RFF REPORT

Global Energy Outlooks Comparison Methods

2017 Update

Richard G. Newell and Stu Iler

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Abstract

We update a harmonization methodology previously developed in 2015 to facilitate comparisons of long-term global energy projections issued by the International Energy Agency, US Energy Information Administration, ExxonMobil, BP and the Organization of the Petroleum Exporting Countries. We continue to find important differences across outlooks in the primary energy units used, the 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 not) 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 10–16 percent lower than for IEA, ExxonMobil and OPEC, which include these sources. Assumptions about the energy content of fossil fuels can vary by 1–12 percent in the data we examined, requiring significant downward adjustment of primary energy consumption estimates for natural gas for BP and US EIA, as well as liquids for US EIA, to make them comparable to IEA and OPEC. Conventions about primary energy conversion of renewables can alter primary energy estimates for these sources, ranging from a 65 percent decrease to a 153 percent increase for particular power sources. 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 additional account of these differences in historical data, our harmonization methodology brings estimates within 2 percent or less of one another for most fuels in the 2014 benchmark year we examine. We conclude that undertaking a harmonization process such as the one we describe is necessary to provide an accurate benchmark for comparing results across outlooks. 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. Enhancing the comparability of different outlook scenarios developed yearly by the IEA, OPEC, industry and other key organizations will stimulate meaningful dialogue among stakeholders to the benefit of energy decisionmaking worldwide.

About the International Energy Forum

The International Energy Forum (IEF) (ief.org) aims to foster greater mutual understanding and awareness of common energy interests among its members. Covering all six continents and accounting for around 90 percent of global supply and demand for oil and gas, the IEF is unique in that it comprises not only consuming and producing countries of the IEA and OPEC, but also Transit States and major players outside of their memberships. The IEF is the neutral facilitator of informal, open, informed and continuing global energy dialogue.

About Resources for the Future

Resources for the Future (RFF) is an independent, nonpartisan organization that conducts rigorous economic research and analysis to help leaders make better decisions and craft smarter policies about energy, natural resources, and the environment. RFF was the first think tank devoted exclusively to natural resource and environmental issues and helped create the field of environmental and natural resource economics. Since 1952, it has provided decisionmakers with the tools to improve the way policy choices are made, strengthening both the environment and the economy.

About this Paper

This paper is one of several produced by Resources for the Future (previously by the Duke University Energy Initiative) in collaboration with the International Energy Forum. The paper updates Newell, R.G. and Qian, Y. 2015. Global Energy Outlooks Comparison: Methods and Challenges. Other papers produced in collaboration with IEF include the background papers for the fourth, fifth, sixth, and seventh IEA-IEF-OPEC Symposium on Energy Outlooks, and the paper Global Energy Outlook 2015, which compares and synthesizes the results of long-term energy outlooks by IEA, OPEC, US EIA, BP, ExxonMobil, and Shell.

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Global Energy Outlooks Comparison Methods: 2017 Update

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Overview

The global energy sector is changing rapidly. Population growth and economic development are driving up world energy demand. At the same time, technological advances are increasing energy efficiency, driving down costs for a variety of technologies, and making more unconventional energy resources economically viable. The results are rapidly changing global trends in energy production, consumption, and trade flows.

Energy outlooks are one way to understand this fast-changing energy world, 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 a number of 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, ExxonMobil, Shell). In recent years, other organizations such as the Russian and Chinese Academy of Sciences, 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 model assumptions and historical databases.

Due to the important role these outlooks play in informing decisions by market players and policymakers, a consistent method of presenting the information from these outlooks is quite valuable to help enable an inclusive and meaningful international energy dialogue. However, each organization uses different methodologies and assumptions, and comparing between and among different outlooks is not at all straightforward. 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.

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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 2014 data as a common baseline year:

- IEA: World Energy Outlook 2016 (WEO2016), published in November 2016.
- OPEC: World Oil Outlook 2016 (WOO2016), published in November 2016.
- US EIA: International Energy Outlook 2016 (IEO2016), published in May 2016.
- ExxonMobil: Outlook for Energy 2017, published in December 2016; Outlook for Energy 2016, published in January 2016.
- BP: Energy Outlook 2016, published in February 2016.

Each outlook discussed in this paper covers a wide range of topics, ranging from quantitative projections of energy consumption, supply, and carbon 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 is rather to control for differences in convention and data sources that in fact obfuscate an accurate assessment of underlying assumptions and judgments made about the short-, medium- and long-term in the 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. The 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.
- 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 a method for harmonizing world energy consumption among various outlooks and identifies the issue of remaining differences in historical baseline data, using 2010 as a benchmark year. Section 6 briefly discusses the differences in geographic groupings among these outlooks, and Section 7 provides a conclusion.

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 for transport, industry, and residential/commercial buildings (or “other” in the case of BP). 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 particular country or region is affected by its population, economic output, economic 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 data 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.

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[1] For example, as discussed below, the U.S. 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. Another example is regional fossil fuel data, which are usually reported in fuel-specifc volume units (e.g., tcf) or mass units (e.g., mbd), rather than in common energy units.

Table 1. Units of Energy Consumption Used in Different Outlooks

	IEA	BP	ExxonMobil	US EIA	OPEC
Primary energy units	mtoe	mtoe	qBtu	qBtu	mboed
Fuel/sector-specific units					
Liquids	mbd	mbd[1]	mboed[1]	mbd	mbd
Oil	mbd	mbd[1]	mboed[1]	mbd	mbd
Biofuels	mboed	mboed[1]	mboed[1]	mbd	mbd
Natural gas	bcm	bcfd[1]	bcfd[1]	tcf	mboed
Coal	mtce	btoe[1]	N.A.	short ton	mboed
Electricity	TWh	TWh[1]	TWh	TWh	N.A.

Note: Units are per year unless otherwise noted. mtoe is million metric tonnes of oil equivalent, qBtu is quadrillion British thermal units (Btu), mbd is million barrels per day, mboed is million barrels of oil equivalent per day, bcfd is billion cubic feet per day, tcf is trillion cubic feet, bcm is billion cubic meters, mtce is million tonnes of coal equivalent, btoe is billion metric tonnes of oil equivalent, 1 short ton is equivalent to 0.9072 metric tonnes, and TWh is terawatt hours. N.A. indicates that the source does not provide data in fuel-specific units. [1]Note that for BP and ExxonMobil, these data in mbd, mboed, bcfd, and btoe are only shown visually in figures, rather than in data tables.

As Table 1 shows, each outlook has a standard reporting unit for primary energy consumption. The IEA and BP use mtoe, the US EIA and ExxonMobil use qBtu, and OPEC uses mboed. 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 mtoe-to-qBtu conversion factor for the IEA and BP, and mboed-to-qBtu conversion factor for OPEC. According to international convention (see IEA[2] and US EIA[3]) 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.[4] 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).

After converting to a common energy unit, we still find a considerable difference in baseline data 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

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[2] IEA, *World Energy Outlook 2016* (Paris: OECD/IEA, 2016), p. 640.

[3] U.S. EIA, *Annual Energy Outlook 2016*, p. CP-5, footnote a.

[4] Internal communication with OPEC. To convert from mboed to mtoe per year for OPEC, multiply by 365 days per year, and then divide by the standard mtoe-to-mboe conversion factor 7.33. The result is 365 days/year ÷ 7.33 mboe/mtoe = 49.8 mtoe/mboed.

coal) to their original energy units. It is our understanding from experts at the US EIA, for example, 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 uses the lower heating value (or *net* calorific value). Other differences in convention appear to be implicit in the adjustments that we found necessary for BP relative to IEA data, but BP confirms that they employ net calorific values. To address this disparity in convention across organizations, 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 of the fuels.

First, identify energy content assumptions made by each organization. To do so, we obtain two sets of data from each outlook when available—one in energy units (i.e., qBtu, mtoe) 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 IEA and BP 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 so that they can be directly compared across the three 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 over time and across regions, but it is not possible for us to calculate a complete set of an outlook's factors for each fuel, each region and each year. We instead use an average of a near-term and long-term factor as an approximate estimate of an outlook's energy content assumption over time: in practice, the factors do not vary that much over time and the US EIA confirms that its energy content assumptions do not in fact vary over time.

Second, we derive an energy content adjustment factor for BP and US EIA by dividing the energy content factors for IEA by those of BP and US EIA. 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 OPEC or

ExxonMobil data for any differences in energy content assumptions, either because their assumptions are the same as IEA's or due to data limitations.[5]

For example, 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 IEA and BP, column (e) multiplies column (d) by 0.03968 qBtu/mtoe to create a qBtu/mbd conversion factor. For US EIA, column (d) divides (b) by (a) to create a qBtu/mbd conversion factor. For each institutional data source an average factor is calculated. Finally, the bottom of Table 2 shows the resulting energy content adjustment factors found by dividing the IEA qBtu/mbd factor by the BP and US EIA qBtu/mbd factors. Similarly, we derive energy content adjustment factors for natural gas (Table 3) and coal (Table 4) using the approach described above for Table 2.

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[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 quads 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.

Table 2. Liquids Energy Content Adjustment

Source	Year of data	Fuel-specific units	Primary energy units		Implied conversion factors for each outlook	
		mbd	qBtu (per year)	mtoe (per year)	mtoe/mbd	qBtu/mbd
		(a)	(b)	(c)	(d=c/a)	(e=d×0.03968 qBtu/mtoe)
BP[1]	2014	92	-	4211	45.77	1.816
	2035	112	-	5115	45.67	1.812
BP average					45.72	***1.814***
IEA[2]	2020	97.9	-	4569	46.67	1.852
	2040	107.7	-	4975	46.19	1.833
IEA average					46.43	***1.842***
						(e=b/a)
US EIA[3]	2011	89.1	180.3	-	-	2.025
	2035	114.6	233.2	-	-	2.035
US EIA average						***2.030***

Energy content adjustment factors for liquids

US EIA: 0.9076 = 1.842 qBtu/mbd ÷ 2.030 qBtu/mbd

BP: 1.015 = 1.842 qBtu/mbd ÷ 1.814 qBtu/mbd

Note: All data in the table are consumption data. [1]BP, Energy Outlook to 2035 (London: BP, 2016). [2]IEA, World Energy Outlook 2016 (Paris: OECD/IEA, 2016). Liquids consumption sums up oil and biofuels. Projected data are from the New Policies Scenario. [3]US EIA, International Energy Outlook 2016 (Washington, DC: US EIA, 2016). Projected data are from the Reference Case Scenario. Dashes indicate the data are not available from a particular source.

Table 3. Natural Gas Energy Content Adjustment

Source	Year of data	Fuel-specific units		Primary energy units		Implied conversion factors for each outlook	
		bcm (per year)	tcf (per year)	qBtu (per year)	mtoe (per year)	mtoe/tcf	qBtu/tcf
			(a)	(b)	(c)	(d=c/a)	(e=d×0.03968 qBtu/mtoe)
BP	2014[1]	3410	120.4[2]	-	3081	25.59	1.015
	2035[3]	-	172.6	-	4428	25.65	1.018
BP average						25.62	***1.017***
IEA[4]	2014	3502	123.7	-	2893	23.39	0.928
	2040	5219	184.3	-	4313	23.40	0.929
IEA average						23.40	***0.928***
							(e=b/a)
US EIA[5]	2011	-	117.1	121.6	-	-	1.038
	2035	-	185.2	192.5	-	-	1.039
US EIA average							***1.039***

Energy content adjustment factors for natural gas

US EIA: 0.8938 = 0.928 qBtu/tcf ÷ 1.039 qBtu/tcf
BP: 0.9133 = 0.928 qBtu/tcf ÷ 1.017 qBtu/tcf

Note: All data in the table are consumption data. [1]BP, Statistical Review of World Energy 2016 (London: BP, 2016). [2]Data converted from bcm to tcf by multiplying by a standard conversion factor of 0.0353147 tcf per bcm. [3]BP, *Energy Outlook to 2035* (London: BP, 2016). Data converted from bcfd to tcf per year by multiplying by 365 days/year and 0.001 tcf/bcf. [4]IEA, *World Energy Outlook 2016* (Paris: OECD/IEA, 2016). Projected data are from IEA WEO2016 New Policies Scenario. [5]US EIA, *International Energy Outlook 2016* (Washington, DC: US EIA, 2016). Projected data are from EIA IEO2013 Reference Case. Dashes indicate the data are not available from a particular source.

Table 4. Coal Energy Content Adjustment

Source	Year of data	Fuel-specific units		Primary energy units		Implied conversion factors for each outlook	
		million short tons (per year)	million metric tonnes (mt) (per year)	qBtu (per year)	mtoe (per year)	mtoe/mt	qBtu/mt
			(a)	(b)	(c)	(d=c/a)	(e=d×0.03968 qBtu/mtoe)
BP[1]	2015	-	7861	-	3830	0.4872	0.01933
	2014	-	8206	-	3989	0.4861	0.01929
BP average						0.4867	***0.01931***
IEA	2014[2]	-	7911	-	3926	0.4963	0.01969
	1990[2]	-	4639	-	2220	0.4787	0.01899
IEA average						0.4875	***0.01934***
							(e=b/a)
US EIA[3]	2012	8902	8076	153.3	-	-	0.01898
	2011	7839	7839	152.0	-	-	0.01939
US EIA average							***0.01918***

Energy content adjustment factors for coal

US EIA: 1.0083 = 0.01934 qBtu/mt ÷ 0.01918 qBtu/mt

BP: 1.002 = 0.01934 qBtu/mt ÷ 0.01931 qBtu/mt

Note: [1]Production data from BP, *Statistical Review of World Energy 2016* (London: BP, 2016). [2]Consumption data in mt from IEA, *Coal Information 2016* (Paris:OECD/IEA, 2016). Consumption data in mtoe from IEA, *World Energy Outlook 2016* (Paris:OECD/IEA, 2016). [3]Consumption data from US EIA, "Coal Consumption", *International Energy Statistics Database*. Accessed January 16, 2017. http://www.eia.gov/beta/international/data/browser/. EIA data converted from short tons to metric tonnes by multiplying by a factor of 0.9072 metric tonnes per short ton. Dashes indicate the data are not available from a particular source.

Table 5 summarizes the resulting energy content adjustment factors for the US EIA and BP for each major fuel. The factors differ moderately across fuels and between the US EIA and BP, and reveal differences in energy content assumptions for each fuel ranging from 1 percent to 12 percent. 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 overestimation of liquids and natural gas for the US EIA, and an overestimation of natural gas for BP, when compared to the IEA, OPEC and ExxonMobil. Note that this adjustment is only necessary for fossil fuels, whereas a different approach is necessary for addressing differences in the primary energy content of nuclear and renewable power (see section 3).

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

	Liquids	Natural gas	Coal
US EIA	0.9076	0.8938	1.0083
BP	1.015	0.9133	1.002

Note that determining a single "correct" adjustment factor for each fuel is not feasible because these factors are a summary metric of underlying assumptions about the energy content of different fuels, which varies 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 Different 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. To estimate primary energy for these sources, the standard approach is therefore to identify the amount of electricity generated from the source (i.e., secondary transformed energy), and divide this estimate by an assumed conversion efficiency rate.[6] The assumed conversion efficiency assumptions for nuclear and renewable power are, however,

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[6] In general, the efficiency rate of a power plant can be calculated by dividing the energy content of the electricity output (i.e., 3412 Btu per kWh) by the energy content of the fuel input. For nuclear and non-combustible renewable power, however, the energy content of the fuel input is not well defined.

inconsistent across outlooks (Table 6). We explain the rationale for each outlook's assumptions below.

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

Source	Nuclear	Hydro	Wind/Solar/Other	Geothermal	Biomass
IEA[1]	33%	100%	100%	15%	35%
ExxonMobil[2]	33%	100%	100%	10%	25%
OPEC[3]	33%	100%	100%	15%	35%
BP[4]	38%	38%	38%	38%	38%
US EIA[5]	33%	35%	35%	35%	36%

Sources: [1]IEA, World Energy Outlook 2015 (Paris:OECD/IEA, 2015); "Power Generation in the New Policies and 450 Scenarios", Accessed January 17, 2017, http://www.iea.org/media/weowebsite/energymodel/WEO_2011_PG_Assumptions_450_Scenario.xls. Note that we use the 35 percent IEA assumption for biomass power plants; [2]Internal communication with ExxonMobil; [3]Internal communication with OPEC; [4]BP, *Statistical Review of World Energy 2016* (London: BP, 2016); [5]Internal communication with US EIA.

IEA, OPEC, and ExxonMobil

The IEA and OPEC make the same conversion efficiency assumptions for a given nuclear or renewable electricity source. Because biomass is combustible (like fossil fuels), the two organizations use a conversion efficiency of 35 percent based on an average energy content of biomass. For nuclear power, they divide 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. The IEA and OPEC also take a similar approach for geothermal power, which involves the conversion of steam energy into electricity, albeit it at a lower efficiency rate (15 percent). For the remaining renewable power sources—hydro, wind, solar, and other (e.g., tidal)—the two organizations use the "captured energy" approach, which assumes the primary energy content is equal to the energy content of the produced electricity (i.e., 3412 Btu per kWh). That is, it is assumed no energy is lost in the conversion process so that the efficiency is 100 percent. ExxonMobil takes the same approach for nuclear and renewables as IEA and OPEC, except that it employs a roughly 25 percent conversion efficiency for biomass power and 10 percent for geothermal.

BP

BP assumes a general conversion efficiency factor of 38 percent (the average for OECD thermal power generation) for electricity generation from nuclear and renewable sources.[7] This assumption is based on the amount of energy required to generate an equal amount of electricity in a conventional fossil-fueled thermal power plant. This is called the “fossil-fuel equivalency” approach.[8]

US EIA

For nuclear power, the US EIA uses the same approach as the IEA, OPEC and ExxonMobil, with a conversion efficiency of roughly 33 percent (although the detailed EIA IEO modeling assumptions vary somewhat by region and over time).[9] The US EIA also uses the same approach as the IEA, OPEC and ExxonMobil for biomass, although the assumed conversion efficiency rate is somewhat higher (36 percent, versus the IEA’s assumed 35 percent).[10] For the remaining (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 (in contrast to BP’s assumption of 38 percent).

3.2. Adjusting Nuclear and Renewable Primary Energy for Comparability Across Outlooks

Due to these differences in assumed primary energy conversion efficiency, adjustments must be made to correctly compare projections across outlooks. This requires choosing a benchmark set of assumptions, for which we use the IEA’s conversion efficiencies.[11] Note that OPEC has already benchmarked to the IEA assumptions for nuclear and renewable conversion

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[7] BP, *Statistical Review of World Energy 2016*, p. 44.

[8] For an overview of alternative approaches to primary energy conversion for non-combustible sources, see IEA, “Frequently Asked Questions”, accessed January 18, 2017, http://www.iea.org/statistics/resources/questionnaires/faq/.

[9] U.S. EIA, *World Energy Projection System Plus Model Documentation 2011: World Electricity Model* (Washington, DC: U.S. EIA, 2011), accessed January 18, 2017, http://www.eia.gov/forecasts/archive/m078(2011).pdf. We obtained additional model assumptions not included in the report through internal communication with U.S. EIA.

[10] IEA, “Power Generation in the New Policies and 450 Scenarios”, accessed January 18, 2017, http://www.iea.org/media/weowebsite/energymodel/WEO_2011_PG_Assumptions_450_Scenario.xls.

[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.

efficiencies, so no adjustment is needed. The situation for ExxonMobil is similar, except for geothermal and biomass power: however, we do not adjust for these differences due to a lack of data.

As an example, when comparing primary energy consumption from nuclear sources between BP and the IEA, we must perform the following steps. 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.

4. Fuel Categorization

Another challenge arises from differing categorization of certain energy sources across outlooks. While the categorization for coal, natural gas, and nuclear energy is generally consistent across different outlooks, the categorization varies 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 and ExxonMobil distinguish biofuels from "oil", as the IEA includes them in the "bioenergy" category and ExxonMobil treats them as part of the "other renewables" category. For OPEC, biofuels are included in the "biomass" category in the primary energy projection table of WOO2016, but treated like crude oil as a liquids category in all other tables for liquids

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[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 U.S. EIA. A somewhat different approach is needed to convert the U.S. EIA figures on renewable power when using the standard published data because at this time the U.S. 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.

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 about 0.57 barrels of oil, and 1 barrel of biodiesel is equivalent to 0.88 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 WEO2016 estimates that about 1.6 mboed of biofuels was produced in 2015, the production level was about 2.3 mbd[14] in terms of actual physical volume (since IEA assumes biofuels have about 70 percent of the energy content of petroleum products on average).

4.2. Renewables Categorization and Non-Marketed Energy

Comparison of renewable energy consumption presents another challenge, in particular the different treatment of non-marketed renewable energy sources across outlooks. The US EIA and BP only include marketed renewables in their projections, whereas the IEA, OPEC and ExxonMobil also 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 result in large gaps in renewable energy consumption estimates among those outlooks, particularly related to traditional biomass.

In 2014, for example, non-marketed renewable energy totaled about 53 qBtu and comprised about 9 percent of global primary energy consumption and 70 percent of all renewable primary energy in the IEA, OPEC and ExxonMobil estimates (see Table 9). This can lead to very misleading comparisons across outlooks in terms of renewable energy consumption, total global energy consumption, and the shares of different energy sources in total energy. For example, for 2014 this difference resulted in overall global energy consumption for the IEA,

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[13] BP Statistical Review of World Energy 2016, p. 44.

[14] IEA, *Medium-Term Oil Market Report 2016*, pp. 77-78.

OPEC and ExxonMobil that is about 12 percent higher than US EIA and BP. Similarly, the total renewable share in IEA, OPEC and ExxonMobil estimates is 13–14 percent, whereas in US EIA and BP estimates it is only about 4 percent. This is almost entirely attributable to the inclusion (or not) of non-marketed energy, particularly non-marketed traditional biomass.

Renewables may also be grouped differently in different outlooks, and sometimes re-categorization is necessary for comparison purposes. Table 7 displays the different categories for which primary energy consumption of various renewable energy sources are reported in the outlooks. The implication is that we must aggregate non-hydro renewables in order to compare across all outlooks.

Table 7. Renewable Energy Categories in Different International Energy Outlooks

Outlook	Renewable energy categories
BP	Hydro; Other renewables (incl. wind, geothermal, solar and biomass/waste).
ExxonMobil	Biomass/waste (incl. non-marketed traditional biomass); Hydro; Other renewables (incl. biofuels). For electricity generation (in qBtu) renewable categories are: hydro, wind and other renewables.
IEA	Hydro; Bioenergy (incl. non-marketed traditional biomass and biofuels); Other renewables. For electricity generation (in TWh) renewable categories are: hydro, bioenergy, wind, geothermal, solar PV, CSP and marine.
OPEC	Hydro; Biomass (incl. non-marketed traditional biomass and biofuels); Other renewables (incl. wind, solar PV, solar thermal, and geothermal).
US EIA	Renewables included in “Other” for primary energy. For electricity generation (in TWh) renewable categories are: Hydro; Wind; Geothermal; Solar; and Other (incl. biomass, waste and tide/wave/ocean).

As shown in Table 7, the US EIA’s IEO2016 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 in Section 0, biofuels are treated differently across outlooks (also shown in Table 7). To make the data comparable across outlooks, we subtract biofuels from “bioenergy”, “biomass” and “other renewables” for the IEA, OPEC and ExxonMobil, respectively, and add these biofuels to liquids, alongside oil.

5. Outlook Harmonization and Historical Data Divergence

In this section, we describe a method for using the information from the prior sections to harmonize various outlook estimates of world total primary energy consumption. We undertake the methodology for 2014 data as an example, but it is deployable for any common projection year.

First, convert all primary energy consumption data to qBtu using the standard conversion factors of 0.03968 qBtu/mtoe (for IEA and BP) and 1.976 qBtu/mboed (for OPEC).

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 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.

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

	BP	US EIA	ExxonMobil	OPEC	IEA (benchmark)
Nuclear	1.15	1	1	1	1
Hydro	0.38	0.35	1	1	1
Wind/Solar/Other	0.38	0.35	1	1	1
Geothermal	2.53	2.33	1[2]	1	1
Biomass	1.09	1.03	1[2]	1	1
Non-hydro average	0.50[1]	N.A.	N.A.	N.A.	N.A.

Note: N.A. indicates the conversion is not applicable. [1]This factor is found by dividing BP's assumed primary energy conversion efficiency of 38 percent by an assumed average 75 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]Note that even though ExxonMobil's conversion efficiency assumption for geothermal and biomass power differs from IEA, we do not adjust due to a lack of data.

Fifth, adjust data to yield a uniform definition of liquids (incl. biofuels) and non-hydro renewables (excl. biofuels). In our approach, we subtract biofuels from renewables in the IEA and ExxonMobil outlook, and add the biofuels to the liquids category. The results are then comparable to the liquids data in EIA and BP's outlooks.

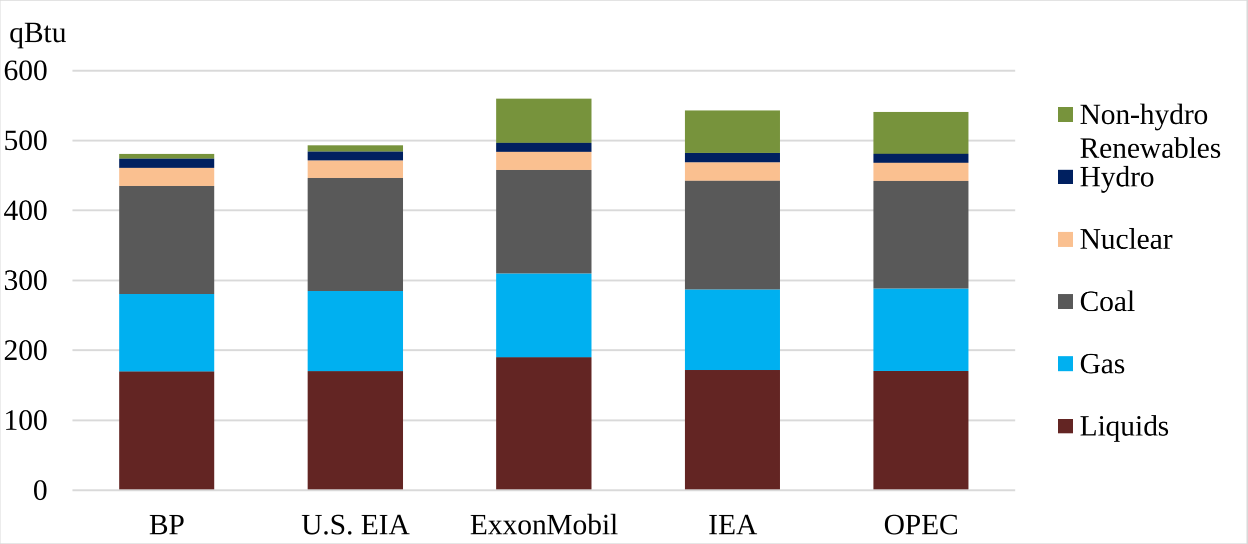
Table 9 and Figure 1 display the results of this calibration process. Other than the biofuels recategorization, ExxonMobil's data are not transformed because its energy consumption data were already presented in qBtu, most of its conversion efficiency assumptions are the same as the IEA's, (which we use as a benchmark), and we could not adjust for the other differences due to a lack of necessary data.

Table 9. Comparison of Outlook Primary Energy Consumption Data in 2014 (in qBtu)

	IEA	ExxonMobil	OPEC	BP	US EIA
Liquids	172	190	171	170	171
Oil (excl. biofuels)	169	187	168	167	168
Biofuels	2.9	3.0	2.7	2.9	3.0
Gas	115	120	118	111	114
Coal	156	148	154	154	162
Nuclear	26	26	26	26	25
Hydro	13	13	13	13	13
Non-hydro renewables (incl. non-marketed sources)	61	63	60	-	-
Non-hydro renewables (only marketed sources)	-	-	-	6	9
Total renewables (incl. non-marketed sources)	74	76	73	-	-
Total renewables (only marketed sources)	-	-	-	20	22
Total energy excluding non-hydro renewables	482	497	481	475	485
Total primary energy[1]	543	560	541	481	493

Note: Totals or subtotals may not sum due to rounding. [1] IEA, ExxonMobil, and OPEC totals are larger because they include non-marketed renewables, whereas US EIA and BP do not, as described in section 4.2. Dashes indicate the data are not available from a particular source.

Figure 1. Harmonized Outlook Primary Energy Consumption Data in 2014



Note: IEA, ExxonMobil and OPEC include non-marketed renewables, whereas BP and the US EIA do not.

The harmonization process adjusts for a significant amount of divergence that would otherwise exist in the outlooks, but it does not eliminate all discrepancies in historical consumption data. In particular, the divergence in fossil fuels consumption estimates is not negligible for some outlooks. For example, ExxonMobil has substantially higher estimates for oil and natural gas consumption, and a significantly lower estimate for coal consumption. It is our understanding from experts at ExxonMobil that the differences exist for four primary reasons: (1) IEA historical data that has evolved over time; (2) ExxonMobil includes flared gas in natural gas totals, whereas IEA omits flared gas; (3) ExxonMobil includes synthetic gas from coal in natural gas totals, whereas IEA includes it in coal totals; and (4) ExxonMobil and IEA may use different energy content assumptions for liquids, which we cannot control for due to a lack of data. The US EIA's estimate for coal is relatively high, whereas BP's estimate for natural gas is on the low side. ExxonMobil's estimate for non-hydro renewables is also atypically high, and the US EIA's estimate for nuclear is atypically low, although these divergences are not large in absolute terms.

Due primarily to their exclusion of non-marketed renewables, BP and the US EIA have far lower consumption estimates than the IEA, OPEC and ExxonMobil. After accounting for the exclusion of non-marketed renewables, the divergence across outlooks in total primary energy consumption is 3 percent or less. These discrepancies may be attributable to limitations in our derived conversion factors or other factors that cannot be harmonized in this paper, such as variances in original consumption data used by different institutions and unidentified differences in definitions of energy categories. Table 10 shows the percentage difference of 2014 primary energy consumption data in other outlooks relative to the IEA.

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 directly cited from the outlooks or from other publications or databases from the same organizations. ExxonMobil and OPEC are not included in Table 11 because they do not present data in fuel-specific units.

Table 10. 2014 Primary Energy Consumption Data Relative to IEA

	BP/IEA	ExxonMobil/IEA	EIA/IEA	OPEC/IEA
Liquids	-1.5%	10.3%	-1.0%	-0.8%
Oil (excl. biofuels)	-1.4%	10.5%	-1.0%	-0.7%
Biofuels	-2.7%	2.4%	1.7%	-8.0%
Gas	-3.2%	4.5%	-0.3%	2.6%
Coal	-1.0%	-5.0%	3.7%	-1.5%
Nuclear	-0.2%	-1.1%	-4.1%	-0.8%
Hydro	-0.3%	-2.2%	-3.3%	-1.9%
Non-hydro renewables (including non-marketed sources)	-	3.9%	-	-1.5%
Non-hydro renewables (only marketed sources)	-	-	-	-
Total renewables (including non-marketed sources)	-	2.8%	-	-1.5%
Total renewables (only marketed sources)	-	-	-	-
Total energy excluding non-hydro renewables	-1.6%	3.0%	0.5%	-0.2%
Total primary energy	-11.4%	3.1%	-9.1%	-0.4%

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

Table 11. Fuel-by-Fuel Comparison of Energy Consumption Data in 2014 (in Fuel-Specific Units)

	BP[1]	US EIA[2]	IEA
Liquids (mbd)	93	92	95
Oil (excl. biofuels) (mbd)	92	91	93[3]
Biofuels (mboed)	1.5	1.5	1.6
Gas (tcf)	120	123	124[4]
Coal (mt)	-	-	7911[5]
Nuclear (TWh)	2543	2504	2535[6]
Hydro (TWh)	3908	3764	3894[6]
Non-hydro renewables (including non-marketed sources) (TWh)	-	-	-
Non-hydro renewables (only marketed sources) (TWh)	1399	1347	-
Total renewables (including non-marketed sources) (TWh)	-	-	-
Total renewables (only marketed sources) (TWh)	5307	5111	-

Note: Units are per year unless otherwise noted. [1]BP, *"BP Statistical Review of World Energy June 2016"* (London: BP, 2016); [2]US EIA, *"International Energy Outlook 2016"* (Washington D.C: US EIA, 2016); [3]IEA, "World Oil Statistics", *IEA Oil Information Statistics Database* (Paris:OECD/IEA, 2016), doi: 10.1787/oil-data-en . [4]IEA, *Natural Gas Information 2016* (Paris:OECD/IEA, 2016). [5]IEA, *Coal Information 2016* (Paris:OECD/IEA, 2016). [6]IEA, World Energy Outlook 2016 (Paris:OECD/IEA, 2016). Dashes indicate the data are not available from a particular source.

Table 12 presents percentage differences relative to IEA data based on the fuel-specific data shown in Table 11. This table helps indicate the amount of discrepancy in Table 10 attributable to fuel-specific historical data, as opposed to other uncontrolled-for differences in energy content or energy conversion.

Table 12. 2014 Historical Data in Fuel-Specific Units Relative to IEA

	BP/IEA	EIA/IEA
Liquids	-2.0%	-2.8%
Oil (excl. biofuels)	-2.0%	-2.8%
Biofuels	-4.2%	-3.0%
Gas	-3.2%	-0.8%
Coal	-	-
Nuclear	0.3%	-1.2%
Hydro	0.4%	-3.3%

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

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. For biofuels the larger difference is easily attributable to rounding error due to the relatively small absolute magnitude of biofuels. There are also greater than one percent differences in oil (excluding biofuels) and nuclear. 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 13. Remaining Differences in 2014 Energy Consumption after Controlling for Differences in Historical Data and Primary Energy Conversion Efficiency Assumptions

	BP/IEA	EIA/IEA
Liquids	1%	2%
Oil (excl. biofuels)	1%	2%
Biofuels	2%	5%
Gas	0%	1%
Coal	-	-
Nuclear	-1%	-3%
Hydro	-1%	0%

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

6. Country Detail and Groupings Across Outlooks

In addition to comparing energy consumption at a global level, regional comparisons across outlooks are also often of interest. A challenge that arises, however, is that outlooks differ in the categorization of countries into regional groupings. Table 14 shows how outlooks vary in their choices for such regional groupings.

All outlooks present data for the Organization of Economic Cooperation and Development (OECD) and non-OECD nations. For data specific to geographic regions, there is no standard grouping 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 more consistent across outlooks, appropriate regrouping is necessary for Americas, Europe and Asia & Oceania. The US EIA, OPEC and the IEA continue to distinguish OECD nations within geographic areas, while BP and ExxonMobil 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. Note, however, that OPEC has disaggregated OPEC member countries into geographical regions in OPEC long-term liquids demand projections, allowing a more direct comparison with IEA. Below we summarize how BP and ExxonMobil differ from the US EIA and IEA’s OECD/Non-OECD system.

Americas

BP and ExxonMobil divide the continent into “North America” and “Central/South America” (or “Latin America”). The difference between “North America” and “OECD Americas” (used by the IEA and US EIA), as indicated by the definitions of these organizations, is that the former excludes Chile and the latter includes it. “OECD Americas” contains four countries: the United States, Canada, Mexico and Chile.

Europe

BP has two sub-regions here—“Europe/Eurasia” and “the Former Soviet Union” (FSU). BP’s definition for “Europe/Eurasia” is not the same as that for the “Non-OECD Europe/Eurasia” category in the IEA and US EIA outlooks. BP’s “Europe/Eurasia” category contains both OECD members and Non-OECD countries that are not included in the FSU. For ExxonMobil, “Europe” (including “East Europe” and “West Europe” by ExxonMobil’s definition) and “Russia/Caspian” are the two sub-regions that constitute the broad Europe region here. The IEA's "Caspian" category largely overlaps with BP's FSU and ExxonMobil's "Russia/Caspian" region, but none of these categories is exactly the same by definition.

Asia and Oceania

BP and ExxonMobil include all Asian and Oceania countries in one "Asia/Pacific" category, including both OECD and Non-OECD nations. Four countries are listed under OECD Asia/Oceania category by the IEA and US EIA: Japan, South Korea, Australia and New Zealand.

Specific Countries

At the national level, only three countries are presented in all four outlooks: the United States, China and India.

Table 14. Region Groupings and Country Detail Across Outlooks

Regions	BP	ExxonMobil	IEA	US EIA
OECD / Non-OECD	OECD Non-OECD	OECD Non-OECD	OECD Non-OECD	OECD Non-OECD
Americas	N. America Central/S. America[1]	N. America Latin America	OECD Americas Latin America	OECD Americas Central/S. America
Europe	Europe/Eurasia Former Soviet Union[2]	Europe Russia/Caspian	OECD Europe[3] Non-OECD Europe/Eurasia	OECD Europe[3] Non-OECD Europe/Eurasia
Asia & Oceania	Asia/Pacific	Asia/Pacific	OECD Asia/Oceania Non-OECD Asia	OECD Asia Non-OECD Asia
Africa	Africa	Africa	Africa	Africa
Middle East	Middle East	Middle East	Middle East	Middle East

Country-specific data	BP	ExxonMobil	IEA	US EIA
	United States[1]	United States	United States	United States
	China	China	China[4]	China
	India	India	India	India
		Russia/Caspian	Russia	Russia
			Japan	Japan
			Brazil South Africa	Brazil
				Mexico/Chile
				Australia/New Zealand
				Canada
				South Korea

Note: OPEC not included here because it only presents primary energy consumption at a global level. [1]BP excludes Puerto Rico from the US and includes it in Central/S. America. [2]Data for the Former Soviet Union are only provided for total consumption and production (with no breakdown by fuel or sector). [3]The US EIA and IEA include Israel in OECD Europe for statistical purpose. [4]The IEA includes Hong Kong in China, while the other outlooks separately count Hong Kong.

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, decisionmakers may not understand the range of possibilities envisioned by different short-, medium- and long-term projections, and what they depend upon. 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 conventions and historical data that mask true differences in outlook.

We find that there are important differences across outlooks in the 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 not) 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 10–16 percent lower than for the IEA, OPEC and ExxonMobil, which include these sources. Assumptions about energy content of fossil fuels can vary estimates by 1–12 percent in the data we examined, requiring significant downward adjustment of primary energy consumption estimates for natural gas for BP and US EIA, as well as liquids for US EIA to make them comparable to IEA, OPEC, and ExxonMobil. Conventions about primary energy conversion of renewables can alter primary energy estimates for these sources ranging from a 65 percent decrease to a 153 percent increase for particular power sources.

After harmonizing these conventions to the extent practicable, we find that at a global level ExxonMobil baseline estimates for liquids and—to a lesser extent—natural gas are substantially higher than other outlooks, and its estimate for coal is atypically low: the differences are primarily due to evolving historical data, the inclusion of flared gas and synthetic gas from coal in natural gas totals, and different energy content assumptions for liquids. The US EIA's estimate for coal is relatively high, whereas BP's estimate for natural gas is on the low side. ExxonMobil's estimate for non-hydro renewables is also atypically high, and the US EIA's estimate for nuclear is atypically low, although these divergences are not large in absolute terms. We also find that there are differences of up to 4 percent in historical data used in these outlooks, and that after we take additional account of these differences in historical data, our harmonization methodology brings estimates within 2 percent or less of one another for most fuels in the 2014 benchmark year we examine.

We conclude that undertaking a harmonization process like we describe is necessary in order 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 are still subject to 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

IEA	International Energy Agency
US EIA	US Energy Information Administration
OPEC	Organization of the Petroleum Exporting Countries
WEO	World Energy Outlook (IEA)
IEO	International Energy Outlook (US EIA)
GDP	Gross Domestic Product

Units

qBtu	quadrillion British thermal units (per year)
mtoe	million metric tonnes of oil equivalent (per year)
mbd	million barrels per day
mboed	million barrels of oil equivalent per day
bcfd	billion cubic feet per day
tcf	trillion cubic feet (per year)
bcm	billion cubic meters (per year)
mt	million metric tonnes of coal (per year)
TWh	terawatt-hours (per year)