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King Abdullah Petroleum Studies and Research Center

A Policymaker's Guide to the Various Ways of Calculating Energy Productivity

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Key Points

The existence of multiple approaches to calculating energy productivity, with its resulting diverse outcomes, makes it difficult to draw meaningful comparisons between economies and monitor their progress over time. To understand better the implications of this, we conducted a systematic in-depth survey of the various approaches.

Our analysis showed that calculated energy productivity could vary vastly depending on the assumptions used in the accounting of renewables, international marine bunkering and traditional biomass. We illustrate this divergence based on three of the most commonly used global energy databases.

When measuring gross domestic product, whether market or purchasing power parity (PPP) exchange rates are used will have an impact, especially on developing economies. The lack of timely PPP exchange rates adds to the complications. Furthermore, for large oil exporters, the way real GDP is measured can affect the evolution of their energy productivity.

We see a need for a greater degree of standardization in the energy economics community on the matters we have raised. Standardization, combined with a deeper understanding of the different ways of calculating energy productivity, should enable policymakers to design better energy and climate policies.

Summary

The energy productivity of an economy, defined as the ratio of gross domestic product (GDP) to primary energy consumption (PEC), appears to have a simple and unambiguous definition. This has propelled it to the top of a list of energy and environmental indicators commonly used by policymakers. Energy productivity and, its inverse, energy intensity are often used to gauge the average level of energy efficiency in an economy, to draw comparisons and to monitor an energy economy's progress over time. However, the existence of different approaches to measuring PEC and GDP makes it difficult to achieve these objectives.

This guide presents a detailed, systematic survey of the different possible approaches to measuring PEC and GDP, and its implications on the calculation of energy productivity. We refer to combinations of different measures of PEC and GDP as different 'versions' of energy productivity. The analysis in this guide focuses on five frequently used versions of energy productivity in academic and policy studies.

Three of the five versions of energy productivity differ through the database from which PEC data is obtained. The three databases are from BP, EIA and IEA. Our analysis shows that the different measures of PEC derived from each database can produce higher or lower levels of energy productivity, depending on the characteristics of the economy in question.

> For economies in which renewables account for a large share of PEC, the assumption used on the conversion losses incurred in the generation of renewable electricity has a large impact. The calculated level of energy productivity in such economies is revealed to be higher with the IEA database, which assumes that renewables incur no losses. For example, Norway's calculated energy productivity increases by 65 percent with a zero-loss assumption.

> For economies with large marine ports, excluding the fuel consumed by ships engaged in international navigation from PEC, as the IEA does, will result in relatively higher levels of energy productivity. In the extreme case of Singapore, for example, its energy productivity is higher by a factor of three when the energy used by ships that dock in Singapore and engage in international navigation is excluded.

> For economies in which large amounts of wood, charcoal and manure are consumed by rural sections of the population for cooking and heating, excluding such energy use from PEC, as BP and the EIA do, will produce a relatively higher level of energy productivity. Nigeria's energy productivity, for example, increases by a factor of six when this type of energy consumption is excluded.

Three of the five versions of energy productivity also differ through the exchange rate used to convert an economy's GDP from local currency units to US$. The results of our analysis show that:

> Developing economies enjoy relatively higher levels of energy productivity when purchasing power parity exchange rates are used to convert GDP into US$ instead of market exchange rates.

> Purchasing power parity exchange rates for developing economies are imprecise, and are prone to large revisions over time. This in turn results in large revisions to the version of energy productivity that rests on these exchange rates.

The approach used to measure PEC and GDP not only affects the level of energy productivity, which makes it difficult to draw meaningful comparisons between economies, but also the growth rate. Different measurement approaches may produce conflicting trends in energy productivity, potentially misleading policymakers. As such, there is a need for a greater degree of standardization in the energy economics community on the accounting of energy productivity.

Policymakers will benefit from a deeper understanding of the different ways of calculating energy productivity and intensity, especially when using these indicators to tackle energy and climate change issues. Moreover, this process would be easier if there were a standardized approach.

Introduction

Energy productivity is the ratio of monetary output to energy consumption. It can be measured at sectoral or economy wide levels. At the economy level, energy productivity is conventionally defined to be equal to gross domestic product (GDP) divided by primary energy consumption (PEC). It reflects how many dollars of GDP each unit of PEC can generate. Its reciprocal, energy intensity, reflects how many units of PEC are needed to generate each dollar of GDP.

It should be noted that energy consumption statistics either measure the consumption of energy that is directly extracted from natural resources (e.g., the consumption of crude oil and coal), or the consumption of energy after it is transformed through power plants or refineries (e.g., the consumption of gasoline and electricity). The former is known as PEC while the latter is termed final or secondary energy consumption. As mentioned above, we use PEC when calculating energy productivity in this guide.

Energy productivity and intensity are among the most commonly used indicators by energy and climate change policymakers. Such indicators are employed to monitor progress toward national energy policy objectives, such as mitigating climate change, improving energy security or maintaining oil export capacity. Policymakers also tend to use energy productivity and intensity as rough markers of the average level of energy efficiency in an economy, in order to make comparisons between economies. They are also used to set targets; for example, the United States of America (USA) has set a target to double national energy productivity by 2030 (DOE 2015), while China is working on reducing its energy intensity by 16 percent by 2015 relative to its level in 2010 (KPMG 2011).

It is not our intention to debate the merits of energy intensity versus energy productivity, since our argument in this guide is independent of which of the two is used. Although energy intensity is currently more widely used, it can be argued that energy productivity is more advantageous because of its positive connotation and ability to portray greater ambition (Bean 2012). A target to reduce energy intensity by 50 percent, for example, can be reformulated as a target to improve energy productivity by 100 percent; we therefore focus on energy productivity in this guide.

At a disaggregated sectoral level, energy productivity and intensity can generally be regarded as reasonable indicators of energy efficiency, allowing reliable comparisons to be made between the same sector in different economies (e.g., the energy productivity of steel manufacturing in Japan compared with China). However, at the economy level, energy productivity and intensity fail to capture the average level of energy efficiency in an economy (country). This stems from their sensitivity to factors other than efficiency, such as energy prices, geographical and climatic factors, the organization and structure of the economy, and culture (Filippini & Hunt 2015). In this guide, we aim to highlight how energy productivity is also sensitive to a deeper, and often overlooked, factor: the existence of different approaches to measuring PEC and GDP.

Policymakers may be surprised to find that energy productivity can be calculated in several different ways, stemming directly from the fact that its components, PEC and GDP, can be measured in several different ways (a fact well-known by energy analysts and economists). However, what is less well-known and has not been investigated in-depth are the implications of this.

This guide is therefore, to the best of our knowledge, the first attempt to survey systematically how different measures of PEC and GDP affect energy productivity across a large number of countries and the implications of such measurement uncertainties. Our work builds on Macknick's (2011) excellent summary of how the different approaches that are used to measure energy use can produce different estimates of global PEC (Macknick 2011). Additionally, Suehiro (2007) shows how different exchange rates can affect GDP, and thus energy intensity. In this guide, we cover how all of these factors, and several more in addition, affect energy productivity in a large number of countries.

How Different Versions of Energy Productivity Affect Static Comparisons

Different combinations of different measures of PEC and GDP produce different levels of energy productivity. In this guide, we consider three different measures of PEC and three different measures of GDP, which generates nine possible energy productivity combinations. However, for the sake of brevity and clarity, we restrict the analysis to five possible combinations, or, as we refer to them in this guide, versions of energy productivity (see Table 1). In Versions A, B and C of energy productivity, GDP is measured in the same way while PEC is measured in three different ways. In Versions C, D and E of energy productivity, GDP is measured in three different ways while PEC is measured in the same way.

The three different measures of PEC are derived from three different databases: BP (2015), the EIA (2016) and the IEA (2015). Therefore, the three different measures of PEC not only reflect differences in the way PEC can be measured, which the analysis focuses on, but also differences in the source of raw data. On the other hand, the three different measures of GDP are all obtained from the same database, which is the World Bank (2015). This eliminates the problem of differences in raw data, thus placing the focus on the different ways GDP can be measured.

Table 1. The different versions of energy productivity

	Energy productivity (Version A)	**Energy productivity (Version B)**	**Energy productivity (Version C)**	**Energy productivity (Version D)**	**Energy productivity (Version E)**
Numerator (GDP)	GDP in market exchange rates from the World Bank	GDP in market exchange rates from the World Bank	GDP in market exchange rates from the World Bank	GDP in purchasing power parity exchange rates from the World Bank using results from ICP 2011	GDP in purchasing power parity exchange rates from the World Bank using results from ICP 2005
Denominator (PEC)	PEC from BP Statistical Review	PEC from EIA Primary Energy Statistics	PEC from IEA World Energy Balances	PEC from IEA World Energy Balances	PEC from IEA World Energy Balances

As mentioned, analysts and policymakers often use energy productivity for benchmarking energy efficiency across different countries. For example, Singapore and the United Arab Emirates (UAE) are both small economies with large petrochemical industries; how do their energy productivities compare? Such comparisons are often made with only one version of energy productivity, and it is often assumed that there is only one possible outcome for the comparison. However, as demonstrated in the following subsections, different versions of energy productivity can produce dramatically different outcomes for such comparisons.

The Effect of the Different Ways of Measuring PEC

The BP, EIA and IEA databases are arguably the most widely used sources of PEC statistics in energy economic studies. However, because of differences in how each organization measures PEC, comparisons of energy productivity between economies can be altered considerably by the choice of database (see Table 2, where Version A, B and C differ through the database from which PEC data were collected).

Many factors contribute to the differences in the estimates of PEC between the three databases (Macknick 2011). Differences in the sources of raw data are a major factor. Moreover, differences in the following assumptions can all give rise to large differences in the estimates of PEC:

- The energy losses incurred by renewables.
- The fuel used by ships engaged in international navigation.
- The use of traditional biomass (i.e., wood, charcoal and manure) for energy.
- The type of calorific value used.

These four ‘controllable’ factors reflect decisions, made by the different institutions that supply the data, about how PEC should be measured, rather than uncertainties in the underlying data. In the following subsections, we survey systematically the impact of each of these four factors on PEC at a country level, and on energy productivity comparisons between countries.

Losses Incurred in Generating Renewable Electricity

The first key difference between the three databases rests on the assumption about the losses incurred in generating renewable electricity (Macknick 2011). In the case of fossil fuels, three joules of natural gas, for example, are typically needed to generate one joule of electricity through a thermal power plant. In the case of renewable electricity, which is not produced in a thermal power plant, there are no thermal conversion losses. Because of this, the IEA counts one joule of renewable electricity as one joule in PEC. In contrast, BP and the EIA follow a different accounting approach. Both count one joule of renewable electricity as roughly three joules in PEC by assuming that renewable electricity incurs the same conversion losses as fossil fuel-driven power plants. This accounting method is known as the fossil fuel equivalency approach (EIA 2011).

The assumption made about the losses incurred in generating renewable electricity can have a large impact on the measured level of energy productivity, particularly for countries where renewables account for a large share of the energy mix (see Table 3 for the top 20 countries).

Table 2. A comparison between energy productivity Version A, B and C in 2012. The difference lies in the database from which the PEC data were obtained. Units: thousand US$ per toe.

Country	Energy Productivity Version A	Energy Intensity Version B	Energy Productivity Version C
Algeria	4.5	3.6	4.4
Australia	12.1	10.2	12.1
Austria	11.5	10.8	12.3
Azerbaijan	5.6	4.6	5.0
Bangladesh	5.2	4.8	4.0
Belarus	2.3	2.1	2.1
Belgium	8.4	7.6	9.2
Brazil	8.7	7.9	8.6
Bulgaria	2.9	2.8	2.9
Canada	5.6	5.4	7.3
Chile	7.9	7.4	7.1
China	3.0	3.2	3.0
Hong Kong	9.6	8.6	18.4
Colombia	9.9	9.5	11.7
Czech Republic	4.9	5.2	4.9
Denmark	18.7	17.3	18.6
Ecuador	6.1	5.4	6.0
Egypt	3.0	2.9	3.4
Ethiopia	…	10.0	1.0
Finland	9.3	8.3	7.6
France	11.0	9.9	10.6
Germany	11.1	10.4	11.3
Greece	8.5	8.1	9.4
Hungary	5.8	5.3	5.4
India	3.2	3.0	2.4
Indonesia	5.4	5.7	4.3
Iran	2.3	2.3	2.5
Israel	10.4	9.8	10.6
Italy	12.7	11.5	12.9
Japan	12.6	11.6	13.2
Kazakhstan	3.5	2.9	2.8
Kuwait	4.6	4.4	5.0
Lithuania	6.9	5.5	5.8
Malaysia	3.7	3.9	3.9

Country	Energy Productivity Version A	Energy Intensity Version B	Energy Productivity Version C
Mexico	6.3	6.1	6.3
Netherlands	9.3	8.1	10.5
New Zealand	8.9	8.1	9.0
Nigeria	…	20.2	3.4
Norway	10.6	10.4	17.2
Pakistan	3.2	3.4	2.6
Peru	8.9	7.0	8.9
Philippines	8.1	7.6	5.8
Poland	5.0	5.0	5.1
Portugal	9.6	8.8	10.0
Qatar	4.2	4.2	5.0
Ireland	15.7	15.1	16.9
Romania	4.8	4.6	4.8
Russia	2.9	2.5	2.7
Saudi Arabia	3.3	3.1	3.7
Singapore	4.0	3.7	11.1
Slovakia	5.7	5.3	5.6
South Africa	3.2	2.8	2.8
South Korea	4.5	4.2	4.6
Spain	9.6	8.9	10.8
Sweden	10.0	9.8	10.8
Switzerland	22.9	20.7	26.0
Thailand	3.1	2.8	2.9
Trinidad & Tobago	1.1	1.0	1.2
Turkey	6.4	6.2	6.7
Turkmenistan	1.2	1.2	1.4
Ukraine	1.4	1.4	1.4
United Arab Emirates	3.9	3.9	5.5
United Kingdom	13.0	12.0	13.6
USA	7.3	6.7	7.6
Uzbekistan	1.0	0.9	1.1
Venezuela	4.6	4.5	5.2
Vietnam	3.0	2.7	2.6
World	5.9	5.6	5.6

Source: BP, EIA, IEA, World Bank and KAPSARC analysis.

Table 3. The top 20 consumers of renewable energy as a share of PEC. The USA is included as the 21st country in this list for comparison purposes only.

Country	Total renewable energy consumption (Mtoe)	Total renewable energy consumption as a % of PEC
Paraguay	5.2	104%
Iceland	5.1	90%
Tajikistan	1.5	64%
Norway	12.3	42%
Costa Rica	1.8	39%
El Salvador	1.5	34%
New Zealand	6.0	31%
Kyrgyzstan	1.2	29%
Philippines	9.7	23%
Albania	0.4	21%
Georgia	0.6	17%
Nicaragua	0.5	16%
Sweden	7.4	15%
Switzerland	3.7	14%
Canada	33.7	13%
Brazil	36.7	13%
Colombia	4.1	13%
Austria	4.2	13%
Mozambique	1.3	12%
Montenegro	0.1	12%
USA	47.3	2%

Source: IEA, KAPSARC analysis.

The larger the share of renewables in the energy mix, the greater the differences between the three versions of energy productivity.

Figure 1 highlights how energy productivity changes depending on how the losses incurred by renewables are measured, focusing on six countries in which renewables account for a large share of the energy mix. Given their heavy dependence on hydroelectricity, Canada and Norway are good examples of how this assumption influences energy productivity in economies with a large share of renewables in their energy mix. Because the IEA does not include any losses in the generation of renewable electricity when calculating PEC, energy productivity Version C in Canada and Norway is higher by 33 percent and 65 percent, respectively. As renewables grow to account for an increasing share of the energy mix over the next few decades, this difference between the three versions of energy productivity will grow even wider.

Energy Consumed by International Marine Bunkering

A second key difference between the three databases lies in whether the boundaries of PEC include or exclude the fuel consumed by international marine bunkers (Macknick 2011).

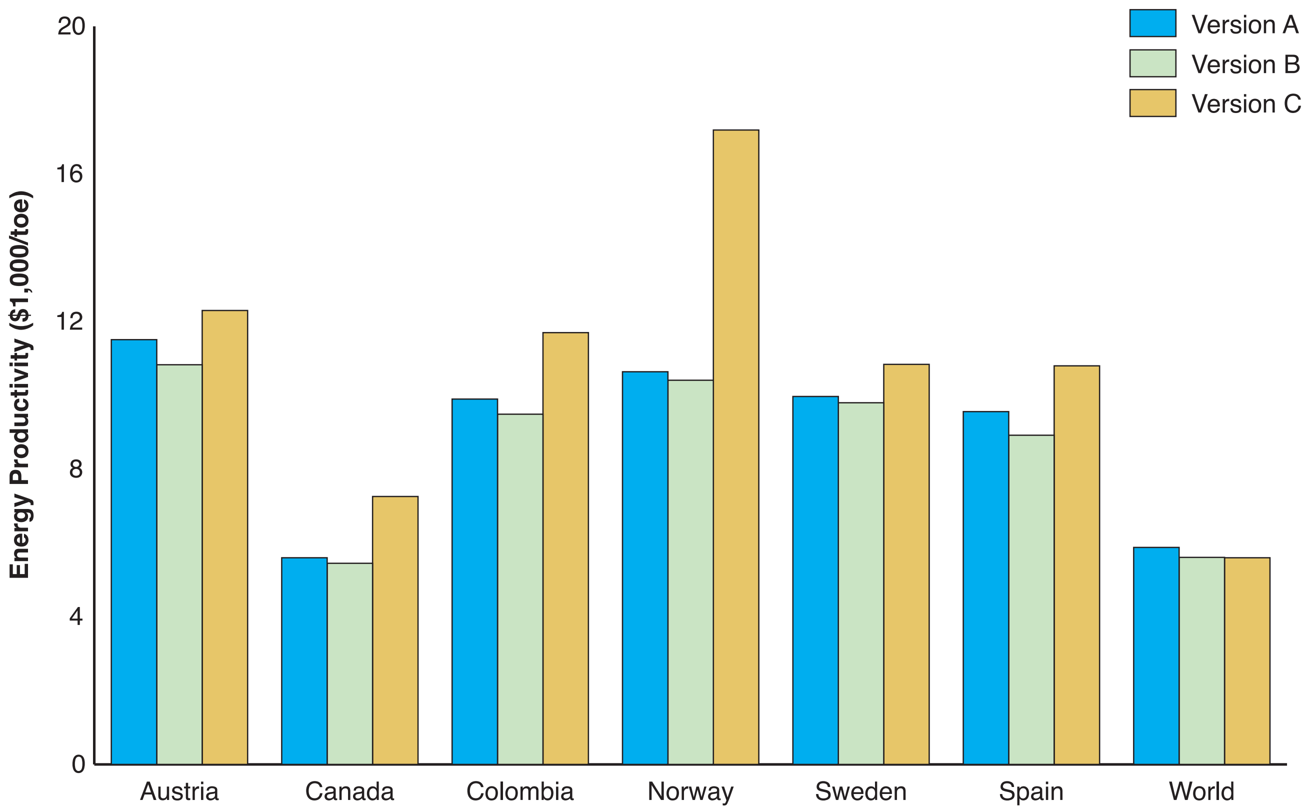


Figure 1. A comparison between three versions of energy productivity across six countries in which renewables account for a large share of energy consumption. The values are shown for the year 2012.

Source: BP, EIA, IEA, World Bank and KAPSARC analysis.

Consumption of fuel for international marine bunkering covers the fuel sold to ships engaged in international navigation. Similarly, the consumption of fuel for international aviation bunkering covers the fuel sold to airplanes engaged in international flights. The IEA excludes the energy consumed by international marine and aviation bunkers from a country's PEC while BP and the EIA include it.

Including or excluding the energy consumed for international marine bunkering can have a large impact on an economy's energy productivity. For example, Singapore, despite its smaller size, consumed roughly three times as much energy for international marine bunkering as the USA (see Table 4 for the top 20 countries). The larger the share of international marine bunkering in PEC, the greater the difference between Versions A and B and Version C.

It has been observed that Singapore's energy intensity exhibits large variation depending on which international database is used to measure PEC (Ministry of Trade and Industry 2006). This variation arises because of Singapore's position as a major global marine bunkering center. Figure 2 highlights the effect of international marine bunkering on the energy productivity of six countries in which it accounts for a large share of PEC. The energy productivity of all the countries in Figure 2 is higher when Version C is used because of the exclusion of marine and aviation bunkering (between the two, international marine bunkering is the more important factor). In particular, Singapore and the UAE, with their extremely busy ports, are 200 percent and 40 percent more energy productive, respectively, under Version C.

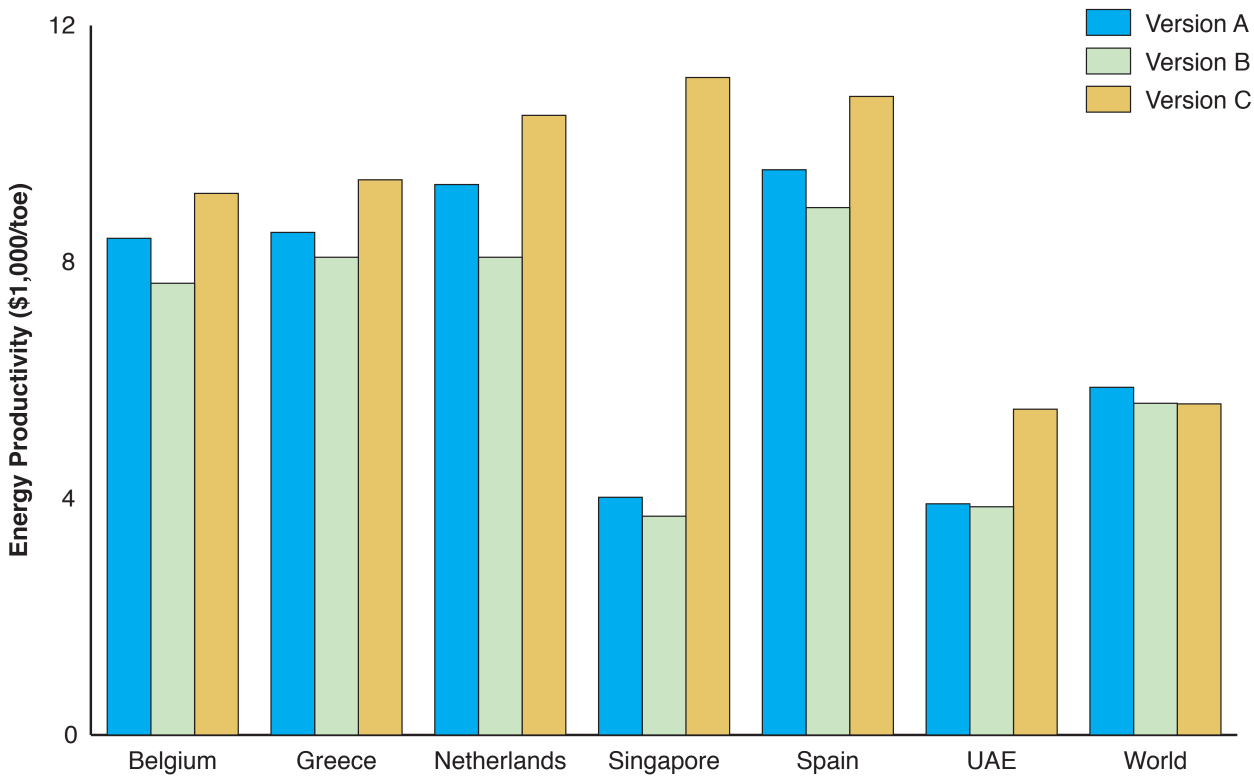


Figure 2. A comparison between three versions of energy productivity across six countries in which international marine bunkering accounts for a large share of energy consumption. The values are shown for the year 2012.

Source: BP, EIA, IEA, World Bank and KAPSARC analysis.

Table 4. The top 20 consumers of energy for international marine bunkering as a share of PEC. The USA is included as the 21st country in this list for comparison purposes only.

Country	Energy consumption for international marine bunkering (Mtoe)	Energy consumption for international marine bunkering as a % of PEC
Gibraltar	4.1	2,408%
Singapore	41.1	158%
Malta	1.2	136%
Panama	3.3	79%
Curacao	1.6	78%
Hong Kong, China	8.3	58%
United Arab Emirates	14.2	21%
Mauritius	0.3	20%
Netherlands	13.4	17%
Belgium	6.0	11%
Gabon	0.2	9%
Cyprus	0.2	9%
Greece	2.2	8%
Estonia	0.4	7%
Uruguay	0.3	7%
Spain	8.3	7%
Latvia	0.2	5%
Syrian Arab Republic	0.7	5%
Colombia	1.2	4%
Ecuador	0.5	4%
USA	15.4	1%

Source: IEA, KAPSARC analysis.

Consumption of Traditional Biomass

A third key difference between the three databases revolves around the wood, charcoal and manure that is consumed by the rural sector (Macknick 2011). Estimates of such consumption suffer from a high degree of uncertainty because wood, charcoal and manure are typically extracted, traded and consumed in rural areas that cannot be easily monitored. The IEA database accounts for such consumption (which they refer to as solid biofuel) within its estimates of PEC. In contrast, it is excluded from the BP and EIA estimates.

Accounting for the rural consumption of wood, charcoal and manure can have a drastic effect on the calculated level of energy productivity in countries where large segments of the population live in rural areas (see Table 5 for the top 20 countries). Figure 3 highlights the effect of accounting for the consumption of traditional biomass on the energy productivity of six economies in which it accounts for a large share of PEC. In Ethiopia and Nigeria, where most of the energy consumed is in the form of traditional biomass, excluding the use of such energy from PEC results in energy productivities that are higher by a factor of 10 and 6, respectively.

The Different Types of Conversion Factors

The fourth key difference between the three databases lies in the calorific value that is used to convert physical quantities of fuel into energy quantities (Macknick 2011).

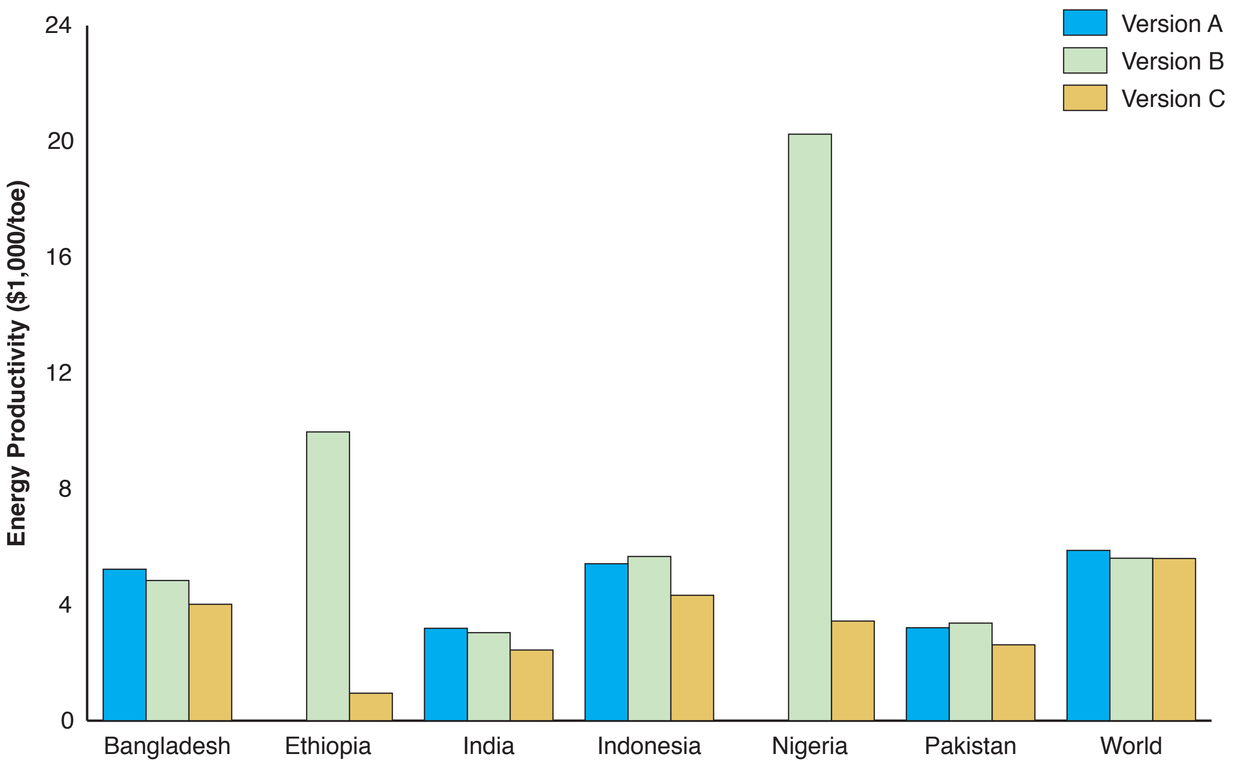


Figure 3. A comparison between three versions of energy productivity across six countries in which traditional biomass accounts for a large share of energy consumption. The values are shown for the year 2012.

Source: BP, EIA, IEA, World Bank and KAPSARC analysis.

Table 5. The top 20 consumers of solid biofuels as a share of PEC. The USA is included as the 21st country in this list for comparison purposes only.

Country	Consumption of solid biofuels for energy (Mtoe)	Consumption of solid biofuels as a % of PEC
Ethiopia	42.4	94%
DR Congo	19.0	93%
Tanzania	19.4	86%
Haiti	3.3	81%
Nigeria	108.1	81%
Mozambique	8.4	80%
Togo	2.5	80%
Nepal	8.0	80%
Zambia	7.2	79%
Eritrea	0.6	78%
Côte d'Ivoire	9.4	75%
Kenya	15.1	74%
Myanmar	10.7	69%
Niger	1.5	68%
Cambodia	3.9	67%
Cameroon	4.7	67%
Guatemala	7.1	64%
Sudan	9.0	63%
Zimbabwe	6.8	62%
Congo	1.4	60%
USA	44.6	2%

Source: IEA, KAPSARC analysis.

Most of the underlying data are collected in physical units, such as tonnes of coal or cubic meters of natural gas. These need to be converted into energy units, such as joules or tonnes of oil equivalents. This is done with a calorific value, which is a measure of the energy released per unit of mass or volume of fossil fuel when that fuel is burned completely (IEA 2005). For any given fuel, there are two measures of calorific value: gross and net calorific value. The two measures differ through the assumption about the energy that is consumed in the vaporization of the water that is present in a fossil fuel. As noted by Macknick (2011), the EIA uses gross calorific value, the IEA uses net calorific value and BP a mixture of the two. The choice of calorific value contributes to the differences in PEC.

The Effect of the Different Ways of Measuring GDP

GDP measures the monetary value of all final goods and services produced in an economy over a specified period. It is conventionally measured in a country's local currency. Saudi Arabia's GDP, for example, is measured in Saudi Arabian Riyals (SARs) while the USA's GDP is measured in US$. In order to compare the GDP of the two countries, the values must be converted into a common currency, usually the US$. The conversion tends to be carried out using the prevailing market exchange rate (MER) in that year. For Saudi Arabia, the MER is pegged at 3.75 zSAR to one US$, while many other countries have floating exchange rates that change every year. Other exchange rates can be used to convert GDP into a common currency and the choice of exchange rate can have a large impact on a country's level of energy productivity (see Table 6, where Versions C, D and E differ through the exchange rate used).

Market and purchasing power parity exchange rates

The purchasing power parity (PPP) exchange rate is also frequently used. Continuing with the Saudi example, the PPP exchange rate reflects the number of SARs needed to purchase the same amount of goods and services in Saudi Arabia that would have been purchased in the USA with a single US$. In 2012 for example, only 1.88 SARs were needed to buy the same amount of goods and services that could be purchased in the USA with a single US$. This large difference (3.75 to 1.88) between the MER for Saudi Arabia and its PPP exchange rate is common for developing economies. As a result, GDP in developing economies, and consequently, their calculated energy productivity, strongly depends on the choice of exchange rate. In contrast, most developed economies have similar market and PPP exchange rates, and so their energy productivity is less sensitive to the choice of exchange rate.

Figure 4 shows how the level of energy productivity in a selected group of economies changes with the exchange rate. All the developing economies in Figure 4 had a lower energy productivity than USA when Version C was used. However, Version D revealed most developing economies to enjoy an energy productivity equal to or higher than USA. Although the choice of exchange rate is an elementary topic, it remains very pertinent, since it can have a drastic effect on some countries' energy productivity.

Table 6. A comparison between energy productivity Version C, D and E. The difference lies in the exchange rate that is used to convert GDP from local currency units into US$. Units: thousand US$ per toe.

Country	Energy Productivity Version C	Energy Intensity Version D	Energy Productivity Version E
Algeria	4.4	10.9	7.1
Australia	12.1	7.7	8.0
Austria	12.3	11.4	11.2
Azerbaijan	5.0	11.0	6.9
Bangladesh	4.0	12.9	8.6
Belarus	2.1	5.3	4.8
Belgium	9.2	8.5	8.1
Brazil	8.6	10.9	8.3
Bulgaria	2.9	6.2	6.4
Canada	7.3	5.8	5.9
Chile	7.1	9.9	10.5
China	3.0	5.4	4.4
Hong Kong	18.4	25.7	25.6
Colombia	11.7	17.9	15.8
Czech Republic	4.9	7.1	6.6
Denmark	18.6	14.1	13.6
Ecuador	6.0	11.1	10.3
Egypt	3.4	11.2	6.8
Ethiopia	1.0	2.6	2.2
Finland	7.6	6.4	6.1
France	10.6	9.7	9.4
Germany	11.3	11.2	10.8
Greece	9.4	10.6	10.8
Hungary	5.4	9.5	9.3
India	2.4	8.3	6.3
Indonesia	4.3	11.1	5.7
Iran	2.5	5.7	…
Israel	10.6	10.3	10.4
Italy	12.9	13.1	12.5
Ireland	16.9	15.8	15.2
Japan	13.2	10.0	9.9
Kazakhstan	2.8	5.0	3.1
Kuwait	5.0	7.8	…

Country	Energy Productivity Version C	Energy Intensity Version D	Energy Productivity Version E
Lithuania	5.8	9.8	9.9
Malaysia	3.9	8.3	6.3
Mexico	6.3	10.4	10.7
Netherlands	10.5	9.8	9.2
New Zealand	9.0	7.5	7.4
Nigeria	3.4	6.8	3.4
Norway	17.2	11.2	11.1
Pakistan	2.6	9.2	5.7
Peru	8.9	15.4	15.0
Philippines	5.8	13.7	9.7
Poland	5.1	9.0	8.7
Portugal	10.0	13.1	12.3
Qatar	5.0	7.2	4.4
Romania	4.8	10.4	10.4
Russia	2.7	4.7	4.6
Saudi Arabia	3.7	7.3	4.4
Singapore	11.1	15.7	12.4
Slovakia	5.6	8.3	8.2
South Africa	2.8	4.7	4.1
South Korea	4.6	6.1	5.8
Spain	10.8	12.2	11.8
Sweden	10.8	8.3	8.2
Switzerland	26.0	17.5	16.6
Thailand	2.9	7.3	5.1
Trinidad & Tobago	1.2	2.1	1.8
Turkey	6.7	11.5	11.6
Turkmenistan	1.4	2.6	2.1
Ukraine	1.4	3.2	2.7
United Arab Emirates	5.5	7.9	5.6
United Kingdom	13.6	12.3	12.3
USA	7.6	7.6	7.6
Uzbekistan	1.1	2.9	2.2
Venezuela	5.2	7.4	5.4
Vietnam	2.6	7.4	5.6
World	5.6	7.5	6.5

Source: IEA, World Bank and KAPSARC analysis.

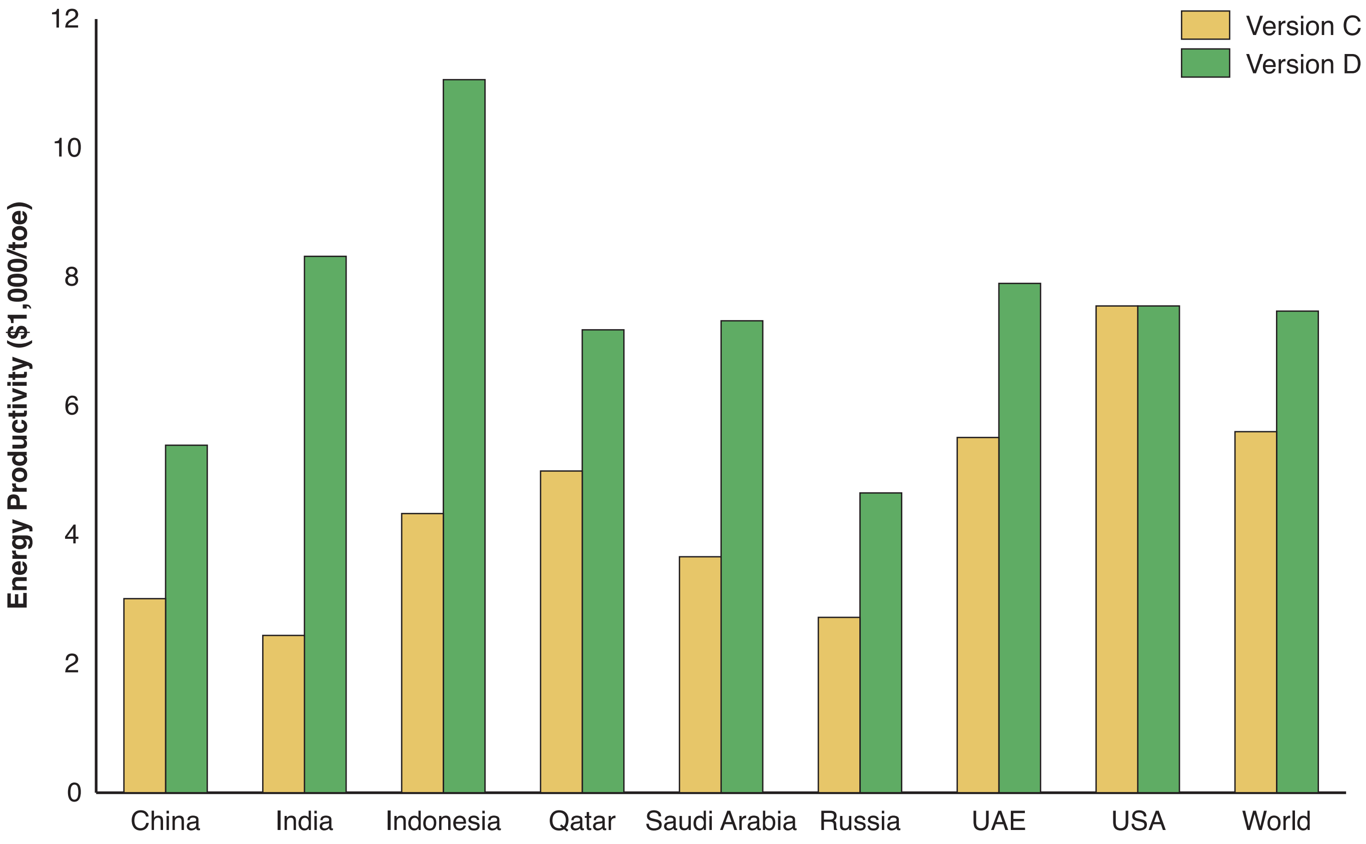


Figure 4. A comparison between Versions C and D of energy productivity across nine economies. The values are shown for the year 2012.

Source: IEA, World Bank and KAPSARC analysis.

Infrequent Revisions to Purchasing Power Parity Exchange Rates

A further complication arises from the use of GDP converted with PPP exchange rates (hereafter PPP GDP). In order to estimate PPP exchange rates, the International Comparison Program (ICP) collects thousands of prices across more than 100 countries (McCarthy 2011). Given the size of such an undertaking, it is only carried out in rounds every few years. The most recent release of PPP exchange rates comes from the 2011 ICP round, which follows the 2005 ICP round.

Prior to the publication of the 2011 ICP results in April 2014, PPP exchange rates were estimated and extrapolated using data from the 2005 ICP round (McCarthy 2011). Following the publication of the results from the 2011 ICP round, researchers found striking differences between the PPP exchange rates derived from each round, particularly for developing economies. This was due to a change in methodology and errors in extrapolation.

In general, the 2011 ICP round revealed that developing economies were substantially larger (in GDP terms) than previous calculations showed. This conspicuous difference has even led some researchers to question whether the new PPP rates were an improvement (Deaton & Aten 2014).

That estimates of PPP exchange rates can change so drastically from round to round highlights the large uncertainties in PPP GDP. This carries implications for energy productivity comparisons that depend on PPP estimates. Prior to the publication of the results from the 2011 ICP round, Saudi Arabia's PPP GDP was estimated at $883 billion in 2012. This value was estimated from data collected during the 2005 ICP round. Following the release of the 2011 ICP data, Saudi Arabia's PPP GDP for 2012 was revised to $1,466 billion. This 66 percent increase suggests a correspondingly large increase in Saudi Arabia's energy productivity for that year. Such sweeping revisions make it difficult, if not impossible, for policymakers in developing economies to benchmark their country's relative energy efficiency using energy productivity. In the case of Saudi Arabia, the 2005 ICP round gave the impression that it was an economy with very low energy productivity, while the 2011 ICP round suggests that Saudi Arabia was as energy productive as the world average. The U.K. presents a contrasting case: its PPP GDP for 2012, estimated using PPP rates derived from each ICP round, differed by a mere 1 percent, suggesting that PPP estimates in developed economies are less prone to sweeping revisions.

Figure 5 demonstrates the impact of revisions to PPP GDP on energy productivity by focusing on a number of developing economies. All the economies shown in Figure 5 appeared to be less energy productive than USA using PPP exchange rates from the 2005 ICP round. Switching to PPP exchange rates from the 2011 ICP round revealed many of them to be as or even more energy productive than USA. Since USA is the 'base' country, its PPP GDP does not change across the two rounds.

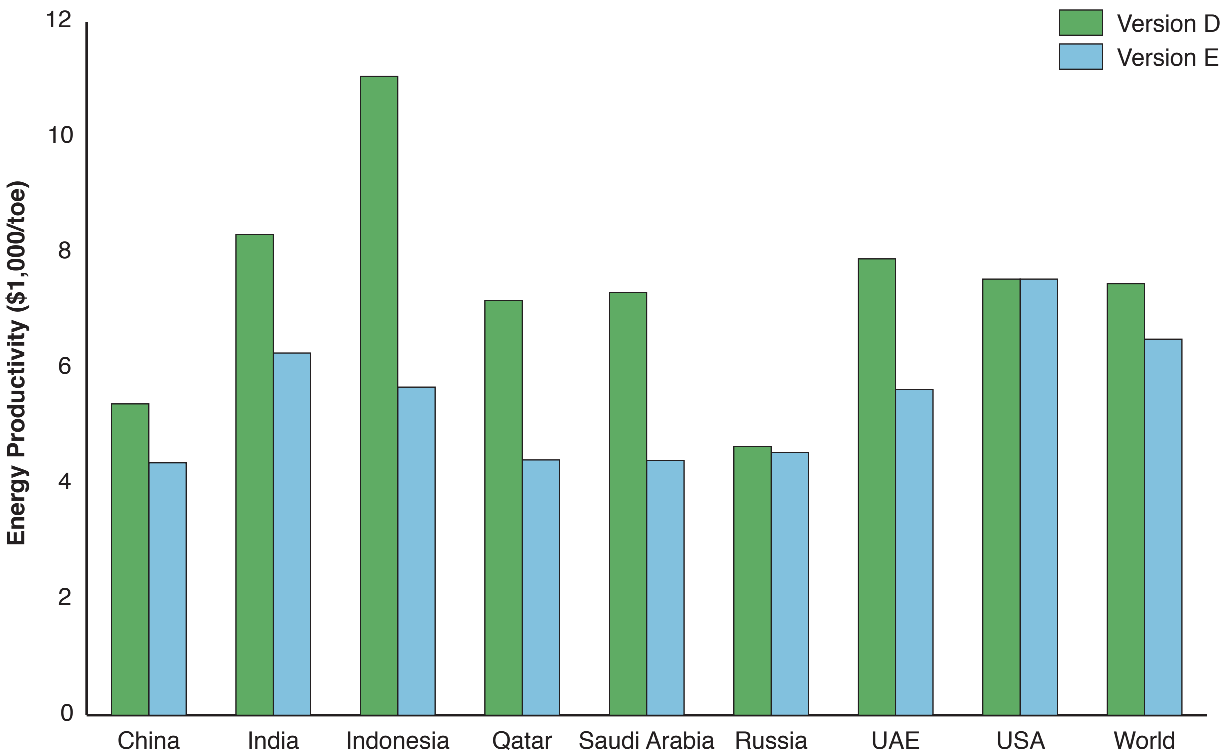


Figure 5. A comparison between Versions D and E of energy productivity across nine economies. The values are shown for the year 2012.

Source: IEA, World Bank and KAPSARC analysis.

How the Different Versions of Energy Productivity Evolve Over Time

The discussion has so far focused on the difficulties associated with comparing the energy productivity of countries at a single point in time. We now move on to the difficulties associated with how energy productivity evolves over time. To compare energy productivity over time, real GDP is used in the numerator. Real GDP, which is calculated by holding the prices of commodities fixed at a base year, is meant to reflect only changes in the quantity of goods and services produced, and not changes in their prices. This allows meaningful comparisons to be drawn between the energy productivity of a country in different years. Real GDP is typically measured in a country's local currency, but it can be converted into US$ using market or PPP exchange rates.

Exchange Rates and Real GDP

Real GDP can be converted into US$ whenever there is a need to compare its evolution between countries. Regardless of whether a country's real GDP is converted into US$ through market or PPP exchange rates, the growth rate remains the same. As a result, the growth rate in energy productivity also remains the same. Figure 6 shows, using Saudi Arabia as an example, that the choice between the two exchange rates affects the level of energy productivity throughout the years, but not the growth rate. In the case of the world, however, the choice affects both the level and growth rate. At first, this may appear counterintuitive since the world consists of countries, each of which carries a growth rate that does not depend on the exchange rate. However, the world's growth rate is a weighted sum of the countries' growth rates, where the weight attached to each country is its relative size (in GDP terms). Although the choice between the two exchange rates does not affect each country's growth rate, it does affect the size of each country's GDP, and consequently, the weight that it carries. As a result, the faster growth rates of developing countries, such as China, carry a heavier weight when PPP exchange rates are used. This explains why the world's energy productivity increased by 39 percent between 1990 and 2013 with PPP exchange rates, compared to only 18 percent with MERs.

Real GDP and Real National Income

When a country's export prices rise relative to its import prices, then the country will be able to buy more imports for each unit of its exports. For example, consider a hypothetical country that exports crude oil in order to import food. The country would be able to import twice as many tonnes of food for each barrel of oil exported in 2008 if the prices of each:

> Barrel of oil exported rises from $40 in 2007 to $100 in 2008.

> Tonne of food imported rises from $40 in 2007 to $50 in 2008.

This boost to national income between the two years is known as the 'terms of trade' effect, which is not captured when real GDP is calculated, since the prices of imports and exports are held fixed to that of the base year. However, it is possible to account for the terms of trade by computing what is known as real gross domestic income (GDI), which is equal to real GDP plus the terms of trade effect (Eurostat 2013). In the USA, GDI is commonly referred to as command-basis GDP.

How the Different Versions of Energy Productivity Evolve Over Time

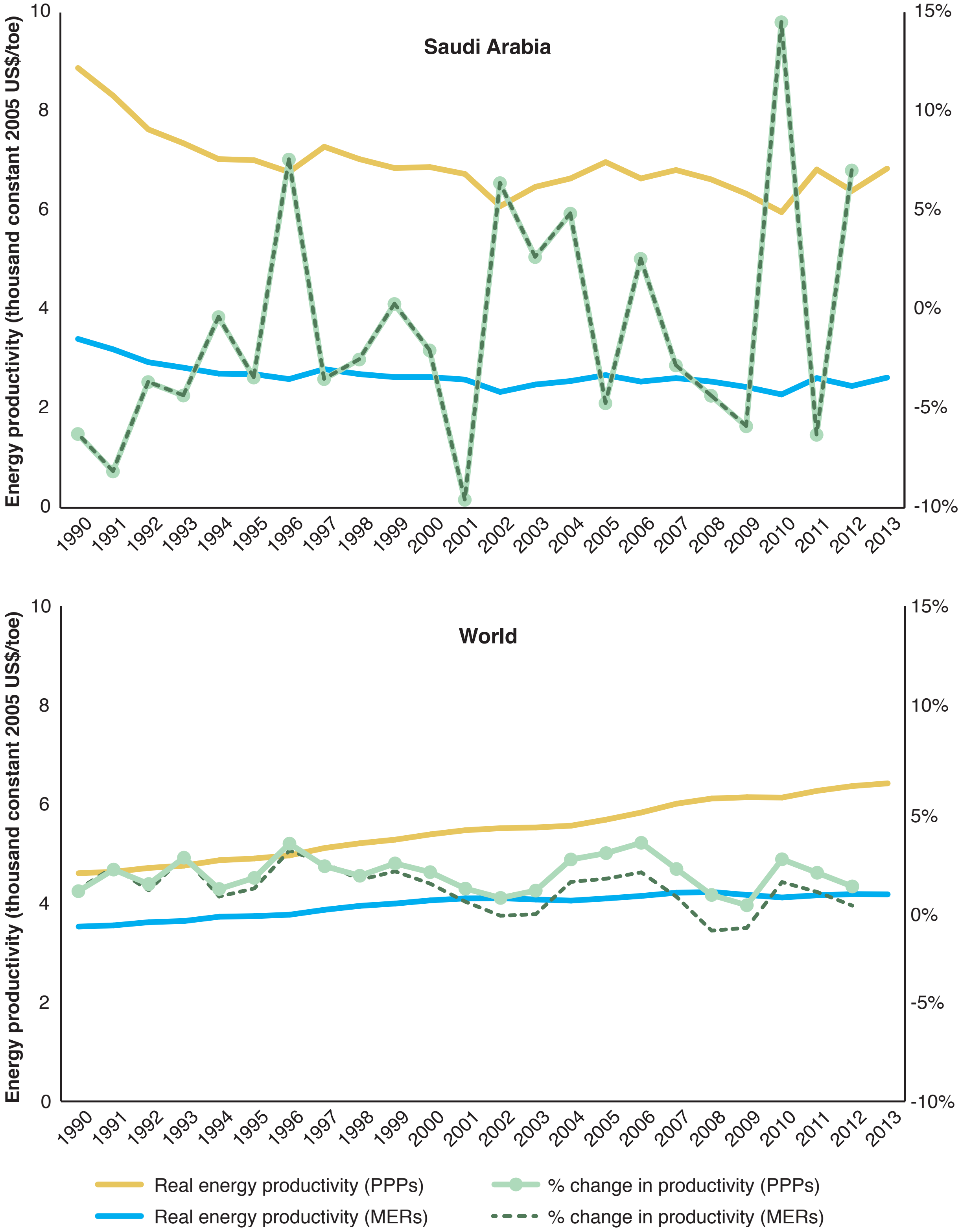


Figure 6. The evolution of real energy productivity in Saudi Arabia and the World when measured using market and PPP exchange rates.

Source: IEA, World Bank and KAPSARC analysis.

As Gutman (1981) points out, the terms of trade effect is generally small for most countries, but can play a significant role in the case of big oil exporters. This stems from their heavy dependence on oil exports and the volatility of oil prices. Although the World Bank publishes data on real GDI (World Bank 2016), its scope is limited for the big oil exporters. Therefore, we calculated real GDI over a 25-year period for Saudi Arabia. We also collected real GDI data from the U.S. Bureau of Economic Analysis (BEA 2016), in order to compare how energy productivity evolved between the two countries. (The dataset from the U.S. Bureau of Economic Analysis is one of the longest publicly available time series of real GDI for any country, which provides an opportunity to examine the long-term differences between real GDP and GDI). The results show that the energy productivity trends derived from real GDP and real GDI did not differ in the case of USA (see Figure 7). However, the two measures produced conflicting trends for Saudi Arabia. Between 1989 and 2013, Saudi Arabia's energy productivity increased by 9 percent with real GDI and decreased by 15 percent with real GDP. In countries similar to Saudi Arabia, real GDI is a better indicator of how national income has evolved over time. However, real GDP is a better indicator of how national output has evolved. In conclusion, the two measures can produce conflicting trends in energy productivity, influencing the perceived progress an energy economy is making.

The Effect of Different Time Series of PEC

The four previously mentioned factors that can cause estimates of PEC to differ at a single point in time could also cause time series of PEC to differ. This in turn can produce conflicting trends (rising or falling) in energy productivity. Before discussing the results, it may be useful to recall that energy productivity will either rise or fall depending on the growth rates of its components, PEC and GDP. If GDP grows faster than PEC, then energy productivity will rise. Conversely, if GDP grows slower than PEC, then energy productivity will fall.

Traditional biomass has a large influence on the evolution of energy productivity in countries where it accounts for a large share of PEC (see Figure 8). For example, between 1983 and 2012, real calculated energy productivity in India, Indonesia and the Philippines grew by 21 percent, -4 percent and 1 percent, respectively, based on data collected from the EIA. In contrast, real calculated energy productivity grew by 74 percent, 28 percent and 48 percent, respectively, based on data collected from the IEA. These divergent trends are due to the consumption of traditional biomass, which has grown slowly in these countries during this period. The IEA, which accounts for the growth of traditional biomass, provides PEC data that grow relatively slower, resulting in faster energy productivity growth. On the other hand, traditional biomass has grown rapidly in Nigeria during this period. Since the IEA accounts for traditional biomass, its PEC data for Nigeria grow much faster, resulting in energy productivity trends that fall in Nigeria.

International marine bunkering and renewables can also play a role. In the case of Singapore, with international marine bunkering, its real energy productivity fell by 1 percent over the 30-year period. In contrast, it rose by 42 percent without international marine bunkering. This divergent trend stems from Singapore's rapidly growing international marine bunkering center. In the case of Norway, the assumptions about renewables also produce different growth rates (60 percent vs 30 percent).

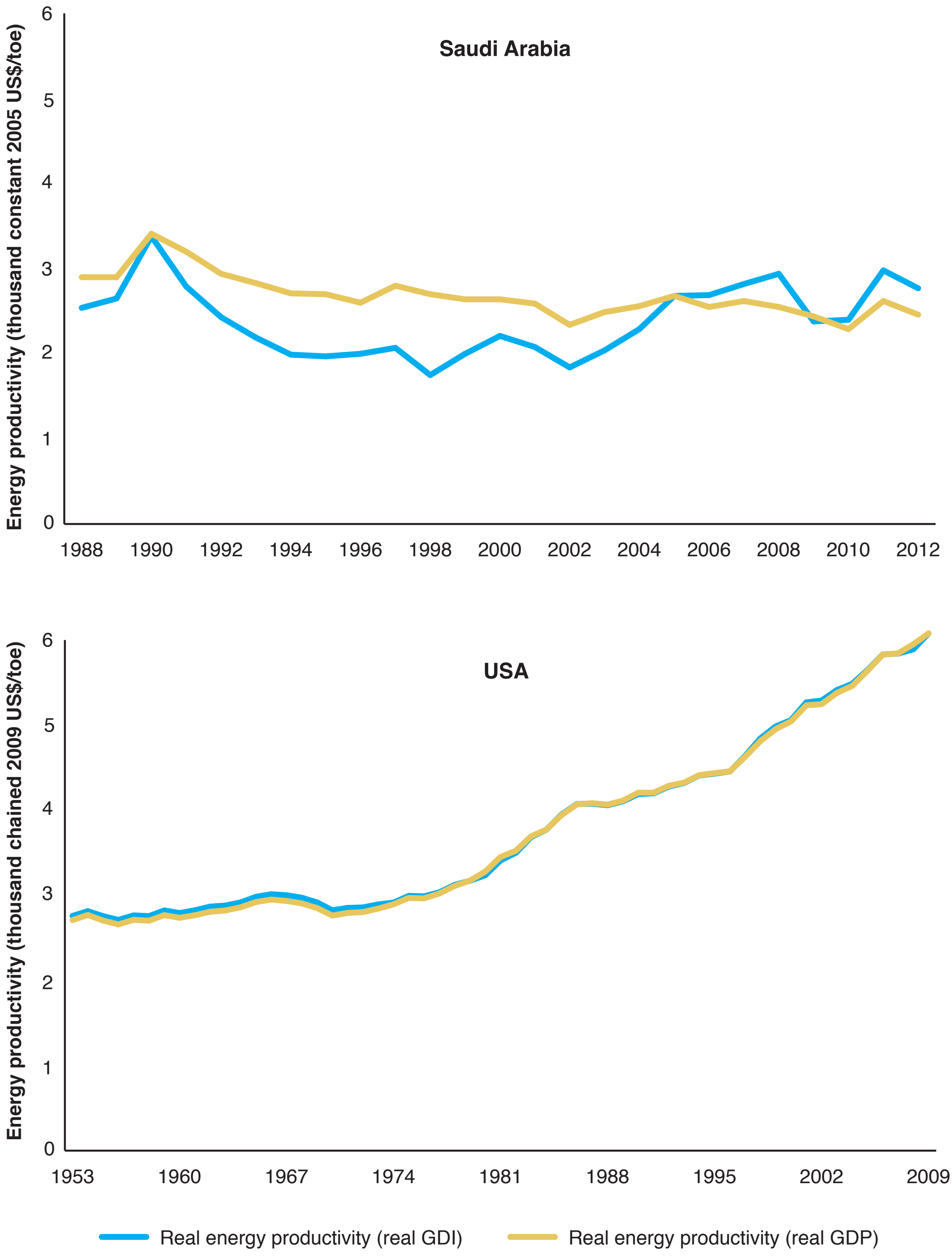


Figure 7. The evolution of real energy productivity in Saudi Arabia and USA using real GDP and real GDI.

Source: IEA, EIA, World Bank, U.S. Bureau of Economic Analysis, and KAPSARC analysis.

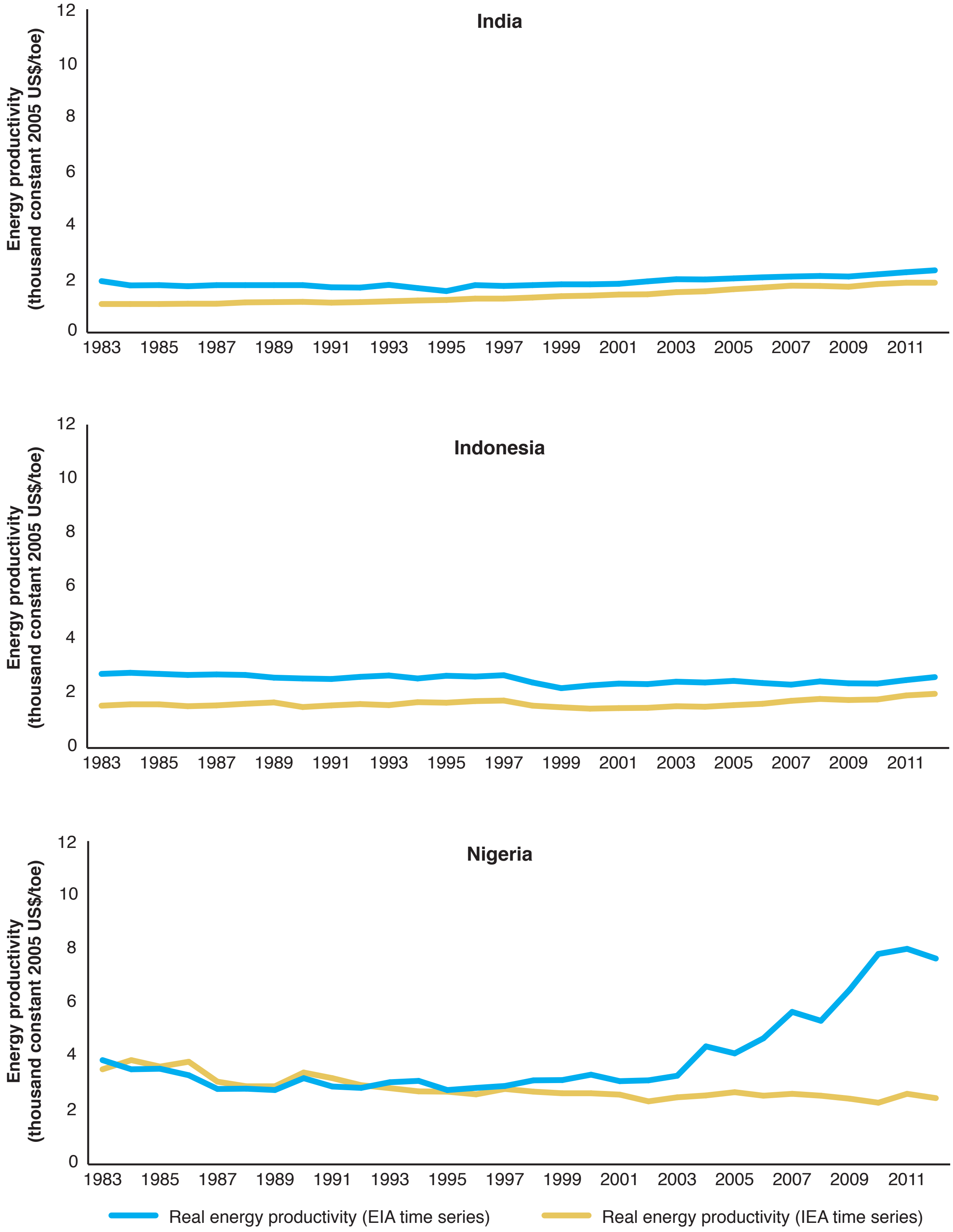
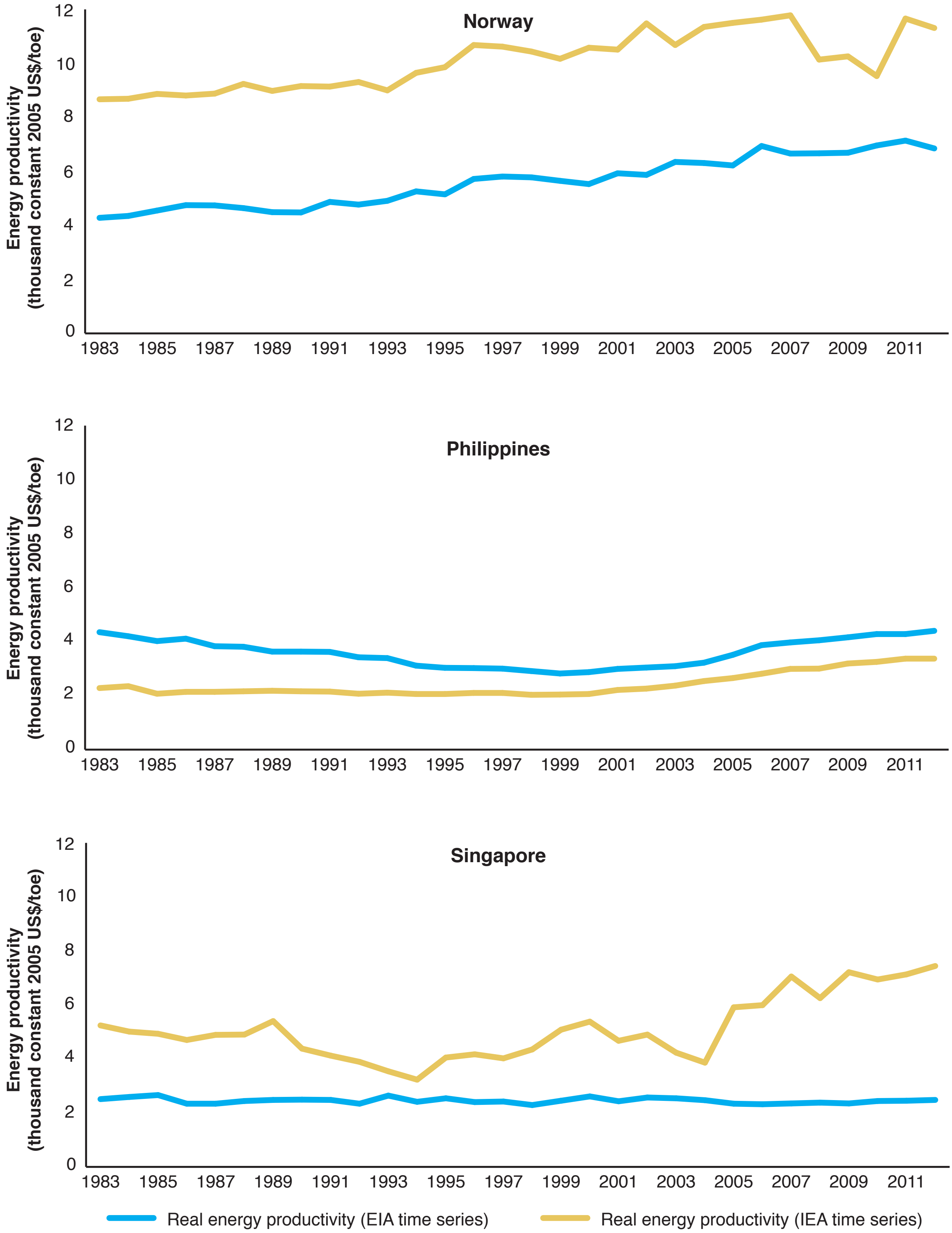


Figure 8. The evolution of real energy productivity with different PEC time series in six countries.

How the Different Versions of Energy Productivity Evolve Over Time



Source: Source: IEA, EIA, World Bank and KAPSARC analysis.

Policy Implications

We developed a general theme throughout this guide about the lack of certainty when attempting to calculate a country's energy productivity, due to the existence of a multitude of approaches for measuring PEC and GDP. We also highlighted the dramatic influence different approaches can have on a country's perceived energy productivity ranking vis-à-vis other countries, and on the evolution of energy productivity over time.

To better illustrate how the different versions of energy productivity influence the outcome of cross-country comparisons, we rank 35 economies in descending order using each version of energy productivity (see Table 7). Spearman's rank correlation coefficient, shown at the bottom of the table, is a measure of how similar two sets of rankings are. We arbitrarily choose to measure the correlation of each set of rankings with respect to that obtained with Version C.

We found that the overall order of the rankings did not change drastically when switching between PEC databases, as shown by the rank correlation coefficients of Versions A and B with respect to Version C. On the other hand, the exchange rates appeared to affect the order of the rankings more drastically, as the rank correlation coefficients of Versions D and E with respect to Version C register at 0.46 and 0.74, respectively.

The existence of different ways of calculating energy productivity has implications on the national energy policy targets that countries might adopt. Many countries adopt a national target based on a commonly used indicator, such as energy productivity, energy intensity or greenhouse gas emissions. Such targets play a central role by allowing policymakers to create a level of shared accountability, follow the impact of enacted energy policies on the economy, send long-term signals to investors and coordinate actions, such as for tackling climate change, with other countries (KAPSARC 2015).

Greater knowledge of the different ways of calculating energy productivity allows policymakers to understand better the policy implications of the targets that they or other policymakers set. Singapore, for example, has set a target to (roughly stated) increase energy productivity by 56 percent by 2030 relative to 2005 (UNFCCC 2016). To simplify our argument, assume that half of the energy consumed by Singapore goes to the international marine bunkering sector and the other half to the rest of the economy. Furthermore, suppose the energy productivity of the international marine bunkering sector remains fixed. The difficulty of meeting a target to increase energy productivity by 56 percent depends on how Singapore's energy productivity is calculated. If international marine bunkering were included, then Singapore would have to improve the energy productivity across the rest of its economy by 112 percent in order to meet the target (since the energy productivity of the marine bunkering sector remains fixed). In contrast, if international marine bunkering were excluded, then Singapore would have to improve the energy productivity of the rest of its economy by 56 percent, which is the target.

In the case of the Gulf Cooperation Council (GCC) countries, it is often stated that energy productivity (energy intensity) in the region is lower (higher) than the world average and that the region should aim to reach the levels of industrialized economies (Glada et al 2013). Such statements tend to be based on PPP GDP, to control for differences in prices across different economies.

Table 7. A comparison between the rankings of 35 economies in 2012 with five different versions of energy productivity.

Country	Rankings for Version A	Rankings for Version B	Rankings for Version C	Rankings for Version D	Rankings for Version E
Switzerland	1	1	1	2	1
Norway	4	3	2	8	6
Japan	2	2	3	14	9
Australia	3	4	4	22	15
Colombia	5	5	5	1	2
Singapore	25	26	6	3	3
Spain	6	6	7	6	4
Netherlands	8	9	8	16	11
Belgium	11	11	9	18	14
New Zealand	9	8	10	24	17
Brazil	10	10	11	11	13
Finland	7	7	12	29	25
US	14	14	13	23	16
Canada	18	19	14	32	26
Chile	13	13	15	15	8
Turkey	15	15	16	7	5
Mexico	16	16	17	13	7
Philippines	12	12	18	4	10

Country	Rankings for Version A	Rankings for Version B	Rankings for Version C	Rankings for Version D	Rankings for Version E
World	17	18	19	25	21
UAE	26	25	20	21	30
Qatar	24	22	21	27	32
Czech Republic	21	20	22	28	20
South Korea	22	23	23	31	27
Algeria	23	27	24	12	18
Indonesia	19	17	25	10	29
Bangladesh	20	21	26	5	12
Malaysia	27	24	27	20	24
Saudi Arabia	28	30	28	26	33
Egypt	32	32	29	9	19
China	33	29	30	33	34
Bulgaria	34	34	31	30	22
South Africa	29	33	32	34	35
Russia	35	35	33	35	31
Pakistan	30	28	34	17	28
India	31	31	35	19	23
Spearman's Rank Correlation	0.91	0.90	1.00	0.46	0.74

Source: BP, EIA, IEA, World Bank and KAPSARC analysis

Spearman's Rank Correlation Coefficient

To gain a better understanding of Spearman's rank correlation coefficient, consider the rank correlation between Version C and itself; which, given it compares the exact same set of rankings, is equal to one. In contrast, imagine a set of rankings that is exactly opposite to Version C, such that the most energy productive country would be the least energy productive and vice versa. In this case, Spearman's rank correlation coefficient would be exactly equal to minus one. Values in between indicate that some rankings change between the two sets while others do not.

Any analysts that worked with PPP GDP data published before April 2014, which would have used PPP exchange rates derived from the 2005 ICP round, would arrive at the same conclusion. The rankings obtained with Version E in Table 6, which rests on the 2005 ICP round, reveal that Saudi Arabia (with a ranking of 33) and the UAE (30) were far below the world average (21) in the year 2012. However, following the release of the new PPP exchange rates, the PPP GDP figures in the GCC underwent some of the largest upward revisions. This is shown in the rankings obtained with Version D, which reveal that Saudi Arabia (26) was only one position below the world average (25) while the UAE (21) jumped ahead of the world average in 2012. Such measurement issues make it difficult for an economy to set a target to reach the level of energy productivity of another economy, when the levels can suddenly change due to measurement uncertainties.

Conclusion

All of this begs the question: Which version of energy productivity should analysts and policymakers use? The most important takeaway from this guide, however, is not a recommendation about the best version of energy productivity, but rather the knowledge that there are many different ways of calculating energy productivity, each of which comes with a set of strengths and weaknesses.

For countries with similar levels of energy efficiency but different levels of energy productivity, it is often assumed that differences in economic structure, geography, climate or energy prices contribute to the difference in productivity. However, this guide shows that there are deeper factors, which relate to how PEC and GDP are measured, that can contribute to differences in energy productivity. Even for two similar economies, the approach used to calculate energy productivity could result in an unexpected difference between them. There is a need for a greater degree of standardization in the energy economics community. A standardized approach to accounting for renewables, international marine bunkering, traditional biomass and exchange rates when calculating energy intensity or productivity can reduce the number of conflicting results.

In conclusion, policymakers will benefit from a greater understanding of the different ways PEC and GDP can be measured when considering the energy productivity of an economy or a comparison between economies. The statements that 'this country is a lot more energy productive than that country' or 'this country's energy productivity has not improved' may only be true under one approach. Such an understanding, in addition to consensus on a standardized approach, should contribute to the design of better-coordinated and more effective energy and climate change policy.

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Notes

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About the Project

This project explores the uncertainties surrounding calculations of energy productivity, which arise through the existence of different approaches to measuring energy consumption and gross domestic product. Many factors can produce conflicting energy productivity estimates, all of which are systematically examined in this study. This project is part of a larger body of KAPSARC research analyzing energy demand, energy efficiency and rebound.

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