Global Energy Outlook Comparison Methods: 2022 Update

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About the Project

This paper is part of a larger multiyear effort on short-, medium-, and long-term energy outlooks by Resources for the Future. The project has resulted in multiple reports, several of which have been produced with support from, and in collaboration with, the International Energy Forum (IEF). This report updates Newell and Raimi Global Energy Outlooks Comparison Methods: 2020 Update (2019). Other reports produced in collaboration with IEF include the background papers for the annual IEA-IEF-OPEC Symposium on Energy Outlooks and previous editions of RFF's Global Energy Outlook, which compares and synthesizes the results of long-term energy outlooks by BNEF, BP, ExxonMobil, Equinor, IEA, IEEJ, IRENA, IPPC, OPEC, Shell, and US EIA.

About RFF

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Abstract

We update a harmonization methodology developed in 2015 to facilitate comparisons of long-term global energy projections issued by Bloomberg New Energy Finance, Equinor, the International Energy Agency (IEA), the International Renewable Energy Agency, the Organization of the Petroleum Exporting Countries, Shell, and the US Energy Information Administration (EIA). Decisionmakers in the public and private sectors rely on these projections to inform investments and policy, but apples-to-apples comparison of the outlooks is not possible due to methodological differences. For example, EIA excludes nonmarketed traditional biomass, resulting in estimates of global primary energy consumption that are more than 10 percent lower than other projections. Assumptions about energy content of fossil fuels can vary by more than 11 percent in the data examined, requiring significant adjustment of primary energy consumption estimates. Conventions about primary energy conversion of renewable energy resources can also alter estimates by as much as a 58 percent decrease to a 3.3-fold increase for particular electricity sources, relative to IEA estimates. We also find significant differences in historical data used in these outlooks, even when measured in fuel-specific physical units, such as barrels, cubic meters, or tonnes. Accounting for these differences, our harmonization methodology brings estimates within 3 percent for major fuels in the benchmark year of 2020. We describe the process by which we enhance the comparability of outlooks by adjusting for differences in assumptions such as fuel classifications, energy content, and conversion efficiencies. We present a selection of the harmonized results, benchmarked to the IEA's 2021 World Energy Outlook. This methodology is used to develop our Global Energy Outlook 2022 report, available at **www.rff.org/geo.**

Contents

1. Introduction

The global energy sector has experienced historical disruption in recent years. Many factors, including the COVID-19 pandemic, the need to deeply reduce greenhouse gas emissions, Russia's invasion of Ukraine among other geopolitical tensions, and evolving technologies have introduced deep uncertainties into the future and even the present of energy. Continued population and economic growth are driving up world energy demand, and access to affordable and reliable energy continues to be a pressing challenge for hundreds of millions, if not billions, of people.

Energy outlooks are one way to understand how these and other factors may affect the trajectory of the interlinked energy and climate systems. Each year, multiple long-term energy outlooks, usually projecting 20–25 years ahead, are issued by organizations such as the International Energy Agency (IEA), the Organization of the Petroleum Exporting Countries (OPEC), the US Energy Information Administration (US EIA), the International Renewable Energy Agency (IRENA), and international energy companies (e.g., BP, Equinor, ExxonMobil, Shell). In recent years, other organizations, such as the Russian and Chinese Academies of Sciences, the Institute for Energy Economics of Japan (IEEJ), Bloomberg New Energy Finance (BNEF), new international organizations (such as the Gas Exporting Countries Forum), and national oil and gas companies (such as the Chinese National Petroleum Company) have also issued annual energy outlooks. Notably, neither BP nor ExxonMobil produced outlooks in 2021, although they have in previous years. In addition, energy modeling teams worldwide have produced long-term scenarios with a variety of socioeconomic and emissions trajectories used to inform reports from the Intergovernmental Panel on Climate Change (IPCC). Each organization and modeling team makes long-term energy projections using its own modeling assumptions and sometimes unique historical databases.

Due to the important role these outlooks play in informing decisions by market participants and policymakers, a consistent method of presenting their information can enhance an inclusive and meaningful international energy dialogue. However, their varying methodologies and assumptions makes comparing between and among different outlooks challenging. To address this issue, we have developed a methodology to harmonize and compare projections from various outlooks, enabling market participants and policymakers to evaluate the range of global energy projections more clearly.

To illustrate this harmonization process, we use the most recent outlooks available for comparative analysis of energy forecasts, with 2020 as a common baseline:

- BNEF: New Energy Outlook 2021 (NEO 2021)[1]
- EIA: International Energy Outlook 2021 (IEO 2021)[2]
- Equinor: Energy Perspectives 2021[3]
- IEA: World Energy Outlook 2021 (WEO 2021)[4]
- IRENA: World Energy Transitions Outlook 1.5°C Pathway 2021[5]

- OPEC: World Oil Outlook 2021 (WOO 2021)[6]
- Shell: Energy Transformation Scenarios 2021[7]

Each outlook discussed in this paper covers a range of topics, from qualitative descriptions of technology development to quantitative projections of energy consumption, supply, and carbon dioxide emissions. Our purpose is not to hide differences across institutions in their views about the future outlook for the energy system but rather to control for differences in convention and data sources that thwart an accurate assessment of underlying assumptions and judgments about the short, medium, and long terms in different outlooks.

We focus on overall primary energy consumption and its key fuel sources—oil and other liquids (e.g., natural gas condensate and biofuels), natural gas, coal, nuclear, and renewables—and provide a detailed description of our approach. This paper identifies that institutional sources differ in the following ways and seeks to address these challenges:

- units of primary energy consumption (e.g., qBtu, mtoe, mboe);
- assumptions about future population and economic growth;
- assumptions for the energy content of fossil fuels and use of net and gross calorific values for fuels;
- assumptions regarding the efficiency of conversion to primary energy and of noncombustible energy sources (e.g., nuclear and renewable electric power);
- reporting of electricity generation (most report gross generation, but the EIA reports net generation);
- inclusion of nonmarketed sources of energy, particularly traditional biomass;
- categorization of energy sources (e.g., biofuels, liquids, oil, synthetic gas from coal, and renewables) and whether flared gas is included;
- historical baseline data; and
- regional groupings of countries.

Sections 2, 3, and 4 elaborate on the first four issues mentioned above. Section 5 presents our harmonization method and identifies the issue of remaining differences in historical baseline data, using 2020 as the benchmark. Section 6 discusses differences in geographic groupings, and Section 7 concludes.

2. Primary Energy Unit Conversion and Energy Content Adjustment for Fuels

Most outlooks project energy consumption in three forms: (1) primary energy, (2) energy use in power generation, and (3) end-use consumption in specific sectors, such as transport, industry, and residential/commercial buildings. Primary energy consumption is a particularly important aggregate measure of long-term trends assessed by energy outlooks. “Primary energy” refers to the energy embodied in natural resources before any conversion or transformation process for end-use consumption. The level of primary energy consumption and its fuel composition for a country or region are affected by its population, economic output and structure, stage of development, indigenous resource availability, and level of energy efficiency. Energy outlooks forecast primary energy consumption by region and fuel type, but data transformation is necessary to directly compare between most outlooks.

The first challenge of comparing primary energy consumption is the use of different units. It tends to be reported in a traditional energy unit, such as quadrillion Btu (qBtu), exajoules (EJ), or million tonnes of oil equivalent (mtoe). However, sometimes the primary consumption of a specific fuel is not directly presented, and comparing primary energy involves derivation from other energy consumption data.[i] Table 1 displays various units used to report consumption of primary energy and specific fuels across outlooks.

As Table 1 shows, each outlook has a standard reporting unit for primary energy consumption; the most commonly used are exajoules (EJ) or petajoules (PJ) (BNEF, IEA, IRENA, Shell), but other outlooks use mtoe (Equinor), qBtu (US EIA), and million barrels of oil equivalent per day (mboed, OPEC). To compare, one needs to place all outlooks in a common unit. We use qBtu as the benchmark, requiring an appropriate conversion factor for outlooks other than those from the EIA. According to international convention (see, for example, IEA[ii]), energy consumption data in mtoe can be converted into qBtu by multiplying by a factor of 0.03968 qBtu/mtoe. Similarly, OPEC uses a standard conversion factor of 7.33 mboe/mtoe, which is equivalent to 49.8 mtoe/mboed.[iii] To transform OPEC’s primary energy data from mboed to qBtu, we therefore multiply by 1.976 qBtu/mboed (= 49.8 mtoe/mboed × 0.03968 qBtu/mtoe).

To convert IEA, IRENA, and Shell primary energy data from EJ to qBtu, we first convert from EJ to qBtu using a factor of 1 EJ = 0.948 qBtu.

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i For example, US EIA does not report primary energy consumption for hydropower and other renewables individually. To compare with other outlooks, one has to use data measured in terawatt hours (TWh) and then convert to primary energy.

ii IEA (2019).

iii Internal communication with OPEC. To convert from mboed to mtoe per year for OPEC, multiply by 365 days per year and divide by OPEC’s mtoe-to-mboe conversion factor, 7.33. The result is 365 days/year ÷ 7.33 mboe/mtoe = 49.8 mtoe/mboed.

Table 1. Units of Energy Consumption Used in Different Outlooks

	BNEF	EIA	Equinor	IEA	IRENA	Shell	OPEC
Primary energy units	PJ	qBtu	mtoe	EJ	PJ	EJ	mboed
Fuel/sector-specific units							
Liquids	N.A.	mbd	mbd	mbd	N.A.	N.A.	mbd
Oil	N.A.	mbd	mbd	mbd	N.A.	N.A.	mbd
Biofuels	N.A.	mbd	N.A.	mboed	N.A.	N.A.	mbd
Natural gas	N.A.	tcf	bcm	bcm	N.A.	N.A.	mboed
Coal	N.A.	mst	N.A.	mtce	N.A.	N.A.	mboed
Electricity	GWh	TWh	TWh	TWh	TWh	N.A.	N.A.

Note: Units are per year unless otherwise noted. "N.A." indicates that fuel-specific data are not available for a given energy source. See Glossary for full terminology.

After converting to a common energy unit, considerable difference in baseline data remains due to differences in organizations' energy content assumptions when converting physical units of fuels (i.e., mbd of oil and other liquids, tcf of natural gas, and mt of coal) to their original energy units. For example, we understand from experts at US EIA that the principle reason for its significantly higher estimates for liquids and natural gas compared to IEA is that it uses the higher heating value (or gross calorific value), whereas IEA and all other outlooks use the lower heating value (or net calorific value). To address these differences, we derive a set of "energy content adjustment factors" for each organization and major fuel source: liquids (Table 2), natural gas (Table 3), and coal (Table 4). Our general approach involves two steps, conducted separately for each organization and fuel when sufficient data are available. In this year's report, we only conduct this harmonization for the EIA due to either lack of available data (OPEC) or internal communication that indicates other outlooks rely on IEA for historical data and energy content assumptions (BNEF, Equinor, IRENA, Shell).

First, we identify each organization's energy content assumptions. We obtain two sets of data from each outlook, where available—one in primary energy units (i.e., qBtu, mtoe, EJ) and the other in fuel-specific physical units (i.e., mbd of liquids, tcf of natural gas, mt of coal). We derive the implicit average energy content assumptions for each fuel, by organization, by dividing the former by the latter. For US EIA, this results in energy content factors measured in qBtu/mbd for liquids, qBtu/tcf for natural gas, and qBtu/mt for coal. For the other outlooks, this results in energy content factors measured in mtoe/mbd for liquids, mtoe/tcf for natural gas, and mtoe/mt for coal, which we then multiply by 0.03968 qBtu/mtoe to create factors involving only qBtu, which can be directly compared across organizations. This yields an energy content factor for each fuel and organization, measured in qBtu/mbd of liquids, qBtu/tcf of natural gas, and qBtu/mt of coal. These factors can vary within an outlook across time and regions, but in practice, the variation over time is slight. It is not possible for us to calculate a complete set of conversion factors for each outlook, fuel, region, and year due to limited data. We instead average near- and long-term factors (where data are available) to estimate each outlook's energy content assumptions.

Second, we derive an energy content adjustment factor by dividing the energy content factors for IEA by those of other outlooks. This approach benchmarks these organizations' estimates so that they are approximately "as if" they had used the average aggregate IEA energy content assumptions for each fuel.

The conversion process for primary energy consumption of liquids is given in Table 2. Data measured in mbd are given in column (a), in qBtu in column (b), and in mtoe in column (c). Column (d) divides (c) by (a) to create an mtoe/mbd conversion factor. For most outlooks, column (e) multiplies column (d) by 0.9478 qBtu/EJ to create a qBtu/mbd conversion factor. For US EIA, column (e) divides (b) by (a) to create a qBtu/mbd conversion factor. The final row of Table 2 shows the resulting energy content adjustment factors found by dividing the IEA qBtu/mbd factor by factors from other organizations. We derive energy content adjustment factors for natural gas (Table 3) and coal (Table 4) using the same approach as Table 2.

Table 2. Liquids Energy Content Adjustment

Source	Year of demand data	Fuel-specific units	Primary energy units		Implied conversion factors	
		mbd	qBtu	EJ	EJ/mbd	qBtu/mbd
		(a)	(b)	(c)	(d) = (c/a)	(e) = (dx0.9478 qBtu/EJ)
IEA[1]	2019	98.6		192	1.95	1.846
	2030	106.4		206	1.93	1.831
	2050	108.7		210	1.93	1.833
IEA avg.					1.93	**1.832**
EIA[2]	2019	101.1	200.4			1.982
	2030	109.2	215.6			1.974
	2050	125.9	248.5			1.974
EIA avg.						**1.977**
Energy content adjustment factors for liquids						
IEA (benchmark): 1						
EIA: 0.9268						

Note: All data in the table are consumption data. Dashes indicate the data are not available from a particular source. BNEF, Equinor, IRENA, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or benchmark their energy content assumptions to IEA. (1) IEA data based on Stated Policies Scenario. (2) EIA based on Reference Scenario.

Table 3. Natural Gas Energy Content Adjustment

Source	Year of demand data	Fuel-specific units		Primary energy units		Implied conversion factors	
		Bcm/y	Tcf/y	qBtu	EJ	EJ/tcf	qBtu/tcf
			(a)	(b)	(c)	(d = c/a)	(e) = (d×0.9478 qBtu/EJ)
IEA[1]	2030	4,554	160.8		157	0.98	0.925
	2050	5,113	180.6		176	0.97	0.921
IEA avg.						0.97	0.923
EIA[2]	2030		160.2	166.5			1.039
	2050		186.0	193.2			1.039
EIA avg.							1.039
Energy content adjustment factors for natural gas							
IEA (benchmark): 1							
EIA: 0.8883							

Note: All data in the table are consumption data. Dashes indicate the data are not available from a particular source. BNEF, Equinor, IRENA, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or benchmark their energy content assumptions to IEA. (1) IEA data based on Stated Policies Scenario. (2) EIA based on Reference Scenario.

Table 4. Coal Energy Content Adjustment

Source	Data year	Fuel-specific units		Primary energy units		Implied conversion factors	
		Million short tons	Million metric tons	qBtu	EJ	EJ/mt	qBtu/mt
			(a)	(b)	(c)	(d = c/a)	(e) = (d×0.9478 qBtu/EJ)
IEA	2020		7,361		160	0.0217	**0.02058**
EIA	2030	7,905	7,171	156			0.02173
	2050	9,152	8,302	177		0.0217	0.02058
EIA avg.		7,904.8					0.02150
Energy content adjustment factors for coal							
IEA (benchmark): 1							
EIA: 0.9572							

Note: All data in the table are consumption data. Dashes indicate the data are not available from a particular source. BNEF, Equinor, IRENA, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or benchmark their energy content assumptions to IEA. (1) IEA data based on Stated Policies Scenario. (2) EIA based on Reference Scenario.

Table 5. Energy Content Adjustment Factors for Liquids, Natural Gas, and Coal

	Liquids	Natural Gas	Coal
IEA (benchmark), BNEF, Equinor, IRENA, OPEC, Shell	1.000	1.000	1.000
EIA	0.927	0.888	0.957

Table 5 summarizes the resulting energy content adjustment factors for US EIA. The factors differ moderately in most cases and substantially in some, revealing differences in energy content assumptions for each fuel: up to 7 percent for liquids, 11 percent for natural gas, and 4 percent for coal. An implication is that failing to adjust for differing energy content assumptions and instead relying on standard mtoe-to-qBtu conversion factors will result in significant under- or overestimates when comparing between outlooks. This adjustment is only necessary for fossil fuels; another approach is necessary to address the differences in assumptions about the primary energy content of nuclear and renewable power (see section 3).

Determining a single “correct” adjustment factor for each fuel is not feasible, as these factors are a summary metric of underlying assumptions about the energy content of different fuels, which vary by region and over time. Controlling fully for these differences would require harmonizing the underlying datasets and energy content assumptions across all the models. Nonetheless, using these more carefully derived energy content adjustment factors resolves a significant amount of the existing difference when comparing estimates across these outlooks.

3. Primary Energy Conversion for Nuclear and Renewable Electricity Generation

3.1. Different Approaches Across Outlooks

It is conceptually straightforward to understand the primary energy of fossil fuels and biomass because these combustible fuels have an easily measurable energy content and their upstream physical supply is commonly tracked. In contrast, calculating it for nuclear power and nonbiomass renewables, such as solar, hydropower, wind, and geothermal, is more complex because the notion of upstream embodied energy is less well defined and widely measured.

To estimate primary energy for these sources, one approach is to identify the amount of electricity generated (i.e., secondary transformed energy)[iv] and divide this estimate by an assumed conversion efficiency rate. However, the assumed rates for nuclear and renewable power are not consistent across outlooks (Table 6). We explain the rationale for each outlook's assumptions.

Table 6. Primary Energy Conversion Efficiency Assumptions for Nuclear and Renewable Power

	Nuclear	Hydropower	Wind	Solar PV	Solar thermal	Geothermal	Biomass
BNEF	33%	100%	100%	100%	33%	10%	35%
EIA	32%	42%	42%	42%	No data	33%	32%
Equinor	33%	100%	100%	100%	33%	10%	35%
IEA (Benchmark)	33%	100%	100%	100%	33%	10%	35%
IRENA	33%	100%	100%	100%	33%	10%	35%
OPEC	33%	100%	100%	100%	33%	10%	35%
Shell	33%	100%	100%	100%	33%	10%	35%

Sources: IEA World Energy Outlook 2021. EIA World Energy Projection System (2021) documentation and internal communication. Internal communication for all other outlooks.

iv Some projections, including the Integrated Assessment Models used to inform reports from the IPCC, take the "direct equivalence" approach, which assumes a conversion efficiency of 100 percent for all nonfossil energy sources. For more, see Koomey et al. (2019).

IEA, BNEF, Equinor, IRENA, OPEC, and Shell

Most outlooks examined follow IEA's assumptions from its WEO series.[v] Because biomass is combustible (like fossil fuels), most of these organizations use a conversion efficiency of 35 percent based on an average energy content. For nuclear power, IEA divides electricity generation by an assumed efficiency factor of 33 percent for the steam generator of a typical nuclear power plant; this yields the amount of heat generated in a nuclear reactor, which is taken as the amount of primary nuclear energy. For geothermal power, which involves converting steam energy into electricity, the IEA conversion efficiency assumption is 10 percent. For the remaining renewable power sources—hydropower, wind, solar, and other (e.g., tidal)—IEA uses the "captured energy" approach, which assumes that the primary energy content equals the energy content of the produced electricity (i.e., 3,412 Btu per kWh). This approach assumes no energy is lost in the conversion process, so the efficiency is 100 percent. For final energy consumption, which we do not analyze, differences emerge between Shell and other outlooks, as Shell incorporates electricity losses during transmission and distributions, but IEA does not. Finally, Equinor reports through internal communication that its conversion efficiencies vary across regions and time, as different technologies are deployed regionally over the projection period.

EIA

US EIA takes a different approach than the other outlooks, relying on conversion efficiency assumptions included in its World Energy Projection System (WEPS). We examined the WEPS documentation[8] and corresponded with US EIA staff to gather the relevant conversion efficiency assumptions. For nuclear and biomass energy, US EIA's assumptions (32 and 32 percent, respectively) are similar to IEA's (33 and 35 percent, respectively). But most renewable sources have considerable variation, with US EIA assuming 42 percent efficiency for hydropower, wind, and solar PV, compared with the 100 percent efficiency assumed by IEA. The difference for geothermal is even greater, with US EIA assuming 33 percent efficiency, more than three times the IEA assumption of 10 percent.

In addition to these differences in conversion efficiency assumptions, and as noted, US EIA reports electricity generation in net terms (including parasitic load), but IEA and other organizations report electricity generation in gross terms (excluding parasitic load).

3.2. Nuclear and Renewable Primary Energy

Due to these differences in assumed primary energy conversion efficiency for nuclear and renewables, adjustments must be made to compare primary energy projections

v Internal communication with BNEF, Equinor, IRENA, OPEC, and Shell.

across outlooks. This requires choosing a benchmark set of assumptions, for which we use IEA's conversion efficiencies.[vi]

For example, consider primary energy consumption from nuclear sources in outlooks from US EIA and IEA. US EIA assumes a nuclear power plant efficiency rate of 32 percent, but IEA assumes 33 percent. Therefore, the primary nuclear energy consumption figure for BP must be multiplied by 0.97 (0.32/0.33) to be comparable to the figure for IEA. The same approach can be used for renewables.[vii] All the multiplicative factors are presented in Table 8.

vi Due to data limitations, we apply these assumptions on a global scale even though they may vary somewhat from region to region within outlooks.

vii This approach requires obtaining the necessary data on the individual renewable power sources (i.e., hydropower, wind, solar, geothermal, and other), in qBtu, from US EIA. Additional steps needed to convert the US EIA figures on renewable power when using the standard published data because US EIA only publishes net electricity generation (in TWh) rather than primary energy for each renewable source. To benchmark these figures with the IEA estimates, we convert the US EIA estimates of net generation in TWh to qBtu (by multiplying by 0.003412 qBtu/TWh) and divide by IEA's conversion efficiency assumptions for each source.

4. Fuel Categorization

Another challenge arises from different groupings of energy sources across outlooks. Categorizations are generally consistent for coal, natural gas, and nuclear energy but vary for liquids, oil, biofuels, and renewable energy.

4.1. Liquids, Oil, and Biofuels Categorization

In general, the term “liquids” usually includes biofuels, whereas “oil” does not. “Liquid biofuels” refers mainly to bioethanol and biodiesel. The US EIA includes biofuels in the liquids category, along with crude oil, natural gas liquids, refined petroleum products, and liquids derived from other hydrocarbon sources (e.g., gas-to-liquids and coal-to-liquids). In contrast, IEA and Shell distinguish biofuels from “oil” and provide biofuels demand data for all relevant regions. Equinor includes biofuels in its “biomass” and “biomass/waste” categories for most regions and only includes a global biofuels estimate in the transport sector. OPEC only publishes information on biofuels supply, which—for the sake of comparable results—we assume equals biofuels demand in the relevant year and add it to “oil” demand to produce a “liquids” variable for OPEC. BNEF and IRENA do not provide biofuels data and instead include it as part of their “bioenergy” grouping, preventing us from constructing a “liquids” variable for both outlooks.

In addition, biodiesel and bioethanol have different energy content per unit volume than petroleum-based diesel and gasoline. To make biofuels comparable to other liquid fuels in terms of their ability to meet transport demand, biofuels are usually measured in *energy-equivalent* volumetric units (i.e., mboed), as shown in Table 1, and the mbd-to-qBtu conversion factor for liquids derived from Table 2 can apply. The amount of biofuels expressed in energy-equivalent terms is smaller than that in pure volumetric terms. For example, when the IEA WEO 2021 estimates global biofuels demand of 1.9 mboed in 2020, the volume of physical demand was roughly 2.6 mbd.[viii]

4.2. Renewables Categorization and Nonmarketed Energy

Comparisons of renewable energy consumption present another challenge, particularly the treatment of nonmarketed renewables. US EIA only includes marketed renewables in its projections, but other outlooks include nonmarketed energy (i.e., traditional biomass). These different approaches can result in large gaps in renewable energy consumption estimates across outlooks, particularly related to traditional biomass.

In 2020, for example, estimates of nonhydropower renewables consumption (excluding

viii Energy equivalent volumes from IEA World Energy Outlook 2018, Table 3.1; physical volumes from IEA, Oil 2018, Tables 5 and 5a.

biofuels) for IEA and US EIA are 69 qBtu and 15 qBtu respectively, with the difference primarily explained by US EIA's exclusion of nonmarketed biomass (see Table 9). This scale of energy consumption from nonmarketed sources can lead to misleading comparisons across outlooks in categories including renewable energy consumption, total global energy consumption, and the shares of different sources in total energy. For example, IEA's 2020 estimate for global primary energy demand is roughly 9 percent higher than that of US EIA. Similarly, the share of primary energy from nonhydropower renewables ranges from 3 percent for US EIA compared with roughly 12 percent for IEA and others.

Renewables groupings also vary between outlooks, and recategorization is necessary to enable direct comparison. Table 7 displays the different categories for which primary energy consumption and electricity generation from renewables are reported in the outlooks. Because of the wide variation in the treatment of nonhydropower renewables, we aggregate these sources into a single category to allow for comparison.

As shown in Table 7, US EIA's IEO 2021 uses a single "Other" category to report primary energy consumption for all renewable power sources, including hydropower, wind, solar, geothermal, biomass, and waste. To derive the US EIA's primary energy consumption estimate for each renewable source, one must convert the amount of electricity generated from that source (in TWh) to its primary energy equivalent, as described in section 3.2. Finally, biofuels are treated differently across outlooks. To make data comparable, we adjust the categorization of biofuels where necessary to ensure inclusion in the "liquids" category alongside oil. In their 2021 outlooks, neither BNEF nor Equinor provide detailed biofuels data, so we are unable to estimate total liquids for either outlook and instead present oil-only information for both.

Table 7. Renewable Energy Categories for Primary Energy and Electricity

	Unique variables	Sources included in "other renewables"
	Primary energy	
	Unique variables	**Sources included in "other renewables"**
BNEF	Wind, solar, biomass	Hydropower, geothermal, marine
EIA	-	Hydropower, wind, solar, geothermal, biomass, marine
Equinor	Hydropower, biomass	Wind, solar, geothermal, marine
IEA	Hydropower, wind, solar, modern bioenergy, traditional biomass	Geothermal, marine
IRENA	Hydropower, wind, solar, biomass, geothermal, marine	-
OPEC	Hydropower, biomass	Wind, solar, geothermal
Shell	Hydropower, biomass, bioefuels, wind, solar, geothermal	Marine
	Electricity	
	Unique variables	**Sources included in "other renewables"**
BNEF	Biomass, wind, solar	Hydropower, geothermal, marine
EIA	Hydropower, wind, solar, geothermal	Biomass, marine
Equinor	Hydropower, biomass, wind, solar	Geothermal, marine
IEA	Hydropower, biomass, wind, solar PV, CSP, geothermal, marine	None
IRENA	Hydropower, biomass, biogas, wind, solar PV, CSP, geothermal, marine	None
OPEC	None	None
Shell	Hydropower, biomass, biofuels, wind, solar PV, CSP, geothermal, tidal, wave	None

Notes: Data from published outlooks and internal communication with each organization.

5. Outlook Harmonization and Historical Data Differences

In this section, we describe a method for using the information provided earlier to harmonize outlook estimates of world primary energy consumption. We apply this methodology to baseline 2020 data but note that it could be applied to any common projection year.

First, we convert all primary energy consumption data to qBtu using the standard conversion factors of 0.03968 qBtu/Mtoe (Equinor), 1.976 qBtu/mboed (OPEC), and 1.0551 qBtu/EJ (BNEF, Shell, IEA, IRENA). Note that US EIA data are published in qBtu terms.

Second, we adjust US EIA fossil fuel data for differences in energy content assumptions by multiplying by the adjustment factors found in Table 5. In this year's outlooks, US EIA is the only one that provides sufficient fuel-specific information to adjust for energy content assumptions of fossil fuels. Our understanding from communication with other organizations included in this analysis is that they follow the relevant IEA conventions.

Third, for individual US EIA renewables categories, we calculate estimates in qBtu by multiplying data in TWh by 0.003412 qBtu/TWh. This conversion excludes biomass and solar thermal energy used in water or space heating and so underestimates total primary energy from both biomass and solar.

Fourth, we use IEA's conversion efficiency assumptions to benchmark primary energy consumption of nuclear and renewable energy. Based on the conversion efficiency assumptions collected in Table 6, we can calculate a multiplicative factor by fuel for each outlook, shown in Table 8.

Table 8. Multiplicative Factors for Each Fuel Source to Convert Primary Energy in Other Outlooks to IEA's Primary Energy Conversion Efficiency Assumptions

	Nuclear	Hydropower	Wind & Solar	Geothermal	Biomass
IEA (Benchmark), BNEF, Equinor, IRENA, OPEC, Shell	1.00	1.00	1.00	1.00	1.00
EIA	0.97	0.42	0.42	3.34	0.90

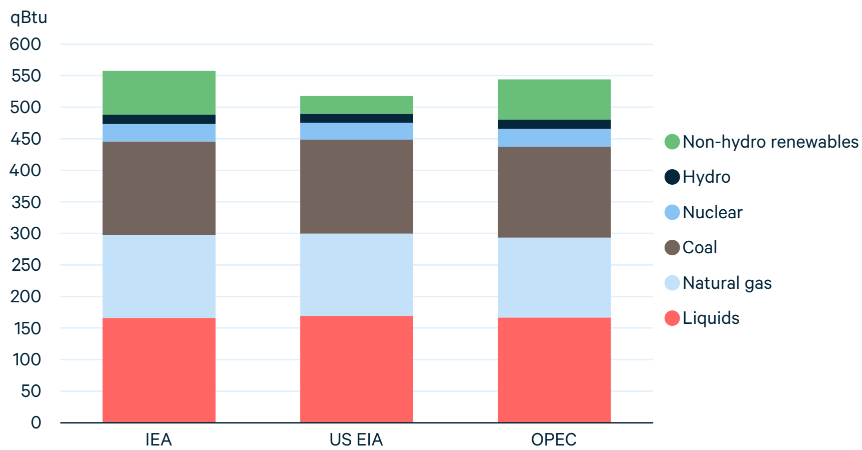
Fifth, we adjust data to yield a uniform definition of liquids (including biofuels) and nonhydropower renewables (excluding biofuels). Table 9 and Figure 1 display the results.

Table 9. Comparison of Harmonized Outlook Primary Energy Consumption 2020 Data (qBtu)

	IEA	OPEC	US EIA
Liquids	166	166	169
Oil (excl. biofuels)	162	163	165
Biofuels	3.6	3.5	3.6
Gas	132	127	131
Coal	148	144	149
Nuclear	28	28	27
Hydropower	15	15	14
Nonhydropower renewables (excl. biofuels, incl. nonmarketable sources)	69	64	N.A.
Nonhydropower renewables (excl. biofuels, only marketable sources)	N.A.	N.A.	15
Total renewables (excl. biofuels, incl. nonmarketable sources)	84	79	N.A.
Total renewables (excl. biofuels, only marketable sources)	N.A.	N.A.	28
Total energy, incl. biofuels, excl. nonhydropower renewables	488	480	489
Total primary energy	557	544	504

Notes: Totals or subtotals may not sum due to rounding. (1) US EIA totals are smaller because they exclude nonmarketed renewables, as described. (2) Limited data availability constrains our ability to fully harmonize OPEC's historical data.

Figure 1. Harmonized Baseline (2020) Primary Energy Consumption



Note: US EIA excludes nonmarketed renewables (e.g., traditional biomass). Limited data availability constrains our ability to fully harmonize OPEC's historical data.

Due primarily to its exclusion of nonmarketed renewables, US EIA has far lower total consumption estimates than other outlooks, which typically rely on IEA historical data. After accounting for the exclusion of nonmarketed renewables, the divergence from IEA in total primary energy consumption is less than 1 percent for US EIA and roughly 2 percent for OPEC.

Although the harmonization process adjusts for a significant amount of divergence, it does not eliminate all discrepancies in historical consumption data. For example, OPEC estimates global natural gas and coal consumption to be roughly 5 qBtu and 4 qBtu lower than IEA, respectively. These discrepancies are likely attributable to limitations in our conversion process, unidentified differences in definitions of energy categories, or other factors, such as variances in original consumption data used by each organization.

Finally, because many organizations rely on IEA for historical data, these organizations tend to use older vintages of data than IEA's most recent outlooks. Consider a given 2021 outlook from hypothetical organization "A." To publish its report in 2021, "A" conducts its modeling analysis in 2019, potentially based on historical data from IEA in 2017 or 2018. Because historical data are subject to revision, these temporal gaps can lead to notable differences in baseline data across organizations.

Nonetheless, this harmonization process results in substantial improvements in comparability across outlooks. To illustrate the significance of these differences, Figure 2 presents pre- and post-harmonization data for global primary energy consumption in 2020 for US EIA alongside IEA. The figure highlights the large differences arising from different assumptions, with US EIA data adjusted by 53 qBtu. For reference, total primary energy consumption across the European Union in 2020 also equaled 53 qBtu based on IEA data in the 2021 WEO.

Figure 2. Harmonized and Unharmonized Primary Energy Consumption in 2020

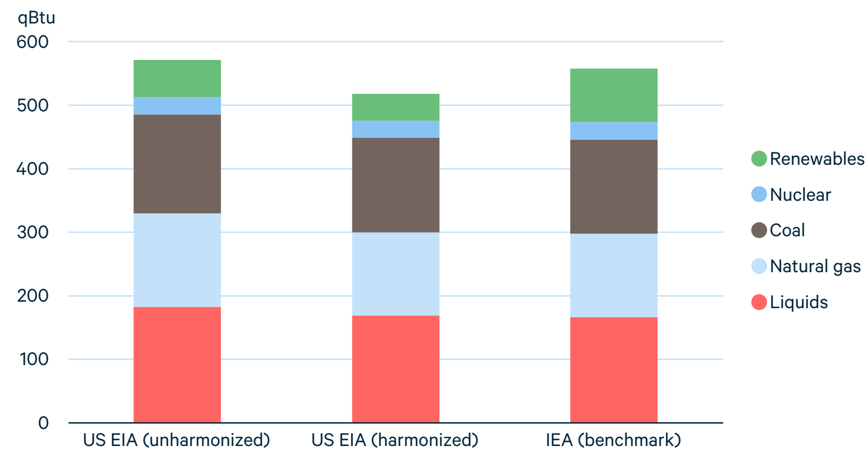


Table 10 shows the percentage difference between IEA and all other outlooks in terms of primary energy consumption by fuel.

To understand whether the differences shown in Table 10 are attributable to inadequacies in our conversion methodology or discrepancies in historical statistics, we also collected energy consumption data in physical units from these organizations, presented in Table 11. These data are either drawn directly from the outlooks or taken from other publications or databases from the same organizations. Other outlooks are not included in Table 11 because they do not present data in fuel-specific units.

Several notable differences emerge in Table 10, some of which are easily explained and others that are difficult to interpret. For biofuels, the difference between OPEC and IEA is due to different methods of reporting biofuels. OPEC does not report biofuels demand, so we use OPEC biofuels supply as a proxy for demand. The imbalance in supply and demand in 2020 likely means that biofuels supplied were considerably higher than biofuels demanded in 2020. For natural gas and coal, we are not able to explain the differences between OPEC and IEA. Potential explanations include OPEC's reporting of a single decimal point in its primary energy data, differences in conversion factors from mboed to QBtu (or EJ), and discrepancies in the underlying data.

For US EIA, substantial differences emerge in nuclear and hydropower. For hydropower, the discrepancy is likely due to the fact that US EIA reports hydropower in physical units of net generation, which differs by more than 7 percent from IEA's reporting of gross generation (Table 11). Our harmonization process brings IEA and EIA hydropower baseline data closer together, but the discrepancy between net and gross generation remains substantial.

For nuclear energy, we are unable to completely explain the divergence between US EIA and IEA. US EIA original data reports primary energy consumption from nuclear at 27.5 QBtu in 2020, quite similar to IEA's 27.9 QBtu (29.4 EJ). However, US EIA uses a conversion factor of 32 percent when converting from physical to primary energy units for nuclear, compared with 33 percent for IEA. Our harmonization process multiplies US EIA's original figure (27.5 QBtu) by the difference between the two harmonization factors (32 percent / 33 percent = 0.97), leading to a harmonized figure for US EIA of 26.7 QBtu (Table 9). This difference may be a result of US EIA converting net electricity generation into primary energy units rather than gross generation, but we are unable to confirm at time of publication.

Table 10. Harmonized Primary Energy Consumption Data Relative to IEA in 2020

	US EIA	OPEC
Liquids	1.8%	0.3%
Oil (excl. biofuels)	1.9%	0.3%
Biofuels	–0.8%	–3.5%
Natural gas	–0.7%	–3.8%
Coal	0.9%	–2.5%
Nuclear	–4.3%	1.4%
Hydropower	–6.9%	0.2%
Nonhydropower renewables (including nonmarketable sources)	N.A.	7.9%
Nonhydropower renewables (only marketable sources)	N.A.	N.A.
Total renewables (including nonmarketable sources)	N.A.	–6.5%
Total renewables (only marketable sources)	N.A.	N.A.
Total energy excluding nonhydropower renewables	0.2%	–1.6%
Total primary energy	–9.6%	–2.4%

Notes: US EIA totals are smaller in part because they exclude nonmarketed renewables, as described in section 4.2. Limited data availability constrains our ability to fully harmonize OPEC's historical data.

Table 11. Fuel-by-Fuel Comparison of Energy Consumption Data in 2020 (in Fuel-Specific Units)

	IEA	US EIA	US EIA/IEA
Liquids (mboe/d)	89.7	91.4	1.9%
Oil (excl. biofuels) (mb/d)	87.9	89.6	1.9%
Biofuels (mboe/d)	1.9	1.8	−4.9%
Natural gas (tcf/yr)	141	142	0.3%
Coal (million metric tons produced)	7,361	7,205	−2.1%
Nuclear (TWh)	2,692	2,630	−2.3%
Hydropower (TWh)	4,347	4,034	−7.2%
Nonhydropower renewables (only marketable sources) (TWh)	3,246	2,955	−9.0%
Total renewables (only marketable sources) (TWh)	7,593	6,989	−8.0%

Notes: (1) US EIA provides data for net electricity generation, but other sources provide data for gross generation.
Sources: IEA oil and natural gas data via World Energy Outlook 2021, coal data from Coal Information 2021; US EIA via International Energy Outlook 2021 data tables. Limited data availability prevents us from sharing OPEC's data.

This table illustrates the scale of discrepancies in Table 10 attributable to fuel-specific historical data, as opposed to other uncontrolled-for differences in energy content or energy conversion.

Subtracting the differences shown in the final column in Table 11 from Table 10 leads us to Table 12, which shows the gap in primary energy consumption remaining after controlling for differences in historical data and conversion efficiency assumptions. That gap is quite small for most energy sources, particularly liquids.

Notable differences remain for several other sources, including biofuels (4.0 percent), coal (3.0 percent), nuclear (2.0 percent), and natural gas (1.1 percent). These discrepancies highlight the continued opportunity for organizations such as IEA and US EIA to further standardize accounting methods to improve the understanding of the global energy system.

Table 12. Remaining Differences in 2020 Energy Consumption After Controlling for Differences in Historical Data and Primary Energy Conversion Efficiency Assumptions

	US EIA/IEA
Liquids	–0.1%
Oil (excl. biofuels)	–0.1%
Biofuels	4.0%
Natural gas	–1.1%
Coal	3.0%
Nuclear	–2.0%
Hydropower	0.3%

6. Country Details and Groupings Across Outlooks

In addition to comparing energy consumption at a global level, insights can be gleaned from regional comparisons across outlooks. One challenge, however, is that outlooks differ in categorizing countries into regional groupings.

Some outlooks, such as US EIA and OPEC, present regional data according to membership in the Organization of Economic Cooperation and Development (OECD). Others use regional groupings that vary by outlook. We examined the regional definitions for each outlook and found that regional data can be regrouped fairly consistently into five broad geographic areas: Africa, the Americas, Asia Pacific, Europe and Eurasia, and Middle East. The definitions for Africa and Middle East are common across most outlooks, but further harmonization is necessary to create comparable groupings for the Americas, Europe, and Asia Pacific. Nevertheless, perfect harmonization is not currently possible across all regions and outlooks. Next, we summarize variation between the regional classification systems in the presentation of primary energy consumption of the outlooks included in this analysis.

Africa

Three outlooks provide a comprehensive "Africa" regional group: Equinor, EIA, and IEA.

Americas

The same three outlooks provide data sufficient to create a comprehensive "Americas" regional group.

Asia Pacific

Two outlooks provide data sufficient to create a comprehensive "Asia Pacific" regional group: EIA and IEA. Both Equinor and OPEC provide primary energy data on China, India, and OECD Asia Pacific but not non-OECD Asia Pacific.

Europe and Eurasia

Two outlooks provide data sufficient to create a comprehensive "Europe and Eurasia" regional group: EIA and IEA. Equinor provides data on the European Union but not Russia or Eurasia, whereas OPEC provides data on OECD Europe, Russia, and Eurasia but not non-OECD Europe.

Middle East

The same two outlooks provide a comprehensive "Middle East" regional group.

East and West

We are able to produce consistent regional groupings of “East” and “West” for only two outlooks: EIA and IEA. “East” includes Africa, Asia Pacific, and Middle East, and “West” includes Americas and Europe and Eurasia.

World

All outlooks include a “World” grouping.

7. Conclusion

Energy industry experts, policymakers, and a range of other stakeholders make decisions and plan for the future based on the information and analysis provided by energy outlooks produced by governmental, intergovernmental, and private institutions. However, outlooks vary in several important methodological aspects, and comparing them is not straightforward. Without a way to clearly compare one outlook to the next, decisionmakers may not understand the range of possibilities envisioned by different short-, medium-, and long-term projections or the assumptions that underpin them. This paper lays out a method to more accurately compare several major long-term energy outlooks; rather than burying important differences in views about the future, this controls for varied conventions and historical data that mask true differences between the outlooks.

We find important differences across outlooks in the assumed energy content of fossil fuels, assumed efficiency of nuclear and renewable electricity conversion from primary energy, categorization of biofuels, and inclusion (or exclusion) of traditional biomass, regional groupings, and more. Excluding nonmarketed traditional biomass from US EIA, for instance, yields estimates of global primary energy consumption 10 percent lower than other outlooks, which include these sources. Assumptions about energy content of fossil fuels can vary by up to 11 percent in the data examined, requiring significant adjustments of primary energy consumption to allow for accurate comparisons. Conventions about primary energy conversion of renewables can also alter estimates by as much as a 58 percent decrease to a 3.3-fold increase for particular electricity sources, relative to IEA estimates.

After accounting for these differences in historical data, our harmonization methodology brings estimates within 3 percent or less for most major fuel sources in the 2020 benchmark year.

We conclude that a harmonization process is necessary to provide a more accurate benchmark for comparing results across outlooks, particularly when examining estimates of primary energy consumption (e.g., qBtu, mtoe). Estimates measured in fuel-specific units (e.g., mbd, tcf, TWh) are less subject to these concerns but still include historical data differences. Our identification of important sources of divergence in convention and historical data also highlights areas where institutions that produce outlooks may find opportunities to identify common assumptions and data improvement, to the benefit of energy dialogue and energy decisionmaking worldwide.

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9. Glossary

Abbreviations and acronyms

BNEF	Bloomberg New Energy Finance
GDP	gross domestic product
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
OPEC	Organization of Petroleum Exporting Countries
US EIA	US Energy Information Administration
WEO	World Energy Outlook (IEA)

Units

bcfd	billion cubic feet per day
bcm	billion cubic meters
btoe	billion metric tonnes of oil equivalent
EJ	exajoules
mbd	million barrels per day
mboed	million barrels of oil equivalent per day
mtce	million metric tonnes of coal equivalent
mtoe	million metric tonnes of oil equivalent
qBtu	quadrillion British thermal units
tcf	trillion cubic feet
mtoe	million metric tonnes of oil equivalent
TWh	terawatt hours