019-2040	
BNEF	—	-0.1	-100.0%	—	—	—	—	—	—
BP BAU	16	0.6	9.4%	6	0	8.7%	10	0	10.0%
BP RT	31	1.4	13.0%	10	0	11.4%	22	1	14.0%
BP NZ	50	2.3	15.5%	16	1	14.0%	34	2	16.5%
Eq Reform	18	0.7	10.0%	—	—	—	—	—	—
Eq Rebalance	27	1.2	12.1%	—	—	—	—	—	—
Eq Rivalry	12	0.5	8.0%	—	—	—	—	—	—
IEA STEPS	20	0.9	10.7%	6	0	8.6%	15	1	11.9%
IEA SDS	38	1.7	14.0%	11	0	11.9%	28	1	15.3%
IPCC SR1.5 IP1	71	3.2	17.4%	—	—	—	—	—	—
IPCC SR1.5 IP2	35	1.6	13.6%	—	—	—	—	—	—
IPCC SR1.5 IP3	42	1.9	14.6%	—	—	—	—	—	—
IPCC SR1.5 IP4	17	0.7	9.8%	—	—	—	—	—	—
IRENA Planned	19	0.8	10.3%	4	0	7.2%	15	1	11.8%
IRENA Transforming	45	2.0	14.9%	15	1	13.9%	30	1	15.7%
OPEC	—	—	—	—	—	—	—	—	—

Table 15. Global electricity generation by source

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
2019	9,849	6,317	4,305	2,789	2,863	785	26,942
2040							
BNEF	6,039	5,077	4,838	3,448	17,379	31	36,812
BP BAU	9,909	9,333	5,951	3,470	12,582	273	41,518
BP RT	2,319	8,256	6,357	4,601	22,266	194	43,992
BP NZ	1,064	2,691	6,691	5,177	32,603	220	48,445
Eq Reform	8,745	9,138	5,730	3,602	12,605	308	40,127
Eq Rebalance	4,986	9,265	6,484	4,485	17,944	155	43,319
Eq Rivalry	10,259	8,386	5,406	3,215	9,293	668	37,226
IEA STEPS	8,984	8,387	5,919	3,439	12,872	463	40,094
IEA SDS	1,951	4,550	6,690	4,320	21,046	187	38,774
IPCC SR1.5 IP1	222	1,327	6,442	5,443	31,253	122	44,810
IPCC SR1.5 IP2	2,192	3,595	6,604	6,240	35,148	1,125	54,905
IPCC SR1.5 IP3	528	7,904	7,800	8,636	19,663	74	44,606
IPCC SR1.5 IP4	878	8,884	7,634	11,404	15,760	0	44,560
IRENA Planned	9,123	8,978	5,809	3,827	13,853	528	42,119
IRENA Transforming	3,937	4,734	6,644	2,815	27,103	30	45,263

Table 16. Global renewable electricity generation by source

TWh	Hydro	Biomass/ waste	Wind	Solar	Geothermal	Other	Total
1990	2,142	131	3.9	0.1	36	—	2,313
2015	3,888	528	818	260	80	—	5,574
2019	4,305	667	1,423	680	92	1	7,167
2040							
BNEF	4,838	351	10,442	6,354	148	84	22,217
BP BAU	5,951	1,153	6,519	4,680	230	—	18,534
BP RT	6,357	2,145	10,521	9,214	551	—	28,623
BP NZ	6,691	2,915	14,409	14,728	386	—	39,294
Eq Reform	5,730	1,185	5,503	5,250	—	667	18,335
Eq Rebalance	6,484	1,429	7,544	7,862	—	1,109	24,428
Eq Rivalry	5,406	1,242	4,109	3,561	—	380	14,699
IEA STEPS	5,919	1,410	5,441	5,652	321	47	18,791
IEA SDS	6,690	2,155	8,680	9,587	553	70	27,737
IPCC SR1.5 IP1	6,442	579	11,050	14,776	31	—	32,878
IPCC SR1.5 IP2	6,604	2,317	22,352	10,368	99	—	41,740
IPCC SR1.5 IP3	7,800	411	13,943	4,586	653	—	27,393
IPCC SR1.5 IP4	7,634	3,092	7,284	5,056	337	—	23,403
IRENA Planned	5,809	1,444	6,978	4,745	427	—	19,403
IRENA Transforming	6,644	2,699	13,258	9,641	779	—	33,021

Notes: "Other" includes geothermal for Equinor. "Other" data are not available for BP, IPCC, and IRENA.

Table 17. Energy-related net carbon dioxide emissions, by region

	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	—	—
2015	32.3	0.5	1.8%	13.0	0.0	-0.3%	18.2	0.5	4.5%
2019	33.3	0.2	0.8%	12.6	-0.1	-0.9%	19.4	0.3	1.6%
2040		2019-2040			2019-2040			2019-2040	
BNEF	27.9	-0.3	-0.8%	—	—	—	—	—	—
BP BAU	32.6	0.0	-0.1%	10.8	-0.1	-0.7%	21.7	0.1	0.5%
BP RT	16.6	-0.8	-3.3%	5.8	-0.3	-3.6%	10.8	-0.4	-2.8%
BP NZ	9.7	-1.1	-5.7%	3.6	-0.4	-5.8%	6.1	-0.6	-5.4%
Eq Reform	29.8	-0.2	-0.5%	—	—	—	—	—	—
Eq Rebalance	18.2	-0.7	-2.8%	—	—	—	—	—	—
Eq Rivalry	36.2	0.1	0.4%	—	—	—	—	—	—
IEA STEPS	33.3	0.0	0.0%	10.1	-0.1	-1.0%	21.4	0.1	0.5%
IEA SDS	14.7	-0.9	-3.8%	4.6	-0.4	-4.6%	9.1	-0.5	-3.5%
IPCC SR1.5 IP1	8.6	-1.2	-6.2%	—	—	—	—	—	—
IPCC SR1.5 IP2	10.9	-1.1	-5.2%	—	—	—	—	—	—
IPCC SR1.5 IP3	13.0	-1.0	-4.4%	—	—	—	—	—	—
IPCC SR1.5 IP4	17.7	-0.7	-3.0%	—	—	—	—	—	—
IRENA Planned	34.4	0.1	0.2%	12.8	0.0	0.1%	21.6	0.1	0.5%
IRENA Transforming	17.8	-0.7	-2.9%	5.7	-0.3	-3.7%	12.1	-0.3	-2.2%
OPEC	36.9	0.2	0.5%	—	—	—	—	—	—

Table 18. Energy-related carbon dioxide emissions, by fuel

	Coal	Avg. annual growth		Oil	Avg. annual growth		Natural gas	Avg. annual growth	
	BMT	BMT	CAAGR	BMT	BMT	CAAGR	BMT	BMT	CAAGR
1965	6.1	—	—	5.1	—	—	1.6	—	—
1990	8.3	0.1	1.2%	8.5	0.1	2.1%	3.7	0.1	3.4%
2015	14.5	0.2	2.3%	11.1	0.2	3.2%	6.5	0.2	5.7%
2019	14.5	0.0	0.1%	11.5	0.1	0.9%	7.3	0.2	3.0%
2040		2019-2040			2019-2040			2019-2040	
BNEF	11.3	-0.2	-1.2%	10.2	-0.1	-0.6%	6.4	0.0	-0.6%
BP BAU	12.8	-0.1	-0.6%	10.6	0.0	-0.4%	9.4	0.1	1.3%
BP RT	4.4	-0.5	-5.5%	7.0	-0.2	-2.3%	7.9	0.0	0.4%
BP NZ	3.1	-0.5	-7.1%	5.0	-0.3	-3.9%	5.1	-0.1	-1.6%
Eq Reform	11.3	-0.2	-1.2%	10.1	-0.1	-0.6%	8.4	0.1	0.7%
Eq Rebalance	5.9	-0.4	-4.2%	6	-0.3	-3.0%	6.3	0.0	-0.7%
Eq Rivalry	15	0.0	0.2%	12.8	0.1	0.5%	8.4	0.1	0.7%
IEA STEPS	12.4	-0.1	-0.7%	11.6	0.0	0.0%	9.3	0.1	1.2%
IEA SDS	3.3	-0.5	-6.8%	6.4	-0.2	-2.8%	5.2	-0.1	-1.6%
IPCC SR1.5 IP1	—	—	—	—	—	—	—	—	—
IPCC SR1.5 IP2	—	—	—	—	—	—	—	—	—
IPCC SR1.5 IP3	—	—	—	—	—	—	—	—	—
IPCC SR1.5 IP4	—	—	—	—	—	—	—	—	—
IRENA Planned	11.7	-0.1	-1.0%	13.2	0.1	0.7%	9.7	0.1	1.4%
IRENA Transforming	5.3	-0.4	-4.7%	7.2	-0.2	-2.2%	3.6	-0.2	-3.3%
OPEC	14.1	0.0	-0.1%	13.5	0.1	0.8%	9.3	0.1	1.2%

Table 19. Carbon capture, storage, and use, by region

	World	Avg. annual growth		West	Avg. annual growth		East	Avg. annual growth	
	MMT	MMT	CAAGR	MMT	MMT	CAAGR	MMT	MMT	CAAGR
1990	0	—	—	0	—	—	0	—	—
2015	28	1.1	—	25	1.0	—	3	0.12	—
2018	38	3.3	10.7%	30	1.7	6.3%	8	1.7	38.7%
2040		2018-2040			2018-2040			2018-2040	
BNEF	—	—	—	—	—	—	—	—	—
BP BAU	200	7.4	7.8%	140	5.0	7.3%	60	2.4	9.6%
BP RT	2,794	125.3	21.6%	841	36.9	16.4%	1,952	88.4	28.4%
BP NZ	3,520	158.3	22.9%	1,039	45.9	17.5%	2,481	112.4	29.8%
Eq Reform	192	7.0	7.6%	—	—	—	—	—	—
Eq Rebalance	1,292	57.0	17.4%	—	—	—	—	—	—
Eq Rivalry	380	15.5	11.0%	—	—	—	—	—	—
IEA STEPS	—	—	—	—	—	—	—	—	—
IEA SDS	—	—	—	—	—	—	—	—	—
IPCC SR1.5 IP1	0.0	-1.7	-100.0%	—	—	—	—	—	—
IPCC SR1.5 IP2	3,098	139.1	22.1%	—	—	—	—	—	—
IPCC SR1.5 IP3	5,695	257.1	25.6%	—	—	—	—	—	—
IPCC SR1.5 IP4	7,170	324.2	26.9%	—	—	—	—	—	—
IRENA Planned	—	—	—	—	—	—	—	—	—
IRENA Transforming	—	—	—	—	—	—	—	—	—
OPEC	—	—	—	—	—	—	—	—	—

Note: 2019 data not available.

6. References

BloombergNEF. 2020. New Energy Outlook 2020. **https://about.bnef.com/new-energy-outlook/**.

BP. 2020. Energy Outlook 2020. **https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html**.

Butnar, I., et al. 2020. A Deep Dive into the Modeling Assumptions for Biomass with Carbon Capture and Storage (BECCS): A Transparency Exercise. *Environmental Research Letters* 15, 084008.

Equinor. 2020. Energy Perspectives 2020: A Time of Great Uncertainty. **https://www.equinor.com/en/how-and-why/energy-perspectives.html**.

Grubler, A. 2008. Energy Transitions. In *Encyclopedia of Earth*. Environmental Information Coalition, National Council for Science and the Environment. Washington, D.C.

IEA (International Energy Agency). 2018. IEA World Energy Statistics and Balances. **https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en**.

IEA. 2020. World Energy Outlook 2020. **https://www.iea.org/reports/world-energy-outlook-2020**.

IEA. 2021. Global Energy Review 2021. **https://www.iea.org/reports/global-energy-review-2021?utm_source=newsletter&utm_medium=email&utm_campaign=newsletter_axiosgenerate&stream=top**.

International Monetary Fund. 2021. World Economic Outlook: Managing Divergent Recoveries. **https://www.imf.org/en/Publications/WEO/Issues/2021/03/23/world-economic-outlook-april-2021**.

IRENA. 2020. Global Renewables Outlook: Energy Transformation 2050. **https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020#:~:text=Global%20Renewables%20Outlook%3A%20Energy%20transformation%202050,-April%202020&text=The%20Global%20Renewables%20Outlook%20shows,a%20sustainable%20future%20energy%20system.&text=Comprehensive%20policies%20could%20tackle%20energy,the%20transformative%20decarbonisation%20of%20societies**.

Johns Hopkins University. 2021. Covid-19 dashboard. **https://coronavirus.jhu.edu/map.html**.

Newell, R.G., and Iler, S. 2013. The Global Energy Outlook. **http://www.nber.org/papers/w18967** (2013) doi:10.3386/w18967.

Newell, R.G., and Raimi, D. 2020. Global Energy Outlook Comparison Methods: 2020 Update. **www.rff.org/geo**.

Newell, R.G., Raimi, D., Villanueva, S., and Prest, B. 2020. Global Energy Outlook 2020: Energy Transition or Energy Addition? **https://www.rff.org/publications/reports/global-energy-outlook-2020/**.

O'Neill, B.C., et al. 2014. A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways. *Climatic Change* 122: 387–400.

OPEC. 2020. World Oil Outlook 2020. **https://www.opec.org/opec_web/en/publications/340.htm**.

Riahi, K., et al. 2017. The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview. *Global Environmental Change* 42: 153–168.

Rogelj, J., et al. 2018. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In Global Warming of 1.5°C. *An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, edited by Masson-Delmotte, V., et al.

UNFCCC. 2015. Paris Agreement. **https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement**.