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Global Energy Outlook Comparison Methods: 2024 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: 2023 Update* (2023). It provides the methodology for harmonizing outlooks included in ***Global Enery Outlook 2024: Peaks or Plateaus?***

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.

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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 bp, the US Energy Information Administration (EIA), Enerdata, Equinor, ExxonMobil, the International Energy Agency (IEA), the Organization of the Petroleum Exporting Countries (OPEC), and Shell. 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, EIA excludes nonmarketed traditional biomass, resulting in estimates of global primary energy consumption that can be 8 percent lower than other projections. EIA also presents primary energy and electricity generation data in different terms of net and gross values than those used by IEA and other organizations. Assumptions about the primary energy content of oil varies among outlooks such as those of bp, EIA, and IEA, requiring adjustment of primary energy consumption estimates. Conventions about primary energy conversion of renewable energy resources can also alter estimates by as much as a 57 percent decrease to a 4.3-fold increase for particular electricity sources relative to IEA estimates. Moreover, we 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 reduces discrepancies in historical data for most energy sources for the benchmark year of 2021. 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 IEA's *World Energy Outlook 2023*. This methodology is used to develop our *Global Energy Outlook 2024* report, available at **www.rff.org/geo**.

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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 and other geopolitical tensions, and evolving technologies, have introduced deep uncertainties about 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 (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 (EIA), the International Renewable Energy Agency, and international energy companies (e.g., bp, Equinor, ExxonMobil, Shell). Other organizations have also issued annual energy outlooks, including 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). 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. This year, we also include a selection of data from proprietary projections produced by Enerdata, an energy consulting firm. Each organization and modeling team makes long-term energy projections using its own modeling assumptions and sometimes unique historical databases.

Because these outlooks play an important role 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 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 available outlooks for comparative analysis of energy forecasts, with 2021 as a common baseline for most outlooks:

- bp: *Energy Outlook 2023*[1]
- EIA: *International Energy Outlook 2023*[2]
- Enerdata: Global Energy Forecasts: EnerFuture 2023[3]
- Equinor: *2023 Energy Perspectives*[4]
- ExxonMobil: *2023 Outlook for Energy*[5]
- IEA: *World Energy Outlook 2023*[6]
- OPEC: *World Oil Outlook 2023*[7]
- Shell: *The Energy Security Scenarios*[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 emissions. Our purpose is not to conceal 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 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
- 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: primary energy; electric power generation and capacity; and 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 fuel composition for a country or region are affected by the 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 across most outlooks.

The first challenge of 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 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) (bp, IEA, Shell), but other outlooks use mtoe (Enerdata, Equinor), QBtu (EIA, ExxonMobil), or million barrels of oil equivalent per day (mboed; OPEC). To compare, we need to use a common unit for all outlooks. We use QBtu as the benchmark, requiring an appropriate conversion factor for outlooks other than those from EIA and ExxonMobil. According to international convention (see, for example, IEA[9]), energy consumption data in mtoe can be converted to 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.[ii] 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 primary energy data from EJ to QBtu, we use a factor of 1 EJ = 0.9478 QBtu.

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

ii 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

	bp	EIA	Enerdata	Equinor	Exxon Mobil	IEA	OPEC	Shell
Standard units for primary energy reporting	EJ	QBtu	mtoe	mtoe	QBtu	EJ	mboed	EJ
Units by energy category								
Liquids	mbd	mbd	N/A	N/A	QBtu	mbd	mbd	EJ
Oil	mbd	mbd	mtoe	mbd	QBtu	mbd	mbd	EJ
Biofuels	mbd	mbd	N/A	mtoe	QBtu	mboed	mbd	EJ
Natural gas	bcm	tcf	mtoe	bcm	QBtu	bcm	mboed	EJ
Coal	EJ	mst	mtoe	mtoe	QBtu	mtce	mboed	EJ
Electricity	TWh	TWh	GWh	TWh	QBtu	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 a full list of terminology.

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 (e.g., mbd of oil) to their original energy units. Some outlooks rely wholly or in part on IEA for historical data (e.g., Enerdata, Equinor, Shell) or do not provide sufficient data to allow for full harmonization (ExxonMobil and OPEC). bp and EIA rely on their own historical databases and provide sufficient information to allow for harmonization. Based on internal communication 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, as deriving and applying such a factor would obscure, rather than shed light on, underlying differences in projections of future energy demand and supply. For EIA, we harmonize across all sources because EIA presents its data in gross calorific values (GCV), whereas IEA and other outlooks provide data in net calorific values (NCV).

To derive a conversion factor for oil for bp, we obtain two sets of data from bp and IEA—one in primary energy units (EJ) and the other in fuel-specific physical units (mbd). First, 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 that we can directly compare across organizations. These factors can vary within an outlook across time and regions, but in practice, the variation over time is slight. Because of limited data, it is not possible for us to calculate 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. For EIA, we take the same approach but adjust the liquids primary energy content from GCV to NCV using a standard factor of 5 percent.[9]

Second, we derive an energy content adjustment factor by dividing the energy content factors for IEA by those of bp and EIA. This approach benchmarks these other estimates so that they are approximately as if the other organizations 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. Column a presents data measured in mbd, column b in QBtu (NCV), and column c in EJ. Column d divides column c by column a to create an EJ/mbd conversion factor. For most outlooks, column e multiplies column d by 0.0.9478 QBtu/EJ to create a QBtu/mbd conversion factor. For EIA, column e divides column b by column a to create a QBtu/mbd conversion factor. The final row of Table 2 shows the resulting energy content adjustment factors found by dividing IEA's QBtu/mbd factor by factors from other organizations.

Table 2. Liquids Energy Content Adjustment

Source	Year of demand data	Fuel-specific units	Primary energy units		Implied conversion factors	
		mbd	QBtu (NCV)	EJ (NCV)	EJ/mbd	QBtu/mbd
		(a)	(b)	(c)	(d) = (c/a)	(e) = (d × 0.9478 QBtu/EJ)
IEA*	2021	95.7		186.5	1.95	1.847
	2030	104.4		201.0	1.92	1.824
	2050	101.8		194.9	1.91	1.814
IEA avg.					1.92	1.819
bp**	2021	97.2		189.0	1.94	1.843
	2030	94.4		182.6	1.93	1.833
	2050	46.7		87.2	1.87	1.770
bp avg.					1.90	1.802
EIA	2021	97.0	177.0			1.825
	2030	105.5	191.9			1.818
	2050	121.5	220.3			1.813
EIA avg.						1.819

Energy content adjustment factors for oil

IEA (benchmark): 1
bp 2023: 1.0099
EIA: 1.0003

Note: All data in the table are demand data. Enerdata, Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units or benchmark their energy content assumptions to IEA.

* IEA data based on Stated Policies Scenario.

** bp based on the *2023 Statistical Review of World Energy*[10] and Accelerated Transition Scenario for projections.

For natural gas (Table 3) and coal (Table 4), we derive energy content adjustment factors for EIA and IEA natural gas using the same approach as in Table 2, with the slight difference that we convert EIA's natural gas primary energy content from GCV to NCV using a standard conversion factor of 10 percent,[6] as opposed to 5 percent for liquids and coal.[11]

Table 3. Natural Gas Energy Content Adjustment

Source	Year of demand data	Fuel-specific units	Primary energy units		Implied conversion factors	
		TCF	QBtu (NCV)	EJ (NCV)	EJ/TCF	QBtu/TCF
		(a)	(b)	(c)	(d) = (c/a)	(e) = (d × 0.9478 QBtu/EJ)
IEA*	2021	149.0		146.3	0.98	0.931
	2030	151.8		148.7	0.98	0.928
	2050	147.4		144.4	0.98	0.929
IEA avg.					0.98	0.929
EIA	2021	144.9	135.1			0.932
	2030	158.9	145.2			0.914
	2050	194.3	177.3			0.912
EIA avg.						0.919

Energy content adjustment factors for natural gas

IEA (benchmark): 1
EIA: 1.0106

Notes: TCF = trillion cubic feet. All data in the table are demand data. bp, Enerdata, Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units or benchmark their energy content assumptions to IEA.

* IEA data based on Stated Policies Scenario.

Table 4. Coal Energy Content Adjustment

Source	Year of demand data	Fuel-specific units	Primary energy units		Implied conversion factors	
		MMT	QBtu (NCV)	EJ (NCV)	EJ/MMT	QBtu/MMT
		(a)	(b)	(c)	(d) = (c/a)	(e) = (d × 0.9478 QBtu/EJ)
IEA*	2020	7,888		167.4	0.0212	0.02011
	2021	8,318		170.2	0.0205	0.01939
IEA avg.						0.01975
EIA	2021	7,841	159.3			0.02032
	2030	7,650	157.8			0.02063
	2050	7,995	163.5			0.02045
EIA avg.						0.02047

Energy content adjustment factors for coal:

IEA (benchmark): 1

EIA: 0.9650

Note: MMT = million metric tons. All data in the table are production data. bp, Enerdata, Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units or benchmark their energy content assumptions to IEA.

* IEA data based on Stated Policies Scenario.

Table 5 summarizes the resulting energy content adjustment factor for liquids of less than 1 percent for bp and EIA, roughly 1 percent for natural gas (EIA), and about 3.5 percent for coal (EIA). In the following section, we describe a distinct harmonization process that is required to address the differences in assumptions about the primary energy content of nuclear and renewable power.

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

	Liquids	Natural gas	Coal
IEA (benchmark), all others except bp and EIA	1.0000	1.0000	1.0000
bp 2023	1.0099	1.0000	1.0000
EIA	1.0003	1.0106	0.9650

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 global flows are commonly tracked. In contrast, calculating the primary energy of 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 not widely measured.

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

iii Some projections, including the Integrated Assessment Models used to inform reports from the Intergovernmental Panel on Climate Change, take the direct equivalence approach, which assumes a conversion efficiency of 100 percent for all nonfossil energy sources

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

	Nuclear	Hydropower	Wind	Solar PV	Solar thermal	Geothermal	Biomass
bp	42.6%	42.6%	42.6%	42.6%	42.6%	42.6%	42.6%
EIA	32.0%	41.6%	41.6%	41.6%	nd	33.4%	31.7%
Enerdata	33%	100%	100%	100%	33%	10%	35%
Equinor	33%	100%	100%	100%	33%	10%	35%
ExxonMobil	nd	nd	nd	nd	nd	nd	nd
IEA (benchmark)	33%	100%	100%	100%	33%	10%	35%
OPEC	33%	100%	100%	100%	33%	10%	35%
Shell	33%	100%	100%	100%	33%	10%	35%

Source: IEA *World Energy Outlook 2023*[6] documentation and internal communication. Internal communication for all other outlooks.

Note: nd = no data.

3.1.1. IEA, Enerdata, Equinor, OPEC, and Shell

Based on internal communication with Enerdata, Equinor, OPEC, and Shell, most outlooks we examined follow IEA's assumptions from its World Energy Outlook series. 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 (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, Shell differs from other outlooks, as it 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.

3.1.2. bp

Unlike IEA's outlook and most others included here, bp uses the input-equivalent approach for estimating the primary energy content of nonfossil fuels in its 2023 outlook. This approach calculates the energy content of the 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 megawatt-hour (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, or 3.8 MWh.

In its 2023 outlook, 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.[12] We use a simple average of these two figures (42.6 percent) for all years.

3.1.3. EIA

Like bp, EIA uses the input-equivalent approach for primary energy in nonfossil fuels. We gather EIA's conversion efficiency assumptions from documentation from its World Energy Projection System[13] and correspondence with EIA staff. For nuclear and biomass energy, EIA's assumptions (32 percent for both) are similar to IEA's (33 and 35 percent, respectively). But most renewable sources have considerable variation, with EIA assuming 42 percent efficiency for hydropower, wind, and solar PV, whereas IEA assumes 100 percent efficiency. The difference for geothermal is even greater, with EIA assuming 33 percent efficiency, more than three times the IEA assumption of 10 percent.

In addition to these differences in conversion efficiency assumptions, EIA reports electricity generation in net terms (including parasitic load), but IEA and other organizations report electricity generation in gross terms (excluding parasitic load). Based on internal communication with EIA staff, we convert EIA electricity generation data from net to gross terms using a constant factor of 1.05.

3.1.4. ExxonMobil

ExxonMobil does not publish its assumptions regarding the conversion efficiency of nonfossil fuels and did not provide them before our publication deadline. We therefore apply IEA's benchmark assumptions.

3.2. Nuclear and Renewable Primary Energy

Because of these differences in assumed primary energy conversion efficiency for nuclear and renewables, we must make adjustments to compare primary energy projections across outlooks. This requires choosing a benchmark set of assumptions, for which we use IEA's conversion efficiencies.[iv]

For example, consider primary energy consumption from nuclear sources in outlooks from bp and IEA. 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.

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. IEA distinguishes biofuels from oil and provides biofuels demand data globally. bp provides line items for all three categories, oil, biofuels, and liquids. EIA publishes biofuels supply and liquids consumption data. For the sake of comparability, we assume biofuels supply equals demand in the relevant year, which allows us to separately estimate biofuels, oil, and liquids demand for EIA (we take a similar approach for OPEC). Enerdata does not provide a unique biofuels category, preventing us from creating a liquids category for their scenarios. Equinor includes biofuels in its biomass and biomass/waste categories for most regions but also includes a global biofuels estimate in the transport sector. ExxonMobil publishes data transportation sector biofuels demand for the world, Organisation for Economic Co-operation and Development (OECD), and non-OECD groups, but not for other regions. OPEC publishes global information only on biofuels supply, which we assume equals biofuels demand in the relevant year and add it to oil demand to produce a liquids variable for OPEC. Shell publishes distinct biofuels data for each region.

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 (mboed). The level of biofuels expressed in

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

energy-equivalent terms is smaller than that in pure volumetric terms. For example, when IEA's *World Energy Outlook* 2021 estimated global biofuels demand of 1.9 mboed in 2020, the volume of physical demand was roughly 2.6 mbd.[v]

4.2. Renewables Categorization and Nonmarketed Energy

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

In 2021, for example, harmonized estimates of nonhydropower renewables primary energy consumption (excluding biofuels) for IEA and bp are 67 QBtu and 26 QBtu, respectively, with the difference primarily explained by bp's exclusion of nonmarketed biomass (see Table 9). This scale of energy consumption from nonmarketed sources can lead to misleading comparisons across outlooks in some categories, including renewable energy consumption and total global energy consumption, and in the shares of different sources in total energy.

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

v Energy equivalent volumes from IEA World Energy Outlook 2021,[14] Annex Tables: World Liquids Demand; physical volumes from IEA, Renewables 2021,[15] Figure 2.3.

Table 7. Renewable Energy Categories for Primary Energy and Electricity

	Primary energy	
	Unique variables	Sources included in "other renewables"
bp	Hydro, biofuels	Wind, solar, geothermal, biomass
EIA	None	Hydro, wind, solar, geothermal, biomass, marine
Enerdata	None	Hydro, wind, solar, geothermal, biomass, marine
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
OPEC	Hydro, biomass	Wind, solar, geothermal
Shell	Hydro, biomass, biofuels, wind, solar PV, CSP, geothermal, tidal, wave	None
	Electricity	
	Unique variables	Sources included in "other renewables"
bp	Hydro, biomass, wind, solar, geothermal	None
EIA	Hydro, wind, solar, geothermal	Biomass, marine
Enerdata	Hydro, wind, solar, biomass	Marine, geothermal, hydrogen fuel cells
Equinor	Hydro, biomass, wind, solar	Geothermal, marine
ExxonMobil	Hydro, wind, solar	Biomass, geothermal, marine
IEA	Hydro, biomass, wind, solar PV, CSP, geothermal, marine	None
OPEC	None	None
Shell	None	None

Note: 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 2021 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 (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 and EIA liquids, natural gas, and coal data for differences in heating values and energy content assumptions by multiplying by the adjustment factors found in Tables 2–4.

Third, for individual bp, EIA, and Enerdata renewables categories, which are not published in primary energy units, we calculate estimates in QBtu by multiplying electricity generation data in terawatt-hours (TWh) by 0.003412 QBtu/TWh. This conversion will generally produce reliable results for wind and solar PV, but it 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 6, we can calculate a multiplicative factor by fuel for each outlook, shown in Table 8.

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

	Nuclear	Hydropower	Wind and solar	Geothermal	Biomass
IEA (benchmark), Enerdata, Equinor, ExxonMobil, OPEC, Shell	1.00	1.00	1.00	1.00	1.00
bp	1.29	0.43	0.43	4.26	1.22
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, 2021 Data (QBtu)

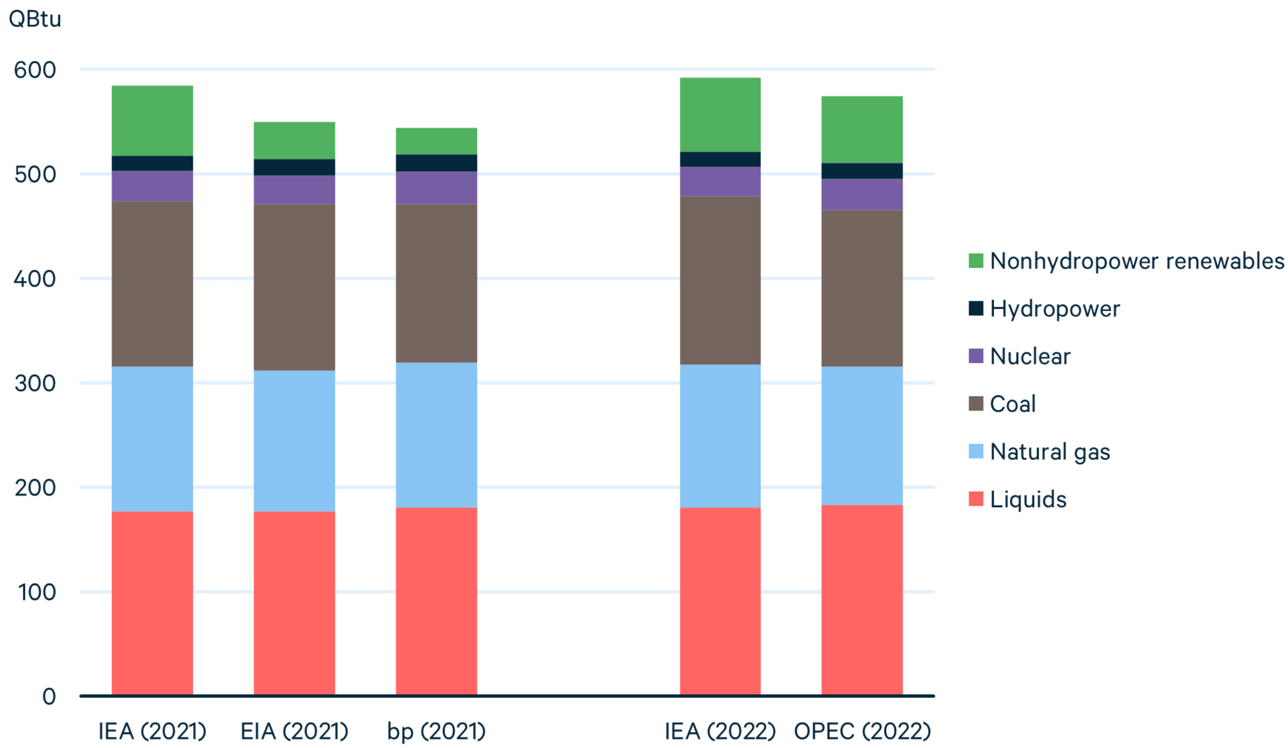
	IEA (2021)	IEA (2022)	bp* (2021)	Exxon Mobil (2021)	EIA (2021)	OPEC** (2022)
Liquids	177	181	181	178	177	183
Oil (excl. biofuels)	173	177	177	174	173	179
Biofuels	3.8	4.0	3.8	4.0	3.7	4.1
Gas	139	137	139	143	135	133
Coal	159	161	152	147	159	150
Nuclear	29.1	27.8	31.0	28.6	27.2	29.6
Hydropower	14.7	14.9	16.3	14.2	15.5	15.3
Nonhydropower renewables (excl. biofuels, incl. nonmarketable sources)	67	71	N/A	69	N/A	64
Nonhydropower renewables (excl. biofuels, only marketable sources)	N/A	N/A	26	N/A	20	N/A
Total renewables (excl. biofuels, incl. nonmarketable sources)	82	86	N/A	83	N/A	79
Total renewables (excl. biofuels, only marketable sources)	N/A	N/A	42	N/A	36	N/A
Total energy, incl. biofuels, excl. nonhydropower renewables	518	522	519	511	514	511
Total primary energy	585	592	544	594	534	575

Note: Totals or subtotals may not sum due to rounding. bp and EIA totals are smaller because they exclude nonmarketed renewables, as described. N/A indicates that fuel-specific data are not available for a given energy source.

* bp data from the *Statistical Review of World Energy*.

** Limited data availability constrains our ability to fully harmonize OPEC's historical data.

Figure 1. Harmonized Baseline Primary Energy Consumption



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

Primarily because of their exclusion of nonmarketed renewables, bp and EIA have 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 roughly 0.2 percent for bp and 0.7 percent for EIA.

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 for global natural gas and coal consumption are roughly 4 QBtu and 11 QBtu lower than the IEA estimates, respectively. These discrepancies are of similar magnitude to those observed in previous years and are likely attributable to limitations in input data (e.g., energy content factors for fossil fuels in OPEC's outlook), unidentified differences in definitions of energy categories, or limitations in our methodology, or they may be due to 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 2022 outlook from hypothetical organization A. To publish its report in 2022, A conducts its modeling analysis in 2020, potentially based on historical data from IEA in 2018 or 2019. 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 2021 for bp and EIA alongside IEA.

Figure 2. Harmonized and Unharmonized Primary Energy Consumption in 2021

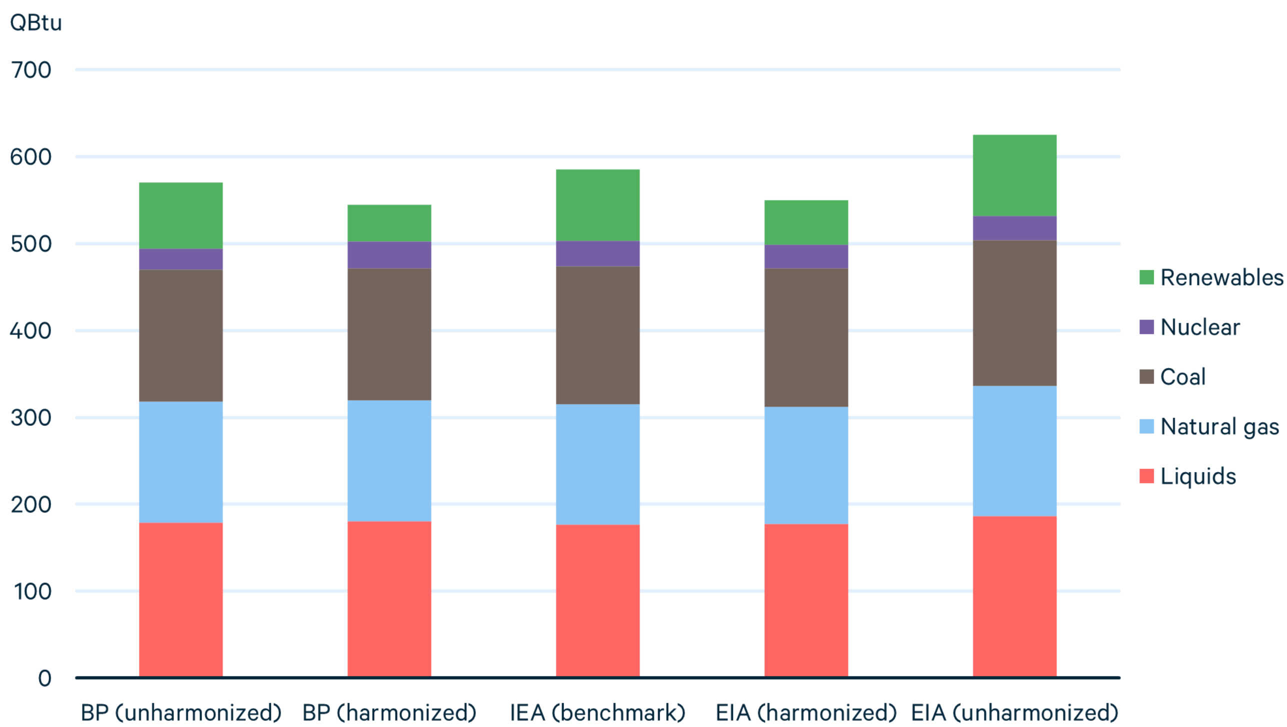


Table 10 shows the percentage difference between IEA and all other outlooks in terms of primary energy consumption by fuel. To understand whether the differences shown in Table 10 are attributable to inadequacies in our conversion methodology or discrepancies in historical statistics, we also collected 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 are evident in Table 10, some of which are easily explained, while others 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. For the substantial differences in natural gas, coal, and nuclear, we are not able to explain the differences between OPEC and IEA. Potential explanations may be OPEC's reporting of a single decimal point in its primary energy data, differences in conversion factors from mboed to QBtu (or EJ), or discrepancies in the underlying data.

For bp, substantial differences emerge in hydro (11 percent), nuclear (7 percent), and coal (4 percent), similar to divergences observed in previous years. 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 apply a single conversion factor for bp, which averages across all projection years, to all years of projected data, including the baseline year of 2021. If we instead used a year-specific conversion factor (40.6 percent in 2021), these baseline figures would be considerably closer, differing by roughly 3 percent instead of 11 or 7 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, we are unable to explain the likely cause of the divergence.

For ExxonMobil, we are unable to explain differences because the company does not make its assumptions about energy content public and did not share those assumptions with us before our publication deadline.

For EIA, we are unable to explain substantial differences in nuclear (6.5 percent) and hydro (5.7 percent). Possible explanations may be limited precision in the harmonization factors we were able to gather from EIA's World Energy Projection System or discrepancies in the underlying data.

Table 10. Harmonized Primary Energy Consumption Data Relative to IEA

	bp (2021)	ExxonMobil (2021)	EIA (2021)	OPEC (2022)
Liquids	2%	1%	0.1%	1.2%
Oil (excl. biofuels)	2%	1%	0.2%	1.2%
Biofuels	–1%	4%	–3.5%	0.4%
Gas	0%	3%	–2.5%	–3.0%
Coal	–4%	–7%	0.4%	–7.0%
Nuclear	7%	–2%	–6.5%	6.8%
Hydro	11%	–3%	5.7%	2.4%
Nonhydro renewables (including nonmarketable sources)	N/A	3%	N/A	–9.5%
Nonhydro renewables (only marketable sources)	N/A	N/A	N/A	N/A
Total renewables (including nonmarketable sources)	N/A	2%	N/A	–7.4%
Total renewables (only marketable sources)	N/A	N/A	N/A	N/A
Total energy excluding nonhydro renewables	0%	–1%	–0.7%	–1.4%
Total primary energy	–7%	2%	–8.6%	–1.7%

Note: bp and EIA 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. N/A indicates that fuel-specific data are not available for a given energy source.

Table 11. Fuel-by-Fuel Comparison of Energy Consumption Data in 2021 (in fuel-specific units)

	bp	IEA	EIA	BP/IEA	EIA/IEA
Liquids (mboe/d)	97.2	95.7	97.0	1.6%	1.4%
Oil (excl. biofuels) (mb/d)	95.4	93.7	95.1	1.8%	1.5%
Biofuels (mboe/d)	1.8	2.0	1.9	–7.9%	–4.8%
Gas (tcf/yr)	144	149	145	–3.6%	–2.7%
Coal (million tonnes produced)	8,160	7,947	7,841	2.7%	–1.3%
Nuclear (TWh)	2,803	2,810	2,813	–0.3%	0.1%
Hydro (TWh)	4,289	4,299	4,540	–0.2%	5.6%
Nonhydro renewables (only marketable sources) (TWh)	3,665	3,666	3,654	0.0%	–0.3%
Total renewables (only marketable sources) (TWh)	7,953	7,964	8,194	–0.1%	2.9%

Sources: IEA oil and natural gas data from *World Energy Outlook 2023*, coal data from *Coal Market Update*,[16] July 2022; bp from *Statistical Review of World Energy*; EIA from *International Energy Outlook*.

Note: EIA electricity generation data converted from net generation to gross generation using a factor of 1.05. Limited data availability prevents us from sharing OPEC's data.

Table 11 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 of Table 11 from Table 10 results in 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, primarily for bp (which relies on the *Statistical Review of World Energy*, no longer being produced directly by bp). These discrepancies are from several sources, including hydro (12 percent), biofuels, coal, and nuclear (all 7 percent), and natural gas (4 percent). They highlight the continued opportunity for organizations such as IEA and bp to further standardize accounting methods to improve understanding of the global energy system.

Table 12. Differences in 2021 Energy Consumption

	bp/IEA	EIA/IEA
Liquids	0.7%	–1.2%
Oil (excl. biofuels)	0.6%	–1.3%
Biofuels	7.4%	1.3%
Gas	3.7%	0.2%
Coal	–6.8%	1.8%
Nuclear	6.9%	–6.6%
Hydro	11.6%	0.1%

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 present regional data according to membership in the OECD, although these groupings are becoming less common over time. More often, recent outlooks ignore OECD membership status and simply group regions by geographic proximity. Based on the regional definitions for each outlook, we find that regional data can be regrouped fairly consistently into five broad geographic areas: Africa, the Americas, Asia-Pacific , Europe and Eurasia, and the Middle East. The definitions for Africa and the Middle East are similar 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. Table 13 shows the outlooks that produce data sufficient to aggregate into each regional grouping.

Table 13. Regional Data Availability for Each Outlook

Region	bp	EIA	Enerdata*	Equinor	ExxonMobil	IEA	OPEC	Shell
Africa	x	x	x	x	x	x		x
Asia-Pacific	x	x			x	x		x
East	x	x			x	x		x
Europe and Eurasia	x	x	x		x	x	x	x
Latin America	x	x		x	x	x		x
Middle East	x	x			x	x		x
North America	x	x		x	x	x		x
West	x	x			x	x		x
World	x	x	x	x	x	x	x	x

* Enerdata includes a country-level global coverage in its proprietary EnerFuture report

7. Conclusion

Energy industry experts, policymakers, and a variety of other stakeholders make decisions and plan for the future based on the information and analysis in 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 clear way to make comparisons across outlooks, 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 conceal important differences in views about the future, this method controls for varied conventions and historical data that mask true differences among 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, inclusion (or exclusion) of traditional biomass, regional groupings, and more. Assumptions about energy content of physical units of oil, natural gas, and coal can vary by roughly 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 alter estimates by as much as a 57 percent decrease to a 4.3-fold increase for particular electricity sources, relative to IEA estimates.

After accounting for these 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, EIA, and IEA, indicating that improvements in standardization across historical data platforms could be made to enhance comparability of baseline data and the outlooks that rely on those data. In addition, some outlooks, such as those from ExxonMobil and OPEC, do not provide sufficient data documentation to allow for full harmonization.

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 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 improve data, to the benefit of energy dialogue and energy decisionmaking worldwide.

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