RESOURCES *for the* FUTURE

Global Energy Outlook Comparison Methods: 2020 Update

Richard G. Newell and Daniel Raimi

Report 20-06
May 2020

About the Authors

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

Daniel Raimi is a Senior Research Associate at Resources for the Future and a lecturer at the Gerald R. Ford School of Public Policy. He works on a range of energy policy issues with a focus on oil and gas regulation and taxation and climate change policy. He has published in academic journals including Science, Environmental Science and Technology, Energy Policy and Journal of Economic Perspectives, popular outlets including The New Republic, Newsweek, Slate, and Fortune, and presented his research for policymakers, industry and other stakeholders around the United States and internationally. **The Fracking Debate**, his first book, combines stories from his travels to dozens of oil and gas producing regions with a detailed examination of key policy issues, and is published by Columbia University Press.

About the Project

This paper is part of a larger multi-year effort on short-, medium-, and long-term energy outlooks by Resources for the Future. The project has resulted in a number of reports, several of which have been produced with support from, and in collaboration with, the International Energy Forum (IEF). This report updates Newell, R.G., and Raimi, D. 2019. Global Energy Outlooks Comparison Methods: 2019 Update. Other reports produced in collaboration with IEF include the background papers for the fourth, fifth, sixth, seventh, eighth, ninth, and tenth IEA-IEF-OPEC Symposium on Energy Outlooks, and the paper Global Energy Outlook 2019, which compares and synthesizes the results of long-term energy outlooks by IEA, OPEC, US EIA, BNEF, BP, Equinor, ExxonMobil, IEEJ, and Shell.

About RFF

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy. The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

Sharing Our Work

Abstract

We update a harmonization methodology previously 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 and Economics (Japan), the Organization of the Petroleum Exporting Countries, Shell, and the US Energy Information Administration. Decisionmakers in the public and private sector rely on these projections to inform investments and policy, but comparing these outlooks on an apples-to-apples basis is not possible due to a variety of methodological differences. For example, the US EIA and BP's exclude non-marketed traditional biomass, resulting in estimates of global primary energy consumption that are 8 to 10 percent lower than other projections. Assumptions about energy content of fossil fuels can vary by more than 11 percent in the data examined here, requiring significant adjustment of primary energy consumption estimates. Conventions about primary energy conversion of renewables can also alter estimates by as much as a 65 percent decrease to a 3.8-fold increase for particular electricity sources, relative to IEA estimates. We also find that there are significant differences in historical data used in these outlooks, even when measured in fuel-specific physical units such as barrels, cubic meters, or tonnes. After taking into account these differences, our harmonization methodology brings estimates within 3.3 percent or less of one another for most fuels in the benchmark years of 2017 and 2018. In this document, we describe the process by which we enhance the comparability of outlooks by adjusting for differences in assumptions such as fuel classifications, energy content assumptions, conversion efficiencies, and more. We present a selection of the harmonized results, benchmarked to the IEA's 2019 World Energy Outlook. This methodology is used to develop our *Global Energy Outlook 2020 report*, available at **www.rff.org/geo**.

Contents

1. Introduction

The global energy sector is changing rapidly. Population and economic growth are driving up world energy demand. At the same time, technological advances are increasing energy efficiency, driving down costs for renewable energy and energy storage technologies, and making more unconventional fossil fuel resources economically viable.

Energy outlooks are one way to understand these changes, with a particular eye toward the longer-term future. Each year, multiple long-term energy outlooks, usually projecting 20 to 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), and international energy companies (e.g., BP, Equinor, ExxonMobil, Shell). In recent years, other organizations such as the Russian and Chinese Academy 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. Each organization makes long-term energy projections using their own modeling assumptions and, in some cases, unique historical databases.

Due to the important role these outlooks play in informing decisions by market participants and policymakers, a consistent method of presenting the information from these outlooks can help enhance an inclusive and meaningful international energy dialogue. However, the varying methodologies and assumptions utilized by different organizations 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 more clearly evaluate the range of global energy projections.

To illustrate this harmonization process, we use the most recent outlooks available for comparative analysis of energy forecasts, as well as several previously published outlooks to enable the analysis of 2016 data as a common baseline year:

- **BNEF:** New Energy Outlook 2019 (NEO2019), published in June 2019.
- **BP:** Energy Outlook 2019, published in February 2019.
- **Equinor:** Energy Perspectives 2019, published in June 2019.
- **ExxonMobil:** Outlook for Energy 2019, published in August 2019.
- **IEA:** World Energy Outlook 2019 (WEO2019), published in November 2019.
- **IEEJ:** Energy Outlook 2020, published in October 2019.
- **OPEC:** World Oil Outlook 2019 (WOO2019), published in October 2019.
- **Shell:** Sky Scenario, published in April 2018
- **US EIA:** International Energy Outlook 2019 (IEO2019), published in September, 2019.

Each outlook discussed in this paper covers a range of topics, from quantitative projections of energy consumption, supply, and carbon dioxide emissions, to qualitative descriptions of technology development. 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 in fact obfuscate an accurate assessment of underlying assumptions and judgments about the short-, medium- and long-term in different outlooks.

We focus here on overall primary energy consumption and its key fuel sources—oil and other liquids (including natural gas condensate), natural gas, coal, nuclear, and renewables—and provide a detailed description of our outlook harmonization approach. This paper identifies and addresses the following specific challenges in harmonizing primary energy consumption across different institutional sources:

- Outlooks use different units of primary energy consumption (e.g., qBtu, mtoe, mboe).
- Outlooks use different assumptions for the energy content of fossil fuels and vary in their use of net and gross calorific values for fuels.
- Outlooks vary in their assumptions regarding the efficiency of conversion to primary energy of non-combustible energy sources (e.g., nuclear and renewable electric power).
- Outlooks vary in whether they include non-marketed sources of energy, particularly traditional biomass.
- Outlooks vary in their categorization of energy sources (e.g., biofuels, liquids, oil, synthetic gas from coal, and renewables), and whether they include flared gas.
- Outlooks use different historical baseline data.
- Outlooks differ in their regional groupings of countries.

Sections 2, 3, and 4 elaborate on the first four issues mentioned above. Section 5 presents our method for harmonizing primary energy consumption among various outlooks and identifies the issue of remaining differences in historical baseline data, using 2017 and 2018 as benchmark years. 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: (i) primary energy, (ii) energy use in power generation, and (iii) end-use energy 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 various energy outlooks. Primary energy refers to the energy embodied in natural resources prior to any conversion or transformation process for end-use consumption. The level of primary energy consumption and its fuel composition for a country or region is 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 by 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. Primary energy consumption tends to be reported in a traditional energy unit, such as quadrillion Btu (qBtu) or million tonnes of oil equivalent (mtoe). However, sometimes the primary consumption of a specific fuel is not directly presented, and the comparison of primary energy involves derivation from other energy consumption data.[1] 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 primary energy units are mtoe or btoe (IEA, BP, Equinor, IEEJ) and qBtu (US EIA, ExxonMobil), with OPEC using million barrels of oil equivalent per day (mboed) and Shell using Exajoules (EJ). To compare across outlooks, one needs to place all outlooks in a common unit. For this paper we use qBtu as the benchmark primary energy unit, requiring an appropriate conversion factor for outlooks other than those from the US EIA and ExxonMobil. According to international convention (see, for example, IEA[2]) 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.[3] 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 Shell's primary energy data from EJ to qBtu, we first convert from EJ to mtoe using a factor of 1 EJ = 23.9 mtoe.[4]

1 For example, as discussed below, the US EIA does not report primary energy consumption for hydro 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..

2 IEA, World Energy Outlook 2019, p. 772.

3 Internal communication with OPEC. To convert from mboed to mtoe per year for OPEC, multiply by 365 days per year, and then 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.

4 As specified in the "Definitions" tab of the data pages for Shell's Sky Scenario.

Table 1. Units of Energy Consumption Used in Different Outlooks

	IKA	BP	Exxon Mobil	US EIA	OPEC	Equinor	IEEJ	Shell
Primary energy units	mtoe	mtoe	qBtu	qBtu	mboed	btoe	mtoe	EJ
Fuel/sector-specific units								
Liquids	mbd	mbd	mboed	mbd	mbd	mbd	N.A.	N.A.
Oil	mbd	mbd	mboed	mbd	mbd	N.A.	N.A.	N.A.
Biofuels	mboed	mboed	mboed	mbd	mbd	N.A.	N.A.	N.A.
Natural gas	bcm	bcm	bcfd	tcf	mboed	bcm	N.A.	N.A.
Coal	mtce	mtoe	N.A.	short ton	mboed	N.A.	N.A.	N.A.
Electricity	TWh	TWh	TWh	TWh	N.A.	TWh	TWh	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 remain due to differences in energy content assumptions made by organizations 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, it is our understanding from experts at the US EIA that the principle reason for its significantly higher estimates for liquids and natural gas than IEA is that the US EIA 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 for each of the major fuel sources: liquids (Table 2), natural gas (Table 3), and coal (Table 4). Our general approach involves two steps, conducted separately for each organization and for each fuel.

First, we identify energy content assumptions made by each organization. To do so, 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 data in energy units by the data measured in fuel-specific physical units. For the 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 the organizations. This yields an energy content factor for each fuel and for each 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 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. In practice, these factors vary little over time.

Second, we derive an energy content adjustment factor by dividing the energy content factors for IEA by those of other outlooks. This approach has the effect of benchmarking these organizations' estimates so that they are approximately "as if" they had used the average aggregate IEA energy content assumptions for each fuel. We do not adjust ExxonMobil, OPEC, or Shell data for any differences in energy content assumptions, due to both data limitations and because they rely in part on IEA's assumptions.[5] We do not adjust Equinor or IEEJ data because they rely on the IEA's assumptions and historical data.

The conversion process for primary energy consumption of liquids is given in Table 2. Liquids consumption 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. We derive energy content adjustment factors for natural gas (Table 3) and coal (Table 4) using the same approach as Table 2.

5 We do not adjust ExxonMobil data in this manner because their baseline data is based on IEA Annual Statistics Data, and all fuels except oil are directly converted from mtoe to qBTU by multiplying by the standard conversion factor of 0.03968 qBtu/mtoe. For oil, ExxonMobil converts IEA data from kilotonnes to qBtu using its own energy content assumptions for individual petroleum products. However, we were not able to create an energy content adjustment factor for ExxonMobil liquids due to a lack of data in mbd from ExxonMobil. Because OPEC does not present non-liquids energy consumption data in both energy units and fuel-specific physical units, the above approach of deriving energy content factors cannot be used for OPEC data. In addition, in other cases OPEC tends to follow IEA conversion assumptions. Shell does not provide fuel-specific physical units.

Table 2. Liquids Energy Content Adjustment

Source	Years of demanded data	Fuel-specific units	Primary energy units		Implied conversion factors	
		mboed	qBtu	mtoe	mtoe/mbd	qBtu/mbd
		(a)	(b)	(c)	(d)=(c/a)	(e)=(d×0.03968 qBtu/mtoe)
IEA[1]	2025	106.4	-	4,924	46.30	1.837
	2040	111.1	-	5,144	46.30	1.837
IEA avg.					***46.30***	***1.837***
BP[2]	2025	104.9		4,903	46.75	1.855
	2040	107.7		5,004	46.44	1.843
BP avg.					***46.60***	***1.849***
US EIA[2]						(e)=(b/a)
	2025	104.0	206.9	-	-	1.989
	2040	111.8	222.9	-	-	1.994
US EIA avg.						***1.992***

Energy content adjustment factors for liquids

IEA (benchmark), Equinor, ExxonMobil, IEEJ, OPEC, Shell: 1 = 1.837 qBtu/mbd ÷ 1.837 qBtu/mbd

BP: 0.9936 = 1.837 qBtu/mbd ÷ 1.849 qBtu/mbd

US EIA: 0.9225 = 1.837 qBtu/mbd ÷ 1.992 qBtu/mbd

Notes: All data in the table are consumption data. Dashes indicate the data are not available from a particular source. Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or they benchmark their energy content assumptions to the IEA. (1) IEA data based on New Policies Scenario. (2) BP based on Energy Transition Scenario. (2) In October 2019, US EIA withdrew most of its data for oil supply projections, citing an issue with conversion factors. However, sufficient liquids demand data were available to make the comparison in the table above. Sources: IEA via World Energy Outlook 2019 Annex Tables; BP via Energy Outlook 2019 data tables and internal communication; US EIA via International Energy Outlook 2019 data tables.

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	mtoe	mtoe/tcf	qBtu/tcf
			(a)	(b)	(c)	(d=c/a)	(e)=(d×0.03968 qBtu/mtoe)
IEA[1]	2025	4,415	155.9	-	3,638	23.33	0.926
	2040	5,404	190.8	-	4,445	23.29	0.924
IEA avg.						***23.31***	***0.925***
BP[2]	2025	4,346	153.5	-	3,737	24.35	0.966
	2040	5,370	189.6	-	4,617	24.35	0.966
BP avg.						***24.35***	***0.966***
							(e)=(b/a)
US EIA	2025	-	139.8	145.2	-	-	1.039
	2040	-	168.8	175.3	-	-	1.039
US EIA avg.							***1.039***

Energy content adjustment factors for liquids

IEA (benchmark), Equinor, ExxonMobil, IEEJ, OPEC, Shell: 1.0 = 0.925 qBtu/tcf ÷ 0.925 qBtu/tcf

BP: 0.9574 = 0.925 qBtu/tcf ÷ 0.966 qBtu/tcf

US EIA: 0.8907 = 0.925 qBtu/tcf ÷ 1.039 qBtu/tcf

Note: All data in the table are consumption data. Dashes indicate the data are not available from a particular source. Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or they benchmark their energy content assumptions to the IEA. (1) IEA data based on New Policies Scenario. (2) BP based on Energy Transition Scenario. Sources: IEA via World Energy Outlook 2019 Annex Tables; BP via Energy Outlook 2019 data tables and internal communication; US EIA via International Energy Outlook 2019 data tables.

Table 4. Coal Energy Content Adjustment

		Fuel-specific units		Primary energy units		Implied conversion factors	
Source	Data year	Million short tons	Million metric tonnes	qBtu	mtoe	mtoe/mt	qBtu/mt
			(a)	(b)	(c)	(d)=(c/a)	(e)=(d×0.03968 qBtu/mtoe)
IEA	2017	-	7,563	-	3,779	0.4997	0.01983
BP	2017		7,704	-	3,755	0.4874	0.01934
	2018		8,013	-	3,917	0.4888	0.01940
BP avg.						0.4881	0.01937
							(e)=(b/a)
US EIA	2016	8,150	7,393	158.2			0.02140
	2010	8,155	7,398	156.2			0.02112
US EIA avg.							0.02126

Energy content adjustment factors for coal

IEA (benchmark), Equinor, ExxonMobil, IEEJ, OPEC, Shell: 1.0 = 0.01983 qBtu/mt ÷ 0.01983 qBtu/mt

BP: 1.0237 = 0.01983 qBtu/mt ÷ 0.01937 qBtu/mt

US EIA: 0.9326 = 0.01983 qBtu/mt ÷ 0.02126 qBtu/mt

Note: All data in the table are production data. Dashes indicate the data are not available from a particular source. Equinor, ExxonMobil, IEEJ, OPEC, and Shell outlooks are not included because they do not present sufficient data in fuel-specific units and/or they benchmark their energy content assumptions to the IEA. (1) Converted to mtoe from million tonnes of coal equivalent using a factor of 0.7.

Sources: IEA physical unit data from Coal Information 2019 and energy data from WEO2019. BP historical data from BP Statistical Review of World Energy 2019. US EIA data from International Energy Statistics and International Energy Outlook 2019 data tables.

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

	Liquids	Natural gas	Coal
IEA, Equinor, ExxonMobil, IEEJ, OPEC, Shell	1.000	1.000	1.000
BP	0.994	0.957	1.024
US EIA	0.922	0.891	0.933

Table 5 summarizes the resulting energy content adjustment factors for the US EIA and BP for each major fuel. The factors differ moderately in most cases and substantially in some, revealing differences in energy content assumptions for each fuel ranging from up to 8 percent for liquids (US EIA vs. IEA), 11 percent for natural gas (US EIA vs. IEA), and 10 percent for coal (BP vs. US EIA). An implication is that if one does not adjust for differing energy content assumptions, and instead only converts primary energy data based on standard mtoe-to-qBtu conversion factors, this will result in a significant under- or over-estimates when comparing between outlooks. Note that this adjustment is only necessary for fossil fuels, whereas another approach is necessary for addressing differences in assumptions about the primary energy content of nuclear and renewable power (see section 3).

Note that determining a single "correct" adjustment factor for each fuel is not currently 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 harmonization of 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 difference that would otherwise exist 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 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 primary energy for nuclear power and non-biomass renewables such as solar, hydro, wind, and geothermal is more complex because the notion of upstream embodied energy is less well-defined and also not as widely measured.

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

Source	Nuclear	Hydro	Wind	Solar PV	Solar thermal	Geo-thermal	Biomass
IEA (benchmark), Equinor, IEEJ, OPEC, Shell	33%	100%	100%	100%	33%	10%	35%
BP	38%	38%	38%	38%	38%	38%	38%
ExxonMobil	33%	100%	100%	100%	100%	10%	10-40%
US EIA	33%	35%	35%	35%	35%	35%	36%

Sources: BP, BP Energy Outlook 2019, p. 139; US EIA, World Energy Projection System Plus Model Documentation (Washington, DC: US EIA, 2017); Internal communication with Equinor, ExxonMobil, IEEJ, Shell, and IEA.

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

IEA, Equinor, ExxonMobil, IEEJ, OPEC, and Shell

Many outlooks follow the assumptions of the IEA in its WEO series.[7] Because biomass is combustible (like fossil fuels), most of these organizations use a conversion efficiency of 35 percent based on an average energy content of biomass (though ExxonMobil uses a range of factors between 10 and 40 percent for biomass, which we simplify in our calculations to an average of 25 percent). For nuclear power, the IEA divides nuclear 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 the conversion of steam energy into electricity, the IEA conversion efficiency assumption is 10 percent. For the remaining renewable power sources—hydro, wind, solar, and other (e.g., tidal)—the IEA uses the "captured energy" approach, which assumes the primary energy content is equal to 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 here, differences emerge between Shell and other outlooks, as Shell incorporates electricity losses during transmission and distributions, while the 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.

BP

BP assumes a general conversion efficiency factor of 38 percent for electricity generation from nuclear and renewables (the average for OECD thermal power generation).[8] This assumption is based on the energy required to generate an equal amount of electricity in a fossil-fueled thermal power plant, known as the "fossil-fuel equivalency" approach.[9]

6 Note that 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% for all non-fossil energy sources. For more, see Koomey et al. 2019. "Inside the Black Box: Understanding Key Drivers of Global Emission Scenarios." Environmental Modeling and Software. vol. 111, no. 1.

7 Internal communication with Equinor, IEEJ, and OPEC.

8 BP Energy Outlook 2019, p. 139.

9 For an overview of alternative approaches to primary energy conversion for non-combustible sources, see IEA, "Frequently Asked Questions", accessed February 13, 2018, at:

US EIA

For nuclear power, the US EIA uses the same approach as the IEA, with a conversion efficiency of roughly 33 percent (although the detailed EIA IEO modeling assumptions vary somewhat by region and over time).[10] The US EIA also uses the same approach as the IEA for biomass, although the assumed conversion efficiency rate is slightly higher (36 percent, versus the IEA's assumed 35 percent). For the non-combustible renewable power sources (i.e., hydro, wind, solar, geothermal, other) the US EIA uses the "fossil-fuel equivalency" approach (like BP) with an assumed efficiency rate of 35 percent

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 projections across outlooks. This requires choosing a benchmark set of assumptions, for which we use the IEA's conversion efficiencies.[11]

To illustrate our harmonization process, consider primary energy consumption from nuclear sources in outlooks from BP and the IEA. BP assumes a nuclear power plant efficiency rate of 38 percent, while the IEA assumes 33 percent. Therefore, the primary nuclear energy consumption figure for BP must be multiplied by 1.15 (0.38/0.33) to be comparable to the primary nuclear energy consumption figure for the IEA. The same approach can be used for BP's outlook for renewable power and the US EIA's outlook for nuclear and renewable power.[12] All multiplicative factors for this purpose are presented later in Table 8.

---

http://www.iea.org/statistics/resources/questionnaires/faq/.

10 US EIA, World Energy Projection System Plus Model Documentation (Washington, DC: US EIA, 2017), accessed February 13, 2018 at: **https://www.eia.gov/outlooks/ieo/weps/documentation/pdf/wepsplus2016_electricitymodule.pdf.** We obtained additional model assumptions not included in the report through internal communication with US EIA.

11 Note that, due to data limitations, we apply these assumptions on a global scale even though they may vary somewhat from region to region within outlooks.

12 This approach requires obtaining the necessary data on the individual renewable power sources (i.e., hydro, wind, solar, geothermal, and other), in qBtu, from the US EIA. A somewhat different approach is needed to convert the US EIA figures on renewable power when using the standard published data because at this time the 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, one would convert EIA's estimates of net generation in TWh to qBtu (by multiplying by 0.003412 qBtu/TWh) and then divide by IEA's conversion efficiency assumptions for each renewable source.

4. Fuel Categorization

Another challenge arises from different groupings of energy sources across outlooks. While the categorization for coal, natural gas, and nuclear energy is generally consistent, categorizations 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 and BP include 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, the IEA, Equinor, ExxonMobil, IEEJ, and Shell distinguish biofuels from “oil”. with the IEA including them in the “bioenergy” category and ExxonMobil treating them as part of the “other renewables” category. Equinor and IEEJ include biofuels in their “biomass” and “biomass/waste” categories, respectively, while Shell provides a unique “biofuels” category in its primary energy data. For OPEC, biofuels are included in “biomass” in the primary energy projection table of WOO2019 (Table 2.2), but included in the “liquids” category in tables and figures describing liquids supply projections. This different treatment of biofuels can make cross-outlook comparison of estimates for liquids, oil, and renewables challenging.

In addition, biodiesel and bioethanol have different energy content per unit volume than petroleum-based diesel and gasoline. BP estimates that the energy content of 1 barrel of ethanol is equivalent to 0.58 barrels of oil equivalent, and 1 barrel of biodiesel is equivalent to 0.86 barrels of oil.[13] To make biofuels comparable to other liquids 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. One should be aware that the amount of biofuels expressed in energy-equivalent terms is smaller than that in pure volumetric terms. For example, when the IEA WEO2019 estimates global biofuels supply of 1.9 mboed in 2018, the volume of physical supply was roughly 2.7 mbd, with physical volumes of 1.9 mbd of ethanol and 0.8 mbd of biodiesel.[14]

13 BP Statistical Review of World Energy 2019, Data Tables, “Approximate conversion factors” tab.

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

4.2. Renewables Categorization and Non-Marketed Energy

Comparisons of renewable energy consumption present another challenge, particularly the treatment of non-marketed renewable energy sources. The US EIA and BP only include marketed renewables in their projections, while the IEA, OPEC, IEEJ, Equinor, ExxonMobil, and Shell include non-marketed energy (i.e., traditional biomass). In addition, BP excludes any renewable energy that is consumed directly in the form of heat. For example, if biomass or waste is used in a combined heat and power plant, BP only includes the power generated, not the heat. These different approaches can result in large gaps in renewable energy consumption estimates across outlooks, particularly related to traditional biomass.

In 2017, for example, estimates of non-hydro renewables consumption (excluding biofuels) for the IEA and BP are 60 qBtu and 13 qBtu respectively, with the difference primarily explained by BP's exclusion of non-marketed biomass (see Table 9). This scale of energy consumption from non-marketed sources can lead to misleading comparisons across outlooks in categories including renewable energy consumption, total global energy consumption, and the shares of different energy sources in total energy. For example, the IEA's 2017 estimate for global primary energy demand is roughly 9 percent higher than BP's. Similarly, the share of primary energy from non-hydro renewables ranges from 2 to 3 percent for organizations that exclude traditional biomass (BP and US EIA), compared with roughly 11 percent for those that do not (all others).

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

As shown in Table 7, the US EIA's IEO2019 uses a single "Other" category to report primary energy consumption for all renewable power sources, including hydro, 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, as we note above, biofuels are treated differently across outlooks. To make data comparable across outlooks, we adjust the categorization of biofuels where necessary to ensure that it is included in the "liquids" category alongside oil. This means that we subtract biofuels from categories such as "biomass" (Equinor, OPEC), "biomass/waste" (ExxonMobil, IEEJ), and "bioenergy" (IEA) to avoid double-counting biofuels in primary energy consumption.

Table 7. Renewable Energy Categories for Primary Energy and Electricity

	Primary energy	
	Distinct categories	Sources included in “other renewables”
BNEF	-	-
BP	Hydro, wind, solar	Biofuels, biomass, geothermal
Equinor	Hydro, biofuels, biomass	Wind, solar, geothermal, tidal
ExxonMobil	Hydro, biofuels, biomass	Wind, solar, geothermal, tidal
IEA	Hydro, biofuels, biomass, traditional biomass	Wind, solar, geothermal, tidal
IEEJ	Hydro, biomass, geothermal	Wind, solar, tidal
OPEC	Hydro, biofuels, biomass	Wind, solar, geothermal
Shell	Hydro, biofuels, biomass, wind, solar, geothermal	Generic “other”
US EIA	-	Hydro, biofuels, biomass, wind, solar, geothermal, tidal
	Electricity	
	Distinct categories	Sources included in “other renewables”
BNEF	Hydro, biomass, wind, solar, geothermal	-
BP	-	-
Equinor	Hydro, biomass, wind, solar, geothermal	CSP, marine, “other”
ExxonMobil	Hydro, wind	Biomass, solar (PV only), geothermal, tidal
IEA	Hydro, biomass, wind, solar PV, solar CSP, geothermal, tidal	-
IEEJ	Hydro, biomass, wind, solar PV, geothermal	Solar thermal, tidal
OPEC	-	-
Shell	Hydro, biomass, wind, solar, geothermal	Generic “other”
US EIA	Hydro, wind, solar, geothermal	Biomass, tidal

Note: BNEF does not publish primary energy data in its NEO series. BP categories shown here includes publicly published data. BP has provided, via internal communication, additional data to allow for more detailed comparison.

5. Outlook Harmonization and Historical Data Differences

In this section, we describe a method for using the information provided above to harmonize outlook estimates of world primary energy consumption. We apply this methodology to baseline year data below (2017 for some outlooks, 2018 for others), but note that it could be applied to any common projection year.

First, convert all primary energy consumption data to qBtu using the standard conversion factors of 0.03968 qBtu/mtoe (BP, IEA, IEEJ), 0.00003968 qBtu/Btoe (Equinor), 1.976 qBtu/mboed (OPEC), and 1.0551 qBtu/TJ (Shell).

Second, adjust BP and US EIA fossil fuel data for differences in energy content assumptions by multiplying by the energy content adjustment factors found in Table 5.

Third, for individual US EIA renewables categories, calculate estimates in qBtu by multiplying data in TWh by 0.003412 qBtu/TWh.

Fourth, use the 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 as shown by Table 8.

Fifth, adjust data to yield a uniform definition of liquids (incl. biofuels) and non-hydro renewables (excl. biofuels). Table 9 and Figure 1 display the results of this methodology. Notably, ExxonMobil's data are not transformed (with the exception of moving biofuels into the "liquids" category). This is due to three factors: ExxonMobil's energy consumption data are presented in qBtu, most of its conversion efficiency assumptions are the same as the IEA's (our benchmark), and data for categories such as biomass conversion efficiency are insufficient for us to make detailed estimates.

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

	Nuclear	Hydro	Wind/Solar/Other	Geothermal	Biomass
BP	1.15	0.38	0.38	3.80	1.09
Equinor	1.00	1.00	1.00	1.00	1.00
ExxonMobil	1.00	1.00	1.00	1.00	1.00
IEA (Benchmark)	1.00	1.00	1.00	1.00	1.00
IEEJ	1.00	1.00	1.00	1.00	1.00
OPEC	1.00	1.00	1.00	1.00	1.00
Shell	1.00	1.00	1.00	1.00	1.00
US EIA	1.00	0.35	0.35	3.50	1.03

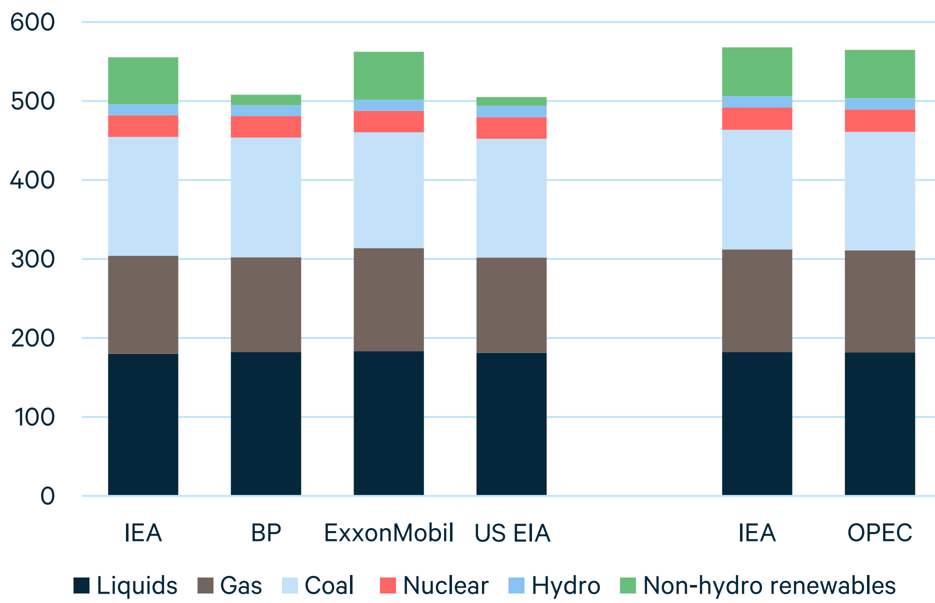
Notes: (1): This factor is found by dividing BP's assumed primary energy conversion efficiency of 38 percent by an assumed average 74.6 percent non-hydro conversion efficiency for IEA (which we computed based on the global share of each non-hydro power source in total non-hydro power). (2): Although ExxonMobil uses a range of conversion efficiencies of 10 to 40 percent for biomass power, whereas IEA uses a 35 percent, we do not adjust due to a lack of data.

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

	2017 baseline				2018 baseline	
	IEA	BP	Exxon Mobil	US EIA[3]	IEA	OPEC
Liquids	180	182	183	181	182	182
Oil (excl. biofuels)	177	179	180	n.a.	179	178
Biofuels	3.3	3.3	3.3	n.a.	3.5	3.6
Gas	124	120	130	121	130	129
Coal	151	152	147	151	152	150
Nuclear	27	27	27	27	28	28
Hydro	14	14	14	14	14	14
Non-hydro renewable[1] (incl. non-marketed)	60	N.A.	61	N.A.	62	61
Non-hydro renewable[1] (excl. non-marketed)	N.A.	13	N.A.	11	N.A.	N.A.
Total renewable[1] (incl. non-marketed)	73	N.A.	75	N.A.	76	76
Total renewable[1] (excl. non-marketed)	N.A.	27	N.A.	25	N.A.	N.A.
Total energy (excl. non-marketed)	496	495	501	494	506	503
Total primary energy[2]	555	508	562	505	568	565

Note: Totals or subtotals may not sum due to rounding. (1) Excluding biofuels. (2) BP and US EIA totals are smaller because they exclude non-marketed renewables, as described in section 4.2. (3) As noted in Table 2, the US EIA withdrew much of its liquids supply data from the its 2019 International Energy Outlook, citing an issue with conversion factors. Remaining data indicate global liquids demand, but does not distinguish between oil and biofuels. Dashes indicate the data are not available from a particular source.

Figure 1. Harmonized Baseline Primary Energy Consumption (qBtu)



Note: BP and the US EIA exclude non-marketed renewables (e.g., traditional biomass).

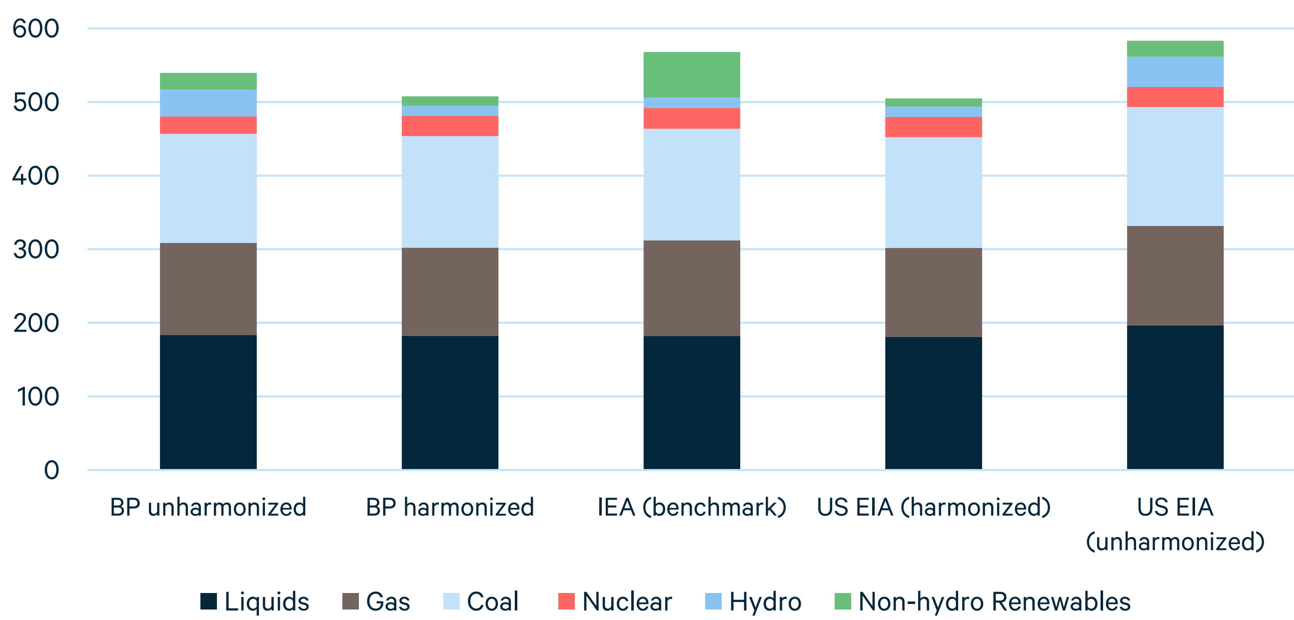
Due primarily to their exclusion of non-marketed renewables, BP and the US EIA have far lower total consumption estimates than other outlooks. After accounting for the exclusion of non-marketed renewables, the divergence from the IEA across outlooks in total primary energy consumption is one percent or less across all outlooks. However, other discrepancies may be 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.

Although the harmonization process adjusts for a significant amount of divergence, it does not eliminate all discrepancies in historical consumption data. For example, ExxonMobil has substantially higher estimates for oil and natural gas consumption, and a significantly lower estimate for coal consumption than the IEA. It is our understanding from experts at ExxonMobil that the differences exist for three primary reasons: (1) ExxonMobil includes flared gas in natural gas totals, whereas IEA and all other outlooks omits flared gas; (2) ExxonMobil includes synthetic gas from coal in natural gas totals, whereas IEA includes it in coal totals; and (3) ExxonMobil and IEA may use different energy content assumptions for liquids, which we cannot control for due to a lack of data.

Finally, because many organizations rely on the IEA for historical data, these organizations tend to use older vintages of data than the IEA in its most recent outlooks. Consider the publication of a given 2019 outlook from hypothetical organization “A.” To publish its report in year 2019, “A” conducts its modeling analysis in year 2018, potentially based on historical data published by the IEA in year 2015. As a result historical data for “A” may diverge by up to 2 years from the IEA’s most recent historical data. Because historical data are subject to revision, these temporal gaps can lead to notable differences.

Nonetheless, the harmonization process described above results in substantial improvements in comparability across outlooks. To understand the significance of these differences Figure 2 presents pre- and post-harmonization data for global primary energy consumption in 2017 for the US EIA and BP, two organizations where substantial differences exist in pre-harmonized baseline data relative to the IEA. The figure highlights the large differences arising from different assumptions across these outlooks, with US EIA data adjusted by XX qBtu and BP data adjusted by XX qBtu. For reference, total primary energy consumption in Central and South America in 2015 was roughly 30 qBtu.

Figure 2. Harmonized and Unharmonized Primary Energy Consumption in 2017 (qBtu)



To understand whether the differences shown in Table 10 are attributable to inadequacies in our conversion methodology or to 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 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.

Table 10. Primary Energy Consumption Data Relative to IEA

	2017			2018
	BP	ExxonMobil	US EIA	OPEC
Liquids	1.2%	1.9%	0.7%	-0.3%
Oil (excl. biofuels)	1.3%	2.0%	n.a.	-0.4%
Biofuels	0.2%	-1.1%	n.a.	2.0%
Gas	-3.4%	5.1%	-2.9%	-0.3%
Coal	0.7%	-2.6%	0.0%	-1.1%
Nuclear	-0.1%	-0.9%	0.4%	0.3%
Hydro	-0.6%	0.6%	2.7%	0.0%
Non-hydro renewable[1] (incl. non-marketed)	-	2.2%	-	-1.0%
Non-hydro renewable[1] (excl. non-marketed)	-	-	-	-
Total renewable[1] (incl. non-marketed)	-	1.9%	-	-0.8%
Total renewable[1] (excl. non-marketed)	-	-	-	-
Total energy (excl. non-marketed)	-0.2%	1.1%	0.4%	-0.5%
Total primary energy[2]	-8.6%	1.2%	-9.1%	-0.6%

Notes: (1) Excludes biofuels. (2) BP and US EIA totals are smaller in part because they exclude non-marketed renewables, as described in section 4.2. Dashes indicate the data are not available from a particular source.

Table 11. Fuel-by-Fuel Comparison of Energy Consumption Data in 2017 (in Fuel-Specific Units)

	BP	ExxonMobil	US EIA
Liquids (mboe/d)	98.4	97.5	98.4
Oil (mb/d)	96.8	95.7	n.a.
Biofuels (mboe/d)	1.6	1.8	n.a.
Gas (tcf/y)	129	133	130
Coal (million tonnes/y)	7,704	7,563	7,521
Nuclear (TWh)	2,639	2,636	2,586[1]
Hydro (TWh)	4,065	4,083	4,192[1]

Notes: (1) US EIA provides data for net electricity generation, while other sources provide data for gross generation.

Sources: BP Statistical Review of World Energy 2019; IEA oil and natural gas data via World Energy Outlook 2019, coal data from Coal Information 2019; US EIA via International Energy Outlook 2019 data tables.

Table 12 presents percentage differences relative to IEA data based on the fuel-specific data shown in Table 11. 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 results in Table 12 from Table 10 leads us to Table 13, which shows the gap in primary energy consumption remaining after controlling for differences in historical data and conversion efficiency assumptions. Note that the remaining gap is quite small for most energy sources, with liquids data varying by one percent or less. As noted previously, the US EIA withdrew much of its liquids supply data from its 2019 International Energy Outlook, which prevents us from identifying distinct estimates of oil and biofuels demand (though data on overall liquids remain available).

Substantial differences also emerge for natural gas, where BP and EIA differ from the IEA by 3.3 and 2.3 percent, respectively. These differences may stem in part from different assumptions about gross calorific values for fuels, as BP and the IEA for example, respectively assume 40 and 38 megajoules per cubic meter. Finally, differences in hydroelectric power generation vary by up to 2.7 percent for the common baseline year of 2017. This difference is partly, though not fully, explained by EIA's use of net electricity generation and the IEA's use of gross generation in their reported data. It is not clear how much of these historical data differences across institutions persist in their future projections, which are built in part on a historical baseline.

Table 12. 2017 Historical Data in Fuel-Specific Units Relative to IEA

	BP	US EIA
Liquids	1.0%	0.9%
Oil	1.1%	n.a.
Biofuels	-8.5%	n.a.
Gas	-3.3%	-2.3%
Coal	1.9%	-0.6%
Nuclear	0.1%	-1.9%[1]
Hydro	-0.4%	2.7%[1]

Note: Dashes indicate the data are not available from a particular source. (1) US EIA provides data for net electricity generation, while other sources provide data for gross generation.

Table 13. Remaining Differences in 2017 Energy Consumption after Controlling for Differences in Historical Data and Primary Energy Conversion Efficiency Assumptions

	BP	US EIA
Liquids	0.3%	-0.3%
Oil	0.1%	n.a.
Biofuels	8.6%	n.a.
Gas	-0.1%	-0.6%
Coal	-1.2%	0.6%
Nuclear	-0.2%	2.3%
Hydro	-0.1%	0.0%

Note: Dashes indicate the data are not available from a particular source.

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. A challenge that arises, however, is that outlooks differ in the categorization of countries into regional groupings.

Most outlooks present data for the Organization of Economic Cooperation and Development (OECD) and non-OECD nations. For other regional categories, however, groupings vary across energy outlooks. We examined the regional definitions for each outlook, and found that regional data can be regrouped into five broad geographic areas: Americas, Europe, Asia & Oceania, Africa and Middle East. While the definitions for Africa and Middle East are fairly consistent across outlooks, further harmonization is necessary to create comparable groupings for the Americas, Europe, and Asia & Oceania. Even after these efforts, however, perfect harmonization is not currently possible across all regions and outlooks.

The US EIA and OPEC distinguish OECD nations within geographic areas, while BP, ExxonMobil, and—as of 2017—the IEA do not distinguish between OECD nations and non-OECD nations in each geographic region. Note that OPEC's WOO has a specific regional category for OPEC member countries and excludes these countries from their geographic areas. As a result, OPEC's data for Latin America, Middle East and Africa are not typically comparable with other outlooks. However, OPEC has disaggregated its member countries into geographical regions in OPEC long-term liquids demand projections, allowing for more direct comparison with other outlooks. Below we summarize variation between the regional classification systems of BP, ExxonMobil, IEA, the US EIA, OPEC, IEEJ, Equinor, and Shell.

Americas

BP, ExxonMobil, the IEA, IEEJ, Equinor, and Shell divide the continent into "North America" and "Central/South America" (or "Latin America"). The difference between "North America" and "OECD Americas" (used by OPEC and the US EIA) is that the former excludes Chile and the latter includes it. "OECD Americas" contains four countries: the United States, Canada, Mexico, and Chile. Because OPEC and the US EIA provide regional groupings in terms of OECD status, GEO data includes Chile (which is part of the OECD) in "North America" for OPEC and the US EIA.

Puerto Rico is grouped with Central and South America or Latin America for all outlooks. The IEEJ and Shell include Mexico in "Latin America," whereas other outlooks include Mexico in "North America." Shell also includes Greenland in "North America," while other outlooks include Greenland in "Europe."

Europe

Outlooks use a variety of terms to describe modestly different geographical groupings across Europe. Most outlooks include Russia and its neighboring states into groups such as the Commonwealth of Independent States (BP, Equinor), Russia/Caspian (ExxonMobil), and Eurasia (IEA, OPEC, and Shell), while the IEEJ and US EIA groups together Non-OECD Europe and Eurasia. For continental Europe, BP, ExxonMobil, the IEA, and Shell include a comprehensive "Europe" category for all European nations, while BP, ExxonMobil, Equinor, IEA, and IEEJ also include a category for the European Union. The US EIA and OPEC group includes a "OECD Europe" category.

Asia and Oceania

BP, ExxonMobil, IEA, and IEEJ include all Asian and Oceania countries in one "Asia/ Pacific" category, including both OECD and Non-OECD nations. BP and the IEA also respectively include "Other Emerging Asia" and "Southeast Asia" categories alongside data for large nations such as China and India. The US EIA and OPEC group Asian nations according to OECD status. Equinor and Shell each create distinct groupings of Asian nations. The IEA includes Hong Kong in China, while the other outlooks separately count Hong Kong.

Middle East

All outlooks include a comprehensive "Middle East" group, with the exception of OPEC, which provides a "Middle East and Africa" grouping that typically excludes OPEC members. There is some variation in how the outlooks define "Middle East," however. The IEA includes the following countries: Bahrain; Islamic Republic of Iran; Iraq; Jordan; Kuwait; Lebanon; Oman; Qatar; Saudi Arabia; Syrian Arab Republic; United Arab Emirates and Yemen. The US EIA includes the 12 countries in IEA's definition, plus the Palestinian Territories. IEEJ and Shell expand further on the EIA definition of the Middle East and include Israel. In contrast, IEA counts Israel as part of OECD Asia Oceania. The US EIA includes Israel in OECD Europe.

Africa

All outlooks include a comprehensive "Africa" group, with the exception of OPEC, which provides a "Middle East and Africa" grouping that typically excludes OPEC members.

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 a number of government and private institutions. However, outlooks vary in a number of important methodological aspects, and comparing between outlooks is not straightforward. Without a way to clearly compare one outlook to the next, decision-makers may not understand the range of possibilities envisioned by different short-, medium- and long-term projections, or the assumptions that underpin those projections. This paper lays out a method for more accurate comparison of several major long-term energy outlooks, not to bury important differences in views about the future, but rather to control for varied conventions and historical data that mask true differences between the outlooks.

We find that there are important differences across outlooks in the chosen baseline years, assumed energy content of fossil fuels, the assumed efficiency of nuclear and renewable electricity conversion from primary energy, the categorization of biofuels, and the inclusion (or exclusion) of traditional biomass. The exclusion of non-marketed traditional biomass from US EIA and BP estimates, for instance, yields estimates of global primary energy consumption that are 9 percent lower than other outlooks, which include these sources. Assumptions about energy content of fossil fuels can vary by up to 12 percent in the data examined here, 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 65 percent decrease to a 3.8-fold increase for particular electricity sources, relative to IEA estimates.

After harmonizing these conventions to the extent practicable, we find a number of substantial differences between outlooks, including differences of up to 11 percent for primary energy consumption from major fossil sources between the IEA and other sources. After accounting for these differences in historical data, our harmonization methodology brings estimates within 3.3 percent or less of one another for major fuel sources in the 2017 benchmark year.

We conclude that undertaking 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 for the identification of common assumptions and data improvement, to the benefit of energy dialogue and energy decision making worldwide.

Glossary

Abbreviations and acronyms

ASEAN	Association of Southeast Asian Nations
BNEF	Bloomberg New Energy Finance
GCV	Gross Calorific Value
GDP	Gross Domestic Product
IEA	International Energy Agency
IEEJ	Institute for Energy and Economics, Japan
IEO	International Energy Outlook (US EIA)
NCV	Net Calorific Value
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
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
TJ	terajoules
mtoe	million metric tonnes of oil equivalent
TWh	terawatt-hours