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Global Energy Outlook Comparison Methods: 2023 Update

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About the Project

This paper is part of a multiyear effort on short-, medium-, and long-term energy outlooks by Resources for the Future. The project has generated 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 Outlook Comparison Methods: 2022 Update* (2022). 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 first developed in 2015 to facilitate comparisons of long-term global energy projections issued by Bloomberg New Energy Finance (BNEF), bp, Equinor, ExxonMobil, the International Energy Agency (IEA), the Institute for Energy Economics – Japan (IEEJ), and the Organization of the Petroleum Exporting Countries (OPEC). 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 because of methodological differences. For example, bp has in the past excluded nonmarketed traditional biomass, resulting in estimates of global primary energy consumption that can be 9 percent lower than other projections. bp and IEA use different assumptions about the primary energy content of oil, requiring adjustment of primary energy consumption estimates. Conventions about primary energy conversion of renewable energy resources can yield estimates as much as 57 percent below or 4.3 times higher than IEA estimates for particular electricity sources.   We also find significant differences in the 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 reduces discrepancies in historical data for most energy sources for the benchmark year of 2021. However, numerous unresolved issues remain in this year's harmonization, indicating continued need for harmonization and standardization by the experts who produce energy outlooks. We describe the process by which we enhance the comparability of outlooks by adjusting for differences in assumptions about fuel classifications, energy content, and conversion efficiencies. We present a selection of the harmonized results, benchmarked to the IEA's 2022 World Energy Outlook. This methodology is used to develop our *Global Energy Outlook 2023* report, available at **www.rff.org/geo**.

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1. Introduction

The global energy sector has experienced historic disruption in recent years. Many factors, including the COVID-19 pandemic, the need to slash 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 the sector. 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 (or in some cases, every two or three years), 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). 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 (e.g., the Gas Exporting Countries Forum), and national oil and gas companies (e.g., the Chinese National Petroleum Company), have also issued annual energy outlooks. In addition, energy modeling teams worldwide have produced long-term scenarios whose socioeconomic and emissions trajectories 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.

These outlooks underpin decisions by market participants and policymakers, yet inconsistencies in their approaches and assumptions make comparisons of different outlooks challenging and hinder meaningful international dialogue about the energy sector. 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 2021 as a common baseline for most outlooks:

- BNEF: New Energy Outlook 2022 (NEO 2022)[1]
- BP: Energy Outlook 2022[2]
- BP: Energy Outlook 2023[3]
- Equinor: Energy Perspectives 2022[4]
- ExxonMobil: 2022 Outlook for Energy[5]
- IEA: World Energy Outlook 2022 (WEO 2022)[6]
- IEEJ: Outlook 2023 (published in 2022)[7]
- OPEC: World Oil Outlook 2022 (WOO 2022)[8]

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 (CO_2) emissions. Our purpose is not to smooth over institutions' differing views about the outlook for the energy system but rather to control for differences in conventions and data sources that thwart an accurate assessment of underlying assumptions and judgments about the short-, medium-, and long-term projections.

We focus on overall primary energy consumption and its main 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 finds that institutional sources differ in the following ways:

- 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 (gross generation versus net generation);
- inclusion of nonmarketed energy sources, particularly traditional biomass (e.g., wood, dung);
- categorization of energy sources (e.g., biofuels, liquids, oil, synthetic gas from coal, 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 2021 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) electric power generation and capacity, and (3) end-use consumption in specific sectors, such as transport, industry, and residential or commercial buildings. "Primary energy" is the energy embodied in natural resources before any conversion or transformation process for end-use consumption. Primary energy consumption is a particularly important aggregate measure of long-term trends assessed by energy outlooks. 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 most outlooks.

The first challenge for comparing primary energy consumption is the use of different units, 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 the units used to report consumption of primary energy and specific fuels across outlooks.

Table 1. Units of Energy Consumption Used in Different Outlooks

	BNEF	BP	Equinor	Exxon Mobil	IEA	IEEJ	OPEC
Primary energy units	PJ	EJ	mtoe	qBtu	EJ	mtoe	mboed
Fuel- or sector-specific units							
Liquids	NA	mbd	NA	qBtu	mbd	mtoe	mbd
Oil	PJ	mbd	mbd	qBtu	mbd	mtoe	mbd
Biofuels	NA	mbd	mtoe	qBtu	mboed	mtoe	mbd
Natural gas	PJ	bcm	bcm	qBtu	bcm	mtoe	mboed
Coal	PJ	EJ	mtoe	qBtu	mtce	mtoe	mboed
Electricity	TWh	TWh	TWh	qBtu	TWh	TWh	NA

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

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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.

As Table 1 shows, each outlook has a standard reporting unit for primary energy consumption; the most common units are exajoules (EJ) and petajoules (PJ) (BNEF, BP, IEA), but other outlooks use mtoe (IEEJ, Equinor), qBtu (ExxonMobil), or 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 ExxonMobil. 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 BNEF, BP, and IEA primary energy data from EJ to qBtu, we convert from EJ to qBtu using a factor of 1 EJ = 0.9478 qBtu.

After converting to a common energy unit, considerable differences in baseline data may remain if organizations vary in their energy content assumptions when converting physical units of fuels (i.e., mbd of oil) to their original energy units. In this year's analysis, most outlooks rely on IEA for historical data (BNEF, Equinor, IEEJ) or do not provide sufficient data to allow for harmonization (ExxonMobil, OPEC). BP relies on its own historical database and provides sufficient information to allow for harmonization. Based on internal communications with BP experts, we understand that the organization gathers energy data primarily in physical units for oil (i.e., barrels) and primarily in energy units for other sources (e.g., coal, natural gas, biofuels). Therefore, we do not attempt to derive an energy content conversion factor for fuels other than oil, since deriving and applying such a factor would obscure rather than illuminate underlying differences in projections of future energy demand and supply.

To derive a conversion factor for oil, we obtain two sets of data from BP and IEA—one in primary energy units (i.e., EJ) and the other in fuel-specific physical units (i.e., mbd). We derive the implicit average energy content assumptions for each fuel by dividing the former by the latter. This results in energy content factors measured in EJ/mbd, which we then multiply by 0.9478 qBtu/EJ to create factors involving only qBtu, which can be directly compared across organizations. These factors can vary within an outlook across time and regions, but in practice, the variation over time is slight. Data limitations prevent us from calculating a complete set of conversion factors for each outlook, fuel, region, and year. We instead average near- and long-term factors (where data are available) to estimate each outlook's energy content assumptions.

Next, 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.

[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.

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 0.03968 qBtu/mtoe 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.

Table 2. Oil 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) = (d×0.9478 qBtu/EJ)
IEA[1]	2020	88.9		172.2	1.94	1.836
	2030	102.4		197.3	1.93	1.826
	2050	102.1		196.7	1.93	1.826
IEA avg.					1.93	1.826
BP 2023	2020	88.7		174.2	1.96	1.860
	2030	90.9		177.1	1.95	1.847
	2050	41.6		77.9	1.87	1.775
BP 2023 avg.					1.91	1.811
BP 2022[2]	2020	88.7		174.2	1.96	1.860
	2030	95.6		186.3	1.95	1.847
	2050	46.5		87.5	1.88	1.783
BP 2022 avg.					1.91	1.815

Energy content adjustment factors for oil

IEA (benchmark): 1

BP 2023: 1.0085

BP 2022: 1.0061

Notes: All data in the table are consumption data. Dashes indicate that data are not available. BNEF, Equinor, ExxonMobil, IEEJ, and OPEC 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) BP historical data based on BP 2022 Statistical Review of World Energy for 2020 and Accelerated Transition Scenario for projections.

Table 3 summarizes the resulting energy content adjustment factor for BP 2022 and BP 2023 of 1.0061 and 1.0085, respectively, indicating a 0.61–0.85 percent difference in energy content. In previous years' analyses, we have also harmonized natural gas and coal for other outlooks, so we include them as placeholders here, indicating the potential for additional harmonization for other outlooks if data become available. However, our communications with BP indicate that for natural gas and coal, BP and IEA both base their fuel-specific projections for these two fuels on primary energy units (e.g., EJ), so there is no need to make adjustments based on different assumptions about energy content of physical units of these two fuels.

Table 3. Energy Content Adjustment Factors for Oil, Natural Gas, and Coal

	Oil	Natural gas	Coal
IEA (benchmark), BNEF, Equinor, ExxonMobil IEEJ, OPEC	1.000	1.000	1.000
BP 2023	1.0085	1.000	1.000
BP 2022	1.0061	1.000	1.000

In this year's report, these adjustments are necessary only for oil; another approach is necessary to address the differences in assumptions about the primary energy content of nuclear and renewable power (see Section 3)

3. Primary Energy Conversion for Nuclear and Renewable Electricity

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 measured energy content and their global flows are commonly tracked. For nuclear power and nonbiomass renewables (e.g., solar, hydropower, wind, geothermal), however, 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 4). We explain the rationale for each outlook's assumptions.

Table 4. 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%
BP	42.6%	42.6%	42.6%	42.6%	42.6%	42.6%	42.6%
Equinor	33%	100%	100%	100%	33%	10%	35%
ExxonMobil	33%	100%	100%	100%	33%	10%	35%
IEA (benchmark)	33%	100%	100%	100%	33%	10%	35%
IEEJ	33%	100%	100%	100%	33%	10%	35%
OPEC	33%	100%	100%	100%	33%	10%	35%

Sources: IEA World Energy Outlook 2022 documentation and internal communication. Internal communication for all other outlooks. "BP" refers to its 2022 and 2023 outlooks. PV = photovoltaic.

3.1.1. IEA, BNEF, Equinor, ExxonMobil, IEEJ, and OPEC

Most outlooks we 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

[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).

[v] Internal communication with BNEF, Equinor, IEEJ, and OPEC.

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. Finally, Equinor reports through internal communication that its conversion efficiencies vary across regions and time, since different technologies are deployed regionally over the projection period.

3.1.2. BP

Unlike the IEA and most other outlooks included here, BP uses the "input-equivalent" approach for estimating the primary energy content of nonfossil fuels in its 2022 and 2023 outlooks (US EIA uses the same general method). This approach calculates the energy content of an equivalent amount of fossil fuels needed to generate a given amount of electricity from the average power plant. For example, if a wind turbine generates 1 MWh of electricity, and the average fossil fuel generator operates with 38 percent efficiency, the primary energy value for wind would equal 1 MWh divided by 38 percent, equal to 3.8 MWh of primary energy.

In its 2022 and 2023 outlooks, BP assumes that conversion efficiency for all nonfossil electricity sources increases linearly from 40.2 percent in 2018 to 45 percent by 2050, reflecting the improving efficiency of fossil-powered generation over the projection period.[9] For simplicity, we use a simple average of these two figures (42.6 percent) for all years.

3.2. Nuclear and Renewable Primary Energy

Because of differences in assumed primary energy conversion efficiency for nuclear and renewables, adjustments must be made to compare primary energy projections 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 the BP and IEA outlooks. BP assumes a nuclear power plant efficiency rate of 42.6 percent, but IEA assumes 33 percent. Therefore, the primary nuclear energy consumption figure for BP must be multiplied by 1.29 (0.426/0.33) to be comparable to the figure for IEA. We use the same approach for renewables.

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

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, “liquids” usually includes biofuels, whereas “oil” does not. “Liquid biofuels” refers mainly to bioethanol and biodiesel. IEA distinguishes biofuels from “oil” and provides biofuels demand data globally. BNEF does not provide biofuels data and instead includes it as part of its “bioenergy” grouping, preventing us from constructing a “liquids” variable for its outlook. BP provides line items for all three categories of oil, biofuels, and liquids. ExxonMobil publishes data on oil and biofuels. Equinor and IEEJ include biofuels in the “biomass” and “biomass/waste” categories for most regions. IEEJ provided regional biofuels data via internal communication . Equinor includes a global biofuels estimate in the transport sector. OPEC publishes information on biofuels supply only, which—for the sake of comparable results—we assume equals biofuels demand in the relevant year; we therefore add it to oil demand to produce a liquids variable for OPEC.

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). The level 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.[vii]

4.2. Renewables Categorization and Nonmarketed Energy

Comparisons of renewable energy consumption present another challenge, particularly the treatment of nonmarketed renewables. In previous years, BP have included only marketed renewables in its projections, while most 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 for traditional biomass. Although BP ’s most recent outlooks (2022 and 2023) include nonmarketed biomass energy, its historical data for 2021, which we use to develop a common baseline with IEA, excludes nonmarketed biomass.

[vii] Energy-equivalent volumes from *IEA World Energy Outlook 2021*, Annex Tables: World liquids demand; physical volumes from *IEA, Renewables 2021,* Figure 2.3.

Renewables groupings also vary between outlooks, and recategorization is necessary to enable direct comparison. Table 5 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.

Table 5. Renewable Energy Categories for Primary Energy and Electricity

	Primary energy	
	Unique variables	Sources included in “other renewables”
BNEF	Wind, solar, biomass	Hydro, geothermal, marine
BP	Hydro, biofuels	Wind, solar, geothermal, biomass
Equinor	Hydro, biomass	Wind, solar, geothermal, marine
ExxonMobil	Hydro, wind, solar, biomass, biofuels, geothermal	None
IEA	Hydro, wind, solar, modern bioenergy, traditional biomass	Geothermal, marine
IEEJ	Hydro, biomass, geothermal	Wind, solar, marine
OPEC	Hydro, biomass	Wind, solar, geothermal
	Electricity	
	Unique variables	Sources included in “other renewables”
BNEF	Biomass, wind, solar	Hydro, geothermal, marine
BP	Hydro, biomass, wind, solar, geothermal	None
Equinor	Hydro, biomass, wind, solar	Geothermal, marine
ExxonMobil	Hydro, wind, solar	Biomass, geothermal, marine
IEA	Hydro, biomass, wind, solar PV, CSP, geothermal, marine	None
IEEJ	Hydro, biomass, wind, solar PV, CSP and marine, geothermal	Fuel cells, unspecified others
OPEC	None	None

Notes: Data from published outlooks and internal communication with each organization. CSP = concentrating solar power. PV = photovoltaic.

5. Outlook Harmonization and Historical Data Differences

In this section, we describe a method for using the information provided earlier to harmonize estimates of world primary energy consumption. We apply this methodology to baseline 2021 data but note that it could be applied to any projection year.

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

Second, we adjust BP oil data for differences in energy content assumptions by multiplying by the adjustment factors found in Table 2. In future harmonization exercises, it may be appropriate to harmonize additional fuels, depending on data availability and the underlying methodology of each outlook.

Third, for individual BP renewables categories, which are not published in primary energy units, we calculate estimates in qBtu by multiplying electricity generation data in TWh by 0.003412 qBtu/TWh. This conversion will generally produce reliable results for wind and solar photovoltaic (PV) but will somewhat underestimate primary energy because it excludes thermal energy from biomass and solar used in water or space heating.

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 4, we can calculate a multiplicative factor by fuel for each outlook, shown in Table 6.

Table 6. Multiplicative Factors to Convert Primary Energy in Other Outlooks to IEA's Primary Energy Conversion Efficiency Assumptions, by Fuel Source

	Nuclear	Hydropower	Wind and Solar	Geothermal	Biomass
IEA (benchmark), BNEF, ExxonMobil Equinor, IEEJ, OPEC	1.00	1.00	1.00	1.00	1.00
BP	0.43	0.43	0.43	0.43	0.43

Fifth, we adjust data to yield a uniform definition of liquids (including biofuels) and nonhydropower renewables (excluding biofuels). Table 7 and Figure 1 display the results.

Table 7. Comparison of Harmonized Outlook Primary Energy Consumption 2021 Data (qBtu)

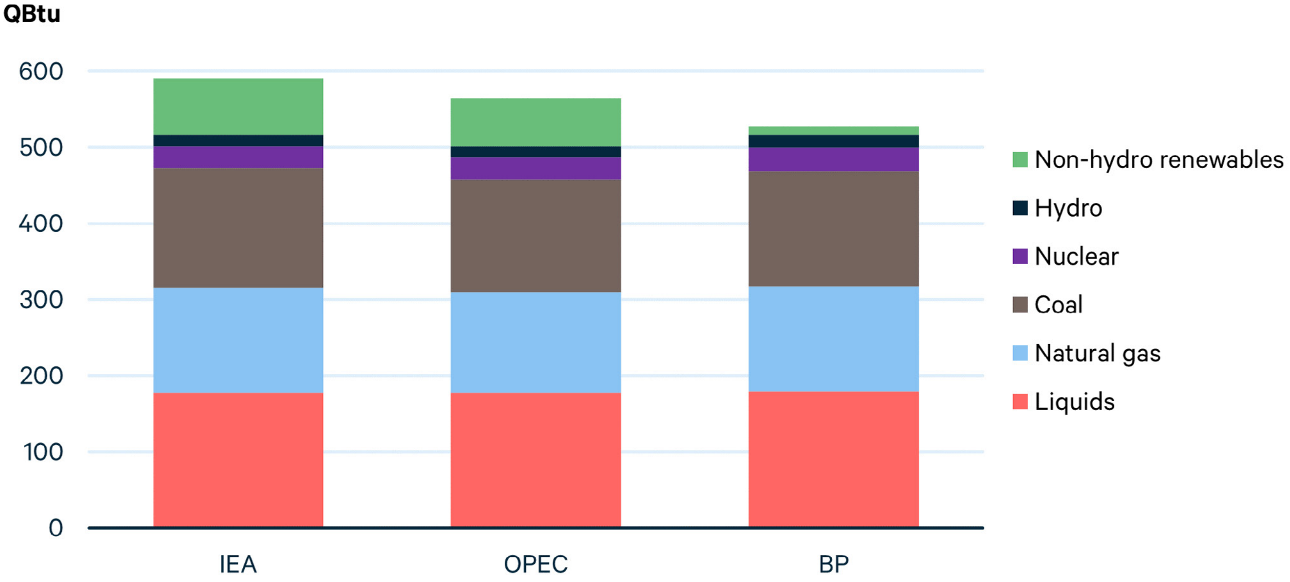
	IEA	BP	OPEC
Liquids	178	180	178
Oil (excluding biofuels)	174	176	174
Biofuels	4.0	3.9	3.6
Gas	139	138	131
Coal	157	152	148
Nuclear	28.7	31.0	30.0
Hydropower	14.8	16.3	14.8
Nonhydropower renewables (excluding biofuels, including nonmarketable sources)	74	NA	63
Nonhydropower renewables (excluding biofuels, only marketable sources)	NA	11	NA
Total renewables (excluding biofuels, including nonmarketable sources)	89	NA	78
Total renewables (excluding biofuels, only marketable sources)	NA	27	NA
Total energy (including biofuels, excluding nonhydropower renewables)	516	516	502
Total primary energy	590	527	565

Notes: Totals or subtotals may not sum because of rounding. (1) BP data from its Statistical Review of World Energy. BP totals are smaller because they exclude nonmarketed renewables, as discussed. (2) Limited data availability constrains our ability to fully harmonize OPEC's historical data.

Largely because it excludes nonmarketed renewables in its historical data, BP has far lower total consumption estimates than other outlooks, which typically rely on IEA historical data. After accounting for the exclusion of nonmarketed renewables, BP 's divergence from IEA in total primary energy consumption is less than 0.01 percent.

Although the harmonization process adjusts for a significant amount of divergence, it does not eliminate all discrepancies in historical consumption data. For example, compared with IEA figures, OPEC's estimates of global natural gas and coal consumption are roughly 8 qBtu and 9 qBtu, 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.

Figure 1. Harmonized Baseline (2021) Primary Energy Consumption



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

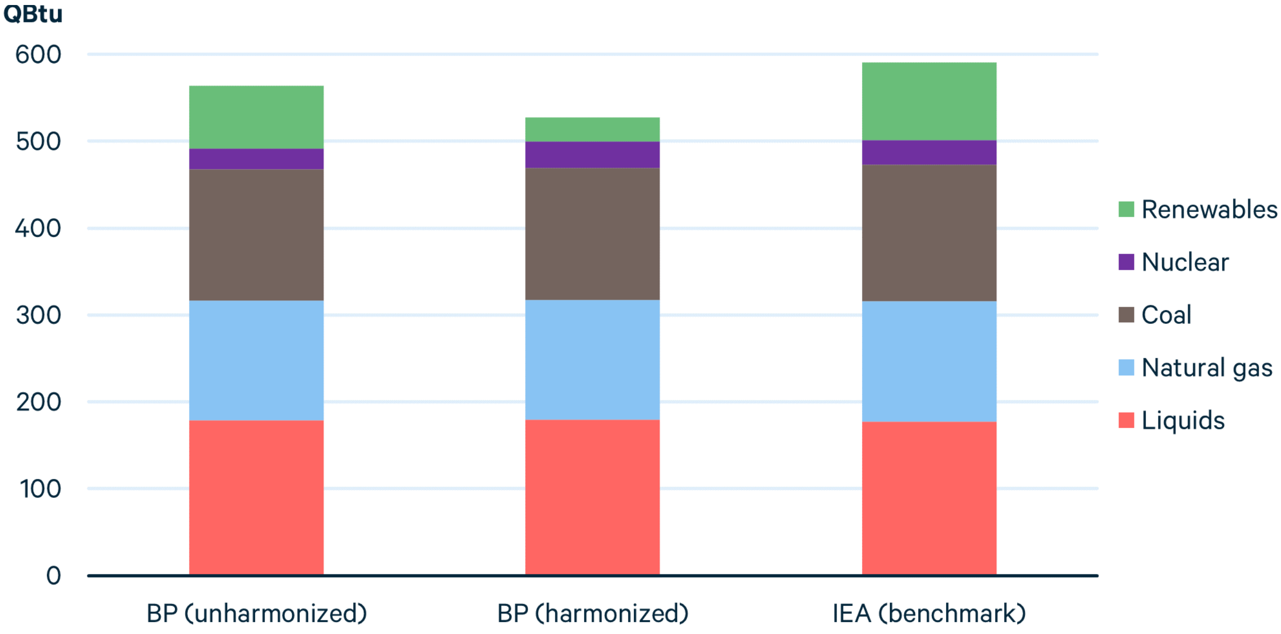
Finally, the many organizations that rely on IEA for historical data tend to use older vintages of data than IEA's most recent outlooks. Consider a 2022 outlook from a hypothetical organization: to publish its report in 2022, the organization conducts its modeling analysis in 2020 using 2018 or 2019 data from IEA. Because historical data are subject to revision, these temporal gaps can lead to notable differences in baseline data across organizations.

Nonetheless, this harmonization process allows good comparability across outlooks. To illustrate the improvement, Figure 2 presents pre- and post-harmonization data for global primary energy consumption in 2021 for BP alongside IEA.

Table 8 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 8 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 9. 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 9 because they do not present data in fuel-specific units.

Figure 2. Harmonized and Unharmonized Primary Energy Consumption in 2021



Several notable differences emerge in Table 8, some of which are easily explained. 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 substantial differences in natural gas and coal, however, are more difficult to account for. 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 BP, substantial differences emerge in hydro (10 percent), nuclear (8 percent), coal (3 percent), and biofuels (3 percent). For hydro and nuclear, it is likely that a portion of this difference is attributable to our method of harmonizing between IEA and BP for assumptions about primary energy content of nonfossil fuels. Specifically, BP 's assumed primary energy conversion factor changes each year between 2021 and 2050, reflecting expected changes in average conversion efficiencies for fossil fuel electricity generation. For simplicity, we use a single conversion factor for BP that averages across all projection years and apply this single conversion factor to all years of projected data, including the baseline year of 2021. If we instead used a year-specific conversion factor (which was 40.6 percent in 2021), these baseline figures would be considerably closer, differing by roughly 3 percent instead of 10 or 8 percent. Although this approach results in baseline data that vary, we believe it remains appropriate for applying throughout the projection period, where on average the conversion factors will appropriately harmonize between the two outlooks.

For differences in coal and biofuels, we are unable to explain the likely cause of the divergence.

This table illustrates the scale of discrepancies in Table 8 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 9 from Table 8 leads us to Table 10, which shows the remaining gap in primary energy consumption estimates 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: biofuels (13 percent), hydro (11 percent), coal (7 percent), nuclear (7 percent), and natural gas (4 percent). These discrepancies highlight the continued opportunity for IEA and BP to further standardize accounting methods to improve understanding of the global energy system.

Table 8. Harmonized Primary Energy Consumption Data Relative to IEA in 2021

	BP	OPEC
Liquids	1%	0.3%
Oil (excluding biofuels)	1%	0.5%
Biofuels	-3%	-10.1%
Natural gas	-1%	-5.3%
Coal	-3%	-5.8%
Nuclear	8%	4.4%
Hydropower	10%	0.3%
Nonhydropower renewables (including nonmarketable sources)	—	-15.1%
Nonhydropower renewables (only marketable sources)	—	NA
Total renewables (including nonmarketable sources)	—	-12.5%
Total renewables (only marketable sources)	—	NA
Total energy (excluding nonhydropower renewables)	0%	-2.8%
Total primary energy	-11%	-4.4%

Notes: BP totals are smaller primarily 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 9. Comparison of Harmonized Outlook Primary Energy Consumption 2021 Data (qBtu)

	IEA	BP	BP/IEA
Liquids (mboe/d)	96.9	96.7	0%
Oil (excluding biofuels) (mb/d)	94.1	94.5	0%
Biofuels (mboe/d)	1.8	2.2	-17%
Natural gas (tcf/yr)	143	149	-4%
Coal (million metric tons produced)	8,173	7,889	4%
Nuclear (TWh)	2,800	2,776	1%
Hydropower (TWh)	4,274	4,327	-1%
Nonhydropower renewables (only marketable sources) (TWh)	—	—	—
Total renewables (only marketable sources) (TWh)	3,657	3,732	-2%

Sources: IEA oil and natural gas data via World Energy Outlook 2022, coal data from Coal 2022; BP via Statistical Review of World Energy. Limited data availability prevents us from sharing OPEC's data.

Table 10. Remaining Differences in 2021 Energy Consumption after Controlling for Differences in Historical Data and Primary Energy Conversion Efficiency Assumptions

	BP /IEA
Liquids	0.9%
Oil (excluding biofuels)	1.6%
Biofuels	13.2%
Natural gas	3.6%
Coal	-6.8%
Nuclear	6.9%
Hydropower	11.3%

6. Country Details and Groupings Across Outlooks

Regional comparisons across outlooks can yield insights into the global energy sector. One challenge, however, is that the outlooks' regional groupings differ.

Some outlooks present regional data according to membership in the Organization of Economic Cooperation and Development (OECD), although these groupings are becoming less common over time. More commonly, recent outlooks ignore OECD membership status and simply group countries geographically. 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-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. Here we summarize variation between the regional classification systems in the presentation of primary energy consumption of the outlooks included in this analysis.

6.1. Africa

Five outlooks provide a comprehensive “Africa” regional group: BP, Equinor, ExxonMobil, IEA, and IEEJ.

6.2. Americas

Four outlooks provide a comprehensive “North America” and “Latin America” regional group: BP, Equinor, ExxonMobil, and IEA.

IEEJ includes Mexico in Latin America, whereas other outlooks include Mexico in North America. OPEC provides regional grouping in terms of OECD status, under which “OECD Americas” includes Chile in addition to the United States, Canada, and Mexico.

6.3. Asia-Pacific

Four outlooks provide data sufficient to create a comprehensive “Asia-Pacific” regional group: BP , ExxonMobil, IEA, and IEEJ (for its Reference Scenario but not its Advanced Technologies scenario). Both Equinor and OPEC provide primary energy data on China, India, and OECD Asia-Pacific but not non-OECD Asia-Pacific.

6.4. Europe-Eurasia

Five outlooks provide data sufficient to create a comprehensive “Europe-Eurasia” regional group: BP, ExxonMobil, IEA, IEEJ (for its Reference Scenario but not its Advanced Technologies scenario), and OPEC. Equinor provides data on the European Union and “Other Europe” but not Russia or Eurasia.

6.5. Middle East

Four outlooks provide data sufficient to create a comprehensive “Middle East” regional group: BP, ExxonMobil, IEA, and IEEJ. Equinor and OPEC do not provide primary energy data on the Middle East.

6.6. East and West

We are able to produce consistent regional groupings of “East” and “West” for four outlooks: BP, ExxonMobil, IEA, and IEEJ (for its Reference Scenario but not its Advanced Technologies scenario). East includes Africa, Asia-Pacific, and Middle East, and West includes Americas and Europe-Eurasia.

6.7. World

All outlooks include a “World” grouping.

7. Conclusion

Energy industry experts, policymakers, and a range of other stakeholders make decisions and plans based on the information and analysis in the energy outlooks produced by governmental, intergovernmental, and private institutions. However, outlooks vary in several important methodological aspects. Because comparing them is not straightforward, decisionmakers may not understand the range of possibilities in different short-, medium-, and long-term projections or see the assumptions that underpin them. This paper lays out a method to more accurately compare several major long-term energy outlooks. It controls, to the extent possible, for the various conventions and historical data that mask true differences in organizations' views about the future.

We find meaningful 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, inclusion (or exclusion) of traditional biomass, regional groupings, and more. Assumptions about the energy content of physical units of oil can vary by up to 1 percent in the data examined, requiring adjustments of oil consumption to allow for more accurate comparisons. Conventions about primary energy conversion of renewables can also yield estimates as much as 57 percent below or 4.3 times higher than IEA estimates for particular electricity sources.

After accounting for differences in historical data, our harmonization methodology improves comparability of major fuel sources in the 2021 benchmark year. However, substantial variation emerges between baseline data for BP and IEA, indicating that further improvements in standardizing across historical data platforms could enhance comparability of baseline data and the outlooks that rely on those data.

We conclude that a harmonization process is necessary to provide a more accurate benchmark for comparing results across outlooks that do not rely on the same historical data sets or methodologies. This is particularly important for 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 reflect historical data differences. By identifying sources of divergence in conventions and historical data, we also highlight areas where institutions that produce outlooks may find opportunities to identify common assumptions and data improvement, to the benefit of dialogue and decisionmaking about energy worldwide.

8. Abbreviations

Table 11. Organizations

BNEF	Bloomberg New Energy Finance
IEA	International Energy Agency
IEEJ	Institute for Energy Economics, Japan
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)

Table 12. 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

9. Endnotes

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