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# Bridging the gap between energy-to-GDP ratio and composite energy intensity index

B.W. Ang[a,b], Tian Goh[a,*]

[a] Department of Industrial Systems Engineering and Management, National University of Singapore, Singapore
[b] Energy Studies Institute, National University of Singapore, Singapore

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ABSTRACT

The energy-to-GDP ratio (EGR) is an indicator often used as a proxy for economy-wide energy efficiency in policy formulation and analysis. It is easy to compute and interpret, but its limitations as an energy efficiency indicator are also well known. Another widely used indicator is the composite energy intensity (CEI) index constructed from disaggregated energy and activity data. The CEI index is seen as a better proxy for energy efficiency but it is more difficult to construct as compared to the EGR. Countries have computed and compared the two indexes and reported their divergence in capturing energy efficiency trends. While economic structure change is one explanation for the divergence, it is not the only contributing factor and the issue has not been studied in detail. This study seeks to fill the gap. It dissects and discusses the fundamentals of the two indicators, and establishes a formal linkage between them by introducing a factor termed the "activity correction" (AC) effect. A case study is presented. The significance and policy implications of the AC effect are discussed.

## 1. Introduction

The ratio of energy consumption to gross domestic product, or the "energy-to-GDP ratio" (EGR), is a widely used energy indicator in energy policy formulation and analysis.[1] It is tracked and reported annually in statistical yearbooks and by international organisations (EEA, 2016; IEA, 2017a). Numerous studies have also been reported on the relationship between energy consumption and GDP (Ang, 1987, 2006; Bullard and Foster, 1976; Stern, 2000).

The EGR has often been used to represent the energy efficiency or productivity of a country. Asia-Pacific Economic Cooperation (APEC), for example, aims to reduce its aggregate EGR by 45% from 2005 levels by 2035 (Asia-Pacific Economic Cooperation, 2011). The EGR is also used in the Sustainable Energy for All (SE4ALL) initiative of the United Nations to track progress towards the goal of doubling the rate of improvement in energy efficiency of world countries by 2030 (World Bank and IEA, 2015). These are but two among many initiatives that use the EGR as a proxy for energy efficiency.

As a performance indicator for energy efficiency, the EGR has several distinct advantages. It is clear in definition and well-suited for target setting in international agreements or national plans. In addition, it is relatively easy to compute and understand. However, it also suffers from the drawbacks of being too aggregate and overly broad in context. For example, structural change in economic output is embedded and a reduction in the ratio may not necessarily represent an improvement in energy efficiency.

To address these drawbacks and as an alternative, countries have developed the so-called composite energy intensity (CEI) index.[2] Unlike the EGR, the CEI index uses disaggregated energy and activity data to evaluate energy efficiency through a bottom-up approach. Both monetary and physical activity indicators can be used as drivers of energy consumption. This flexibility allows for a consistent comparison of efficiencies across a particular energy service. It permits analysts and researchers to better tailor the index to suit national circumstances. However, the derivation of the CEI index is more complex and subjective in comparison to the EGR.

* Corresponding author.
*E-mail address:* gohtian@u.nus.edu (T. Goh).

[1] In the energy literature, the term "energy-to-GDP ratio" is commonly used to refer to energy consumption divided by GDP. Although energy divided by GDP is more accurately described as a quotient, the term "energy-to-GDP ratio" is used in this paper for ease of understanding. In the literature, other terms that are commonly used include the energy intensity of GDP, GDP energy intensity, and aggregate energy intensity.

[2] See, for example, the studies by Australia (Petchey, 2010), Canada (Office of Energy Efficiency, 2006), United States (Belzer et al., 2017) and European countries (ODYSSEE-MURE, 2016). The CEI index is known as the OEE Energy Efficiency Index in Canada, the Composite Energy Intensity in Australia, the Economy-wide Energy Intensity Index in the United States, the ODEX Aggregate Energy Efficiency Index in Europe, and the Energy Efficiency Index in New Zealand. We adopt the term "Composite Energy Intensity" index to highlight that the term is characterized as an index that quantifies the change in energy use per activity.

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Country studies have compared the two indicators and shown that they give diverse results on energy efficiency performance. As each has specific strengths and weaknesses, they can be used to complement each other. In this regard, the ability to explain the divergence between them will provide analysts and policymakers with a more complete picture of the energy system. So far, this issue has not been studied in detail. This study aims to fill this gap by explicitly quantifying the divergence between the EGR and CEI indexes through the introduction of a new factor known as the "activity correction" (AC) factor in an index decomposition analysis study.

## 2. Energy-to-GDP ratio (EGR)

The EGR is generally computed as a country's total primary energy consumption (TPEC) divided by its GDP. A decrease in the ratio over time indicates that a country uses less energy to generate a unit of GDP. This is a positive development as it enhances energy security, improves economic competitiveness and promotes sustainability.

GDP is a single-number aggregate. Based simply on changes in the EGR, movements in energy efficiency at the sector or end-use level are unknown. Changes in the EGR may take place with no bearing on energy efficiency. For example, studies have shown that the EGR takes on an inverse U-shape with increasing GDP (Ang, 2006; Galli, 1998). It increases in the early phase of economic development as energy-intensive industries are introduced, reaches a peak and then decreases as development progresses and the country shifts away from energy-intensive industries towards less energy-intensive industries including services. A large part of this behaviour can be explained by structural shifts in production and is unrelated to energy efficiency.

In fact, due to the limitations of measuring energy efficiency as the ratio of energy input to GDP, many countries prefer to define energy efficiency in terms of energy service or physical output. For instance, the European Union defines energy efficiency as the "ratio of output of performance, service, goods or energy, to input of energy" (The European Parliament and the Council of the European Union, 2012), while the United States defines energy efficiency as "the activity or product that can be produced with a given amount of energy" (Office of Energy Efficiency and Renewable Energy, n.d.). In the internationally recognised ISO 50001 specification for an energy management system, energy efficiency is defined as the "ratio or other quantitative relationship between an output of performance, service, goods or energy and an input of energy" (ISO, 2011). From an energy systems analysis perspective, these physical definitions of energy efficiency are free of price changes and can better account for energy efficiency.

It is often assumed that the numerator (TPEC) and the denominator (GDP) of the EGR have a one-to-one correspondence. The actual situation is more complex. In energy accounting, the TPEC is allocated to the following sectors: industry, passenger transport, freight transport, services, residential and the energy sector. This classification is universally accepted and adopted in energy balances (IEA, 2017a; United Nations, 2016). The approximate shares of these sectors in the global TPEC in 2015 are shown in Fig. 1.[3] About 42% of the TPEC was used for production purposes (for producing goods and services), 25% for consumption purposes (for personal use), and 33% in the energy sector. Fig. 1 indicates that the TPEC consists of two parts, consumption in energy end-use sectors and consumption in the energy sector.

The GDP can be allocated by sector via three different methods – the production approach, the expenditure approach and the income approach.[4] None of them is the same as that used in the allocation of the TPEC. The incompatibility between the allocation of GDP and TPEC to various sectors is a concern because the energy intensity of GDP of some sectors cannot be properly accounted for to reflect energy efficiency in these sectors.

The production approach is most commonly used in energy analyses. The GDP is allocated to production sectors based on the National Account Standard Industrial Classification (SIC) (United Nations, 2008). The SIC sectors cover only that part of the energy consumption which is used to produce goods and services. There are no "sectors" related to residential and personal transport energy consumption. From Fig. 1, the production approach can at best capture about 75% of the TPEC if the energy sector's consumption is included. If the focus is on energy end-use sectors, it captures only 42% of the TPEC.

An issue in using the production approach is how to deal with the energy consumed in the residential and personal transport sectors. In the literature, some solutions have been reported. An easy option is to exclude them since they do not contribute to production-based GDP (Nagata, 1997). While this is suitable for analysing the productivity of the economy, from an energy analysis perspective it excludes important segments of a country's energy system. Other solutions are to include but treat them in an indirect manner, such as by using total GDP (Bosseboeuf et al., 1997; Patterson, 1993) or population as the activity indicator (Torrie et al., 2016).[5] The energy intensity is computed as the ratio of the energy consumed in the sector to total GDP or total population. The energy intensity effects estimated by the two solutions are more aggregate as intra-sectoral structural changes are not quantified. Intra-sectoral structural changes for consumption sectors can provide additional information that may be useful to policymakers.[6] Other complications in the application of the EGR to track changes in energy efficiency using the production approach occur in the public passenger transport[7] and freight transport sectors.[8]

In the expenditure approach, the GDP is allocated based on expenditure for consumption, investment, public spending and net exports (i.e. exports minus imports). In order to achieve a correspondence between the TPEC and the GDP, some reallocation is required such that the definition of sectors are aligned (Bossanyi, 1979). The factors affecting the EGR are price and income-driven changes in demand, structural and technical factors (Kaufmann, 2004). The impact of price and income on demand are included as factors as the approach is based on expenditures on goods and services. This makes it less consistent with the idea that the EGR measures the productivity of the economy with energy as an input and GDP as an output.

Another disadvantage of using the expenditure approach is that the use of the same amount of energy for the same service can result in very different energy intensities. For example, for the same distance travelled, the energy intensity of a personal car differs from that of a taxi as the expenditures are different. The first is based on personal expenditures while the second is based on expenditures for the transportation service (Kaufmann, 2004). As the energy intensity is an estimate of energy efficiency, the difference is not easy to explain since

[3] The shares are estimated from the 2015 IEA world energy balance (IEA, 2017b). Energy consumed by the energy sector is taken as the difference between the total primary energy supply and total final energy consumed, and includes losses due to transformation, electricity and heat generation and energy sector's own use.

[4] The income approach is not used in energy analyses and is therefore not discussed in this study.

[5] Per capita GDP is used in the study to integrate the results with the decomposition of the EGR.

[6] For example, for the passenger transport and household sectors the impact of transport modal shifts and changes in the share of housing types can be estimated by the intra-sectoral structural effect respectively.

[7] The public passenger transport sector generally contributes to a small share of only a few percent of total GDP but consumes a relatively large share of TPEC. If derived directly based on these reported figures, the energy consumed per value added, or the sectoral energy intensities, are unreasonably high. Any changes in the sectoral energy intensity may not be reflective of actual changes in energy efficiency of the passenger transport sector.

[8] Similarly, for the freight transport sector, the small share of total GDP causes the derived sectoral energy intensities to be unreasonably high and experience large fluctuations when value added changes significantly. Another problem faced with the use of the production approach for the freight transport sector is that the GDP generated by this sector is not easily identified as it is partly classified in the NAICS codes of commercial freight carriers as well as firms which own and operate their own fleets.