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The determinants of energy intensity in Indonesia

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Abstract

Purpose – Indonesia is the fourth most populous country in the world, which has a strong effect on primary energy use and depletion of natural resources. This paper considers energy intensity (EI) defined as a measure of the amount of energy it takes to produce a dollar's worth of economic output. The purpose of the paper is to explore how different factors contributed to the decline in Indonesia's EI.

Design/methodology/approach – The cointegration regression methodology is applied to explore the long-term nexus between EI and its factors in Indonesia during 1990–2016.

Findings – Results show that domestic credit to the private sector, as well as the share of alternative energy, has a significant impact on the decline of EI in Indonesia.

Research limitations/implications – We do not try to rule out other possible determinants of EI. We consider the determinants of EI using time series data, while an ideal analysis would be based on panel-level data. Another limitation is that the study covers only the small-time period from 1990 to 2016.

Practical implications – Our findings serve to aid the government and policymakers in prioritizing improvements in the sphere of energy policy. An important policy implication, regarding Indonesia, that arises from our study is that, for the country to be able to decrease its EI, it must be able to develop its financial market and zero-carbon energy sources, mainly geothermal energy with its huge potential.

Originality/value – We show that energy prices, financial development and the share of alternative energy sources contribute to EI decrease. Policy recommendations include geothermal and solar energy development as one of the most prospective sources of alternative energy in Indonesia.

Keywords Energy intensity, Alternative energy sources, Renewables, Cointegration, Indonesia

Paper type Research paper

1. Introduction

The energy sector is currently experiencing a multifaceted challenge, whereby energy decision-makers are dealing with energy efficiency, energy security and environmental concerns altogether (Verma *et al.*, 2018). Energy intensity (EI) is a measure of the amount of energy it takes to produce a dollar's worth of economic output. Schipper and Grubb (2000) define EI as the ratio of energy use to a relevant measure of activity or output (like value-added in steel or another industry, floor space heated to a given temperature, vehicles or people (or freight) moved a given distance). The International Energy Agency (IEA, 2018) measures EI as the energy used per unit of gross domestic product (GDP). Less energy use for creating a unit of GDP increases the economy's global competitiveness and provides an added incentive for environmental sustainability and energy security. The value varies widely across countries, depending on the level of industrialisation, the mix of services and manufacturing and the attention paid to EI. The study of the dynamics of primary EI helps to

JEL Classification — P18, Q20, Q28, Q40, Q42

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understand how energy demand varies under conditions of significant changes in the economy's structure and public policy (Rudenko and Raschetova, 2018). Overall, finding roots of lower EI may help the countries to develop more competitive and efficient economies and achieve more sustainable economic growth. Moreover, nowadays emerging economies are not interested in economic growth at any cost, higher income highlights other values, so people pay more attention to environmental conditions.

EI brings benefits in climate mitigation, energy security and often co-benefits in pollution reduction and health. The discussion about decreasing Indonesia's EI is of high importance due to the substantial contribution of Indonesia to the global energy consumption and carbon emissions, as well as associated local air pollution that affects public and ecosystem health. Indonesia represents a unique case, given the size of its population (above 250 million people) and its economy, its potential natural resources, the ambitious targets to mitigate greenhouse gas emissions and the country's willingness to take a leading role in climate change negotiations. Indonesia's existing electricity generation mix differs in many ways from other developing countries. On the one hand, Indonesia is the country that has one of the highest shares of renewable energy in the total primary energy supply among Asia–Pacific countries. On the other hand, currently, it is generating less than 5% of its electricity from renewable sources. Despite the considerable progress made in improving energy efficiency since the Asian Financial Crisis, Indonesia still belongs to the group of countries with the high primary EI of GDP. Share of renewables in Indonesia is even much lower comparing to well-known coal burner – China, where the share of renewable energy amounts around 24.5%, it is crucial to make transition towards higher share of zero-carbon energy to stay competitive.

The present study contributes to the existing research literature by examining the determinants of EI for the Indonesian case. We follow the empirical literature on the determinants of EI (Fisher-Vanden *et al.*, 2004; Hübler and Keller, 2010; Hübler, 2011; Adom and Kwakwa, 2014; Adom, 2015b; Akal, 2016; Rudenko and Raschetova 2018). This paper contributes to the existing literature in several ways. First, to the author's knowledge, this paper is the first one trying to investigate the impact of energy transition on EI in Indonesia. Second, this paper conducts an empirical analysis of the factors underlying EI in Indonesia. It extends the research period to 2016, which year attracted little attention due to the lack of statistics about that time. Third, studies into EI explore the influence of technological factors, industrial structure and the openness of economy. Nevertheless, the factors that determine EI are various, and some of them are underexplored. We extend previous studies by paying attention to the role of alternative energy sources and financial development in determining EI. The case of Indonesia, a country where the state subsidizes energy consumption, provides a compelling example aiding us in our study of the issue. Fourth, the paper contributes to the existing methodology by using fully modified least squares (FM-OLS), dynamic least squares (DOLS) and canonical cointegrating regression (CCR) to estimate cointegrating equations that are becoming a standard practice in energy economics.

The remainder of the paper proceeds as follows. Section 2 reviews the literature. Section 3 discusses the energy sector of Indonesia. Section 4 describes the data and methodology. Empirical results are presented in Section 5, followed by a discussion and concluding remarks on Indonesia's energy policy in Section 6.

2. Literature background

Numerous empirical papers are examining the factors affecting EI. However, there is no clear conclusion on the effect of those factors that may come from different models, economic structures and samples analysed by these studies. Three fundamental factors lead to the decline in EI, including the structural adjustment of terminal demand, the improvement of energy utilisation efficiency and the substitution of more efficient fuels (Bernardini and Galli, 1993). Authors define several common factors of EI. These factors are foreign direct investment (FDI) inflows, trade openness and export–import structure of trade, prices of primary energy sources, role of the manufacturing industry in the country and structural effects as well as the technological level of the economy.

FDI as a key factor of economy transition towards a more energy-efficient production is described by Bu *et al.* (2019) who confirm a significant negative relationship between FDI and EI. Large spending on technology tends to lower the difference between local and foreign companies in terms of better ability of local companies to adopt best practices.

Increased energy price via economic instruments leads to a decrease in EI (Birol and Keppler, 2000). According to the study of 28 transition countries higher energy prices have the energy-saving potential (Cornillie and Frankhanser, 2004). Similarly, Hang and Tu (2007) find that the price of energy harms EI in China. In addition, Rock (2012) suggests Indonesian government draw such successful Chinese initiatives as a standard energy-saving program, liberalisation of domestic markets, technological catch-up, industrial development strategy and openness of the economy to trade and investment. The implication of the above findings suggests that government focuses on reducing subsidies leading to higher energy prices, reducing the budget deficit and EI.

Typically, the industrial sector is more energy intensive. As a result, a higher level of the industrial base increases energy requirements and causes EI to increase. Poumanyvong and Kameko (2010) find a positive impact of industrial activity on EI, which is significant for low- and middle-income economies. Adom and Kwakwa (2014) establish a positive and significant link between manufacturing activity and EI. When industrialisation is expected to increase energy requirements, changes in the industrial structure could produce energy-saving effects. Inglesi-Lotz and Pouris (2012) examine the factors affecting energy efficiency trends in South Africa between 1993 and 2006 and show that structural changes have generated the economy-wide reduction in EI. Lin and Moubarak (2014) show that changes in industrial structure are negatively related to EI in China. Based on the case of Ghana, Adom and Kwakwa (2014) find that post-reform changes in the structure of the manufacturing sector (technical and composition) have decreased EI. Li and Lin (2014) show that a structural shift to the less energy-intensive sector improves energy productivity. The existence of the non-linear impact of industry structure implies that significant structural changes in the economy can asymmetrically affect the EI. Zhu and Lin (2020) investigate convergence characteristics of EI in China. They suggest that the cities with a higher population density, a higher proportion of FDI and a higher marketisation degree level tend to converge to lower EI club. In contrast, natural resources and a higher proportion of secondary industry tend to increase EI.

The importance of technological change in reducing energy requirements is stressed in Garbaccio *et al.* (1999). They find that technological development contributes to the decline in EI. Ma and Stern (2008) use the Logarithmic Mean Divisia index and prove the fact that technological development has a significant impact on EI. Lin and Moubarak (2014) also establish a negative relationship between technology and EI. Voigt *et al.* (2014) show that technological change caused improvement in EI between 1995 and 2007. Hille and Lambernd (2020) find that trade openness, government environmental expenditures, and in part innovation, reduce the total EI in South Korea.

While these studies have greatly enriched our understanding of the determinants of EI, most studies focus on globalisation, prices of primary energy sources, the role of industry and structural effects that are only one of the many determinants of EI. Therefore, in order to gain a better understanding of the determinants of EI, we must examine not only FDI but also the structure of energy consumption as well as institutional and financial factors. Moreover, the relationships between financial development and EI have still not been fully elucidated by researchers (Chen *et al.*, 2019).

The variety of methodology used in the field is very extensive. Studies using time-series methods (single-country) as well as panel methods (panel-country or panel-region) in the literature related to EI are reported in Table 1. Based on literature review we can highlight three types of studies: study of many countries, regions of one country or a single country. Among first two the most popular methodology is panel analysis. Among single country studies we found out many ways to analyse data: time series, cointegration, etc. However, the most common and recently used method is the fully modified least squares (FM-OLS), the canonical cointegrating regression (CCR) and the dynamic least squares (DOLS). We follow Adom and Kwakwa (2014) directly and employ these techniques to analyse the long-run impact of selected variables on Indonesia's EI.

3. The energy intensity of Indonesia

Over the last decades, Indonesia has become the eighth largest economy in the world by GNI in terms of purchasing power parity (PPP), showing signs of a rapid economic development. As indicated in Figure 1, Indonesia's GDP per capita (PPP adjusted) in constant 2011 international dollars has steadily climbed from 4,625 in the year 1990 to 11,188 in 2017. Indonesia has experienced the impressive growth of GDP per capita of 240% concerning 1990 largely coincided with an extraordinarily powerful commodities boom. Although Indonesia is not one of the world's most resource-intensive economies, the country's development has been strongly influenced by the global natural resources boom (Garnaut, 2015).

Such a rapid economic growth caused an increase in demand for energy. In the last decades, Indonesia's total primary energy supply (TPES) has increased from around 100 million tons of oil equivalent (MTOE) in 1990 to 230 MTOE in 2016, and the energy mix has also changed significantly. According to IEA statistics, total energy production increased from 168.5 MTOE in 1990 to 352.1 MTOE in 2009. It is estimated at 434 MTOE in 2016, which is more than 250% increase from 1990, as shown in Figure 2, and it is considered the highest among ASEAN countries. Total final energy consumption was 79.9 MTOE in 1990 and reached 164.8 MTOE in 2016. Apart from economic and population growth, the total primary energy supply increased drastically due to rapid urbanisation and industrialisation.

Indonesia is a significant player at the global energy market, possessing a variety of abundant energy resources. Despite its vast renewable-energy potential, the share of fossil fuels is currently 96% of the total primary energy consumption according to BP statistics (BP, 2018). However, the BP data do not include traditional biomass, so that including biomass fuels, only 66% of the total primary energy supply is dominated by fossil fuels (IEA, 2018). Figures 3 and 4 indicate the growth in the total primary energy supply since 1990, and the mix of different energy sources in total primary energy supply in the year 2016 respectively.

In the year 2016, the total primary energy supply was 230 MTOE, making Indonesia twelfth most abundant in the world. Oil accounted for around 30% of the total primary energy supply. Oil continues to dominate Indonesia's overall energy mix, and this makes the country's energy security situation vulnerable, in terms of supply disruptions and international price spikes, which can make the energy market unstable in a short-term as well as long-term. In the year 2016, 49 MTOE of oil was imported, which is two times higher than the import of 2000.

As shown in Table 2, Indonesia had produced 46.4 million tons of crude oil in 2017, with a production decline rate of 3% over the decade; this was followed by the rise of crude oil consumption by 19% over the period from 2007 to 2017. Small domestic oil production is used for export instead of domestic purposes due to the limited capacity of domestic refineries, with the result that domestic petroleum production could not meet the domestic demand. This situation resulted in Indonesia's dependence on imported petroleum products and crude oil simultaneously. However, despite the government's efforts to diversify energy sources, the

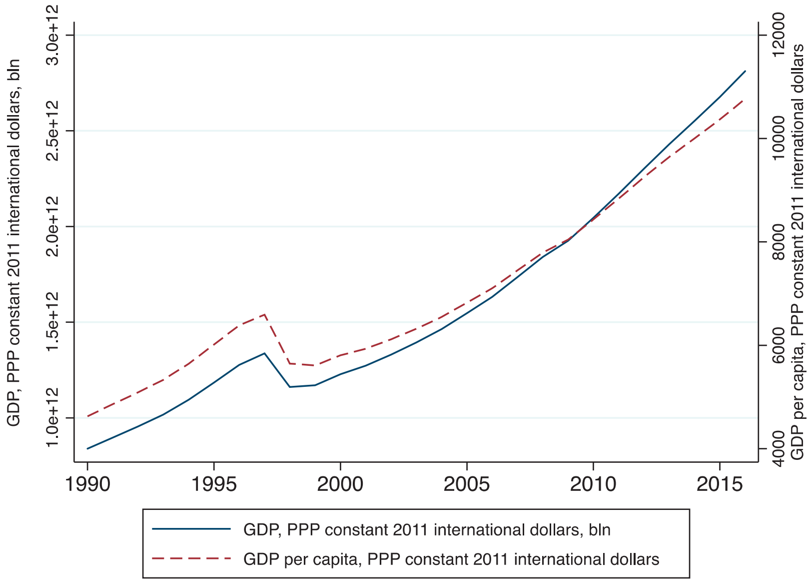
Author	Country	Period	Methodology	Parameters
Fisher-Vanden *et al.* (2004)	China	1997–1999	Panel fixed effects	Energy prices (–) R&D spending (–) Industrial structure shifts (–)
Cole (2006)	32 developed and developing countries	1975–1995	Panel fixed effects	Trade liberalisation (+)
Hang and Tu (2007)	China	1985–2004	Panel fixed effects	Energy sources price (–) Industrial structure shifts (–)
Hü bler and Keller (2010)	60 developing countries	1975–2004	Panel fixed effects	FDI inflows (+-)
Zhang *et al.* (2019)	China	1999–2007	Panel varying-coefficient regression	Export (+) FDI inflows (–)
Cui *et al.* (2014)	China, India, Japan, USA, Brazil, France, Germany, Russia, UK	2008–2012	Panel fixed effects	Technology improvements (–)
Parmati *et al.* (2016)	20 emerging economies	1991–2012	Panel non-causality	Economic output (–) FDI inflows (–) Stock market development (–)
Huang *et al.* (2018)	China	2000–2013	Panel cointegration analysis, Panel threshold analysis	FDI (–) Export (+) R&D (–)
Otsuka and Goto (2018)	Japan	1990–2010	Panel fixed effects	Population density (–)
Chen *et al.* (2019)	21 OECD, 77 non-OECD	1990–2014	Panel fixed effects	Financial development (–)
Zhu and Lin (2020)	China	2005–2016	Ordered probit model	Population density (–) FDI inflows (–) Marketisation degree (–) Industrialisation (+)
Azhgaliyeva *et al.* (2020)	31 OECD, 13 non-OECD	1990–2016	Panel	Energy prices (–)
Hille and Lambernd (2020)	South Korea	2002–2017	Limited Information Maximum Likelihood	Trade openness (–) Government expenditure (–)
Adom and Kwakwa (2014)	Ghana	1975–2011	FM-OLS, DOLS, CCR	Urbanisation (+) Trade openness (–) Manufacturing (+)
Li and Lin (2014)	China	1980–2009	Threshold cointegration	Industrial structure (–) Technological progress (–) Energy price (–)
Adom (2015a, b)	South Africa	1970–2011	FM-OLS	Oil prices (–) Net import (–) De-industrialisation (–)
Akal (2016)	Turkey	1980–2011	Autoregressive Cause Effect Model	GDP per capita (–) World energy price (–) Net energy import (+)
Taghavee *et al.* (2016)	Iran	1974–2012	Cointegration	Economic growth (+) Urbanisation (+) Trade openness (–)

(continued)

Table 1.
Relative literature

Author	Country	Period	Methodology	Parameters
Rudenko and Raschetova (2018)	Russia	1992–2015	FM-OLS, DOLS, CCR	Oil prices (–) Share of alternative energy sources (–)
Dargahi and Khameneh (2019)	Iran	1974–2014	ARDL, SVAR	Energy prices (–) Economic development (–) Renewable energy share (–)
Emir and Bekun (2019)	Romania	1990–2014	ARDL, DOLS	Economic development (–)

Table 1.



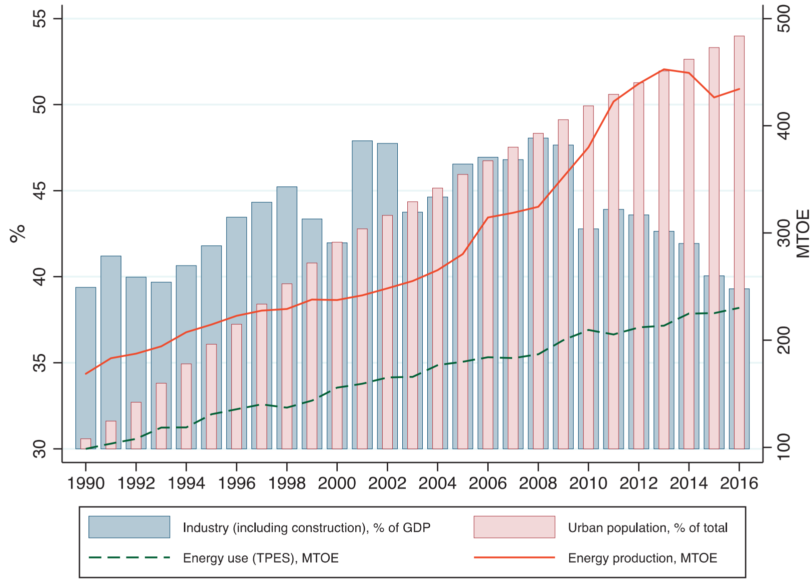
Source(s): Data from World Bank (2018)

Figure 1.
The annual Indonesian GDP growth, 1990–2016

increasing domestic energy demand forced Indonesia to become a net importer of oil in 2004 finally, and it subsequently left OPEC in 2008.

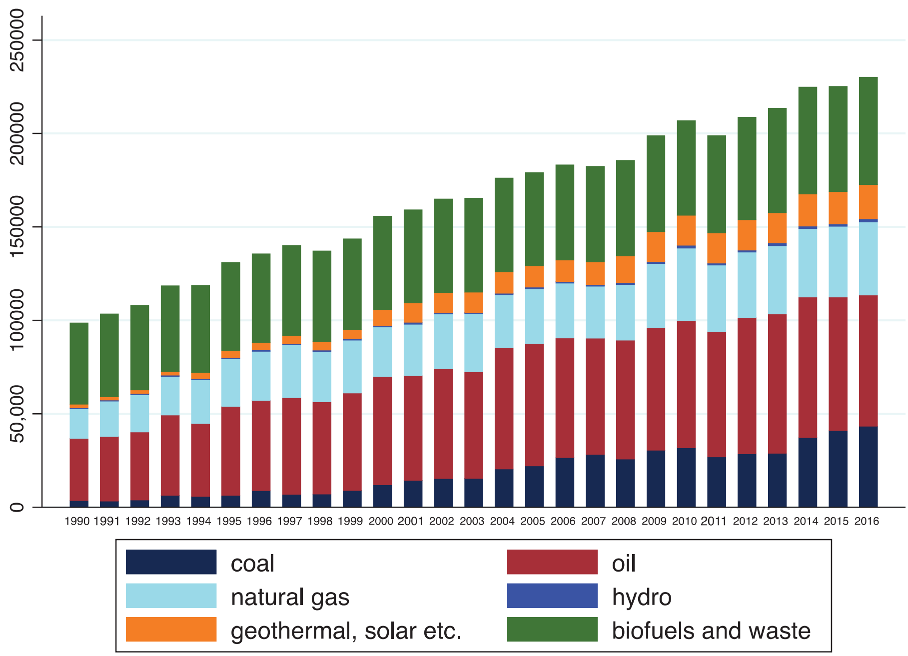
Throughout 2007–2017, Indonesia's proven natural gas reserves have decreased by 4.3%, but the production rate has declined by 6.3%. Indonesia is known as the ninth most significant natural gas exporter, particularly in the form of LNG, while Japan and South Korea are the largest consumers of Indonesia's LNG. Furthermore, some natural gas is exported through a gas pipeline towards Singapore and Malaysia.

Nevertheless, unusually being among the world's significant producers of oil and gas, Indonesia had no substantial increase in gas production (64.5 MTOE in 2016 against 61.1 MTOE in 2000) and a substantial fall in oil production (42.6 MTOE in 2016 against 71.6 MTOE in 2000) through the period of extraordinarily high petroleum prices. Several factors put downward pressure on Indonesia's oil output each year, including licensing approvals at the regional level of government, land acquisition and permit issues, oil theft in the South



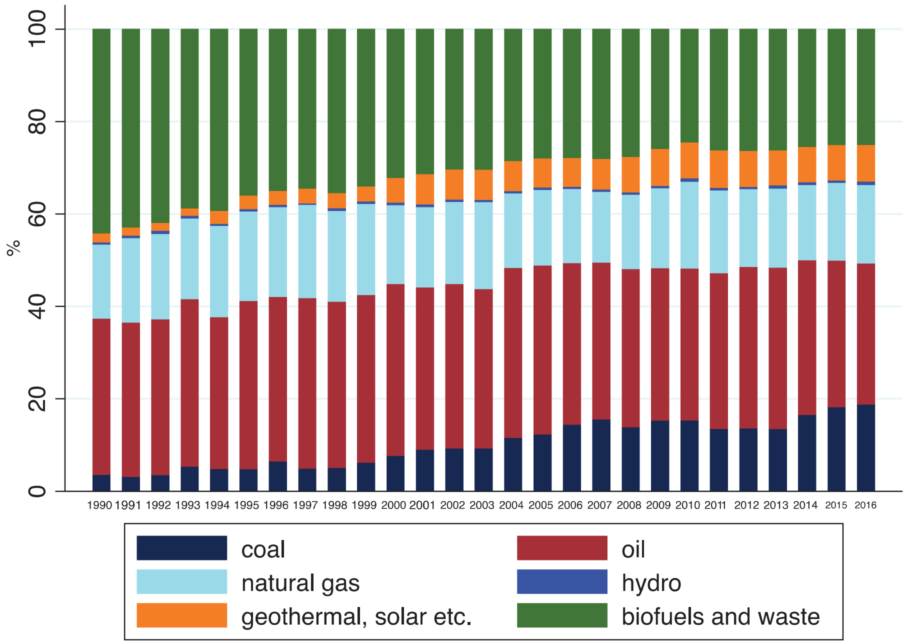
Source(s): Data from the World Bank (2018) and International Energy Agency (2018)

Figure 2.
Annual energy use and production in Indonesia



Source(s): Data from the International Energy Agency (2018)

Figure 3.
Total primary energy supply by fuel in Indonesia



Source(s): Data from the International Energy Agency (2018)

Figure 4.
Indonesian energy mix in 1990–2016

Table 2.
Energy sources of Indonesia

Variable	Quantity	Share of the world's total (%)	Ranking in the world	Change in 2017 to 2007 (%)
Oil proved reserves (billion barrels)	3,2	0.2	29	−20.5
Oil production (million tonnes)	46.4	1.1	21	−3.1
Oil consumption (million tonnes)	73.7	1.6	15	19.3
Natural gas proved reserves (trillion cubic meters)	2.9	1.5	14	−4.3
Natural gas production (MTOE)	58.4	1.8	12	−6.3
Natural gas consumption (MTOE)	33.7	1.1	25	13.1
Coal reserves (billion tonnes)	22.6	2.2	10	–
Coal production (MTOE)	271.6	7.2	5	112.5
Coal consumption (MTOE)	57.2	1.5	9	57.8
Hydroelectricity consumption (MTOE)	4.2	0.5	30	62.6
Renewables: consumption – geothermal, biomass and other (MTOE)	2.9	0.6	26	84.6
Total primary energy consumption (MTOE)	172.5	1.3	15	30.4
Carbon dioxide emissions (million tonnes CO_2)	511.5	1.5	11	32.3

Source(s): Data from BP (2018)

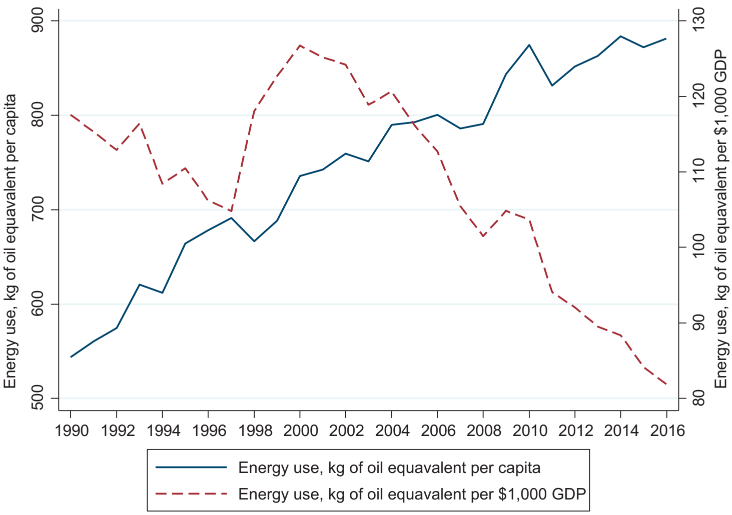
Sumatra region, ageing oil fields and infrastructure and insufficient investment in unexplored reserves. Indonesia's resource base would have supported a substantial increase in gas and probably oil production with less restricted access to international expertise and capital (Garnaut, 2015).

The empirical findings show that Indonesia's energy use has risen faster than the population growth resulting in per capita energy use increase (Figure 5). The Asian financial crisis of 1998 influenced Indonesian primary energy supply and consumption negatively bringing it down by 2%. There was the growth of primary energy production and consumption after 1998, while the country's EI increased due to weak GDP growth. Although the world's energy consumption was quite high, i.e. 2 TOE per capita in 2016, Indonesia used only 0.88 TOE per capita with an average year to year growth of primary energy use per capita around 2% since 1990 (0.6% in the world). More importantly, for the global resources boom, Indonesia came to use much less energy per unit of economic output.

Energy use per thousand PPP $ of GDP was 0.08 TOE in 2016, which was one of the lowest among ASEAN and also well below the global average (0.13 kg TOE in 2016). The GDP per unit of energy use in Indonesia was instead one of the highest in ASEAN at 11.37 PPP $ per kg of oil equivalent in 2013. The average level of reducing Indonesia's EI for the period from 1990 to 2016 made up 5.44% per year.

4. Methodology

This section discusses the construction of an empirical model specification. The authors estimate the impact of chosen factors on EI in Indonesia by using a time series dataset covering the period from 1990 to 2016. Specifically, we consider the following variables: EI, the share of alternative and nuclear energy, industry value-added, trade openness, FDI net inflows, domestic credit to the private sector and real prices of Brent crude oil. The sample period begins in 1990 because it was in that year that the World Bank, along with the IEA, started to update EI data annually. Nevertheless, the timeframe is representative, covering various stages of economic cycles in Indonesia.



Source(s): Data from the World Bank and International Energy Agency

Figure 5. The Indonesian energy intensity and energy use, 1990–2016

In an attempt to understand the variation in EI changes better, Bernstein *et al.* (2003) identify the following factors of EI: energy prices, the composition of an economic sector's output, capacity utilisation, capital investment and new construction, technological innovation, population and demographics, climate and energy policy. Azhgaliyeva *et al.* (2020) argue that major determinants of country-level energy efficiency in the literature include energy prices, real GDP per capita, economic structure and trade openness. The control variables are chosen on the basis of empirical literature (Fisher-Vanden *et al.*, 2004; Hübler and Keller, 2010; Hübler, 2011; Adom and Kwakwa, 2014; Adom, 2015b; Akal, 2016; Rudenko and Raschetova 2018), data availability and the nature of this study. We believe that the chosen variables cover the major indicators of Indonesia's energy sector, as well as the country's openness to new technologies and its financial ability to implement them. As a novelty, the current study captures the effects of financial development and energy use structure on EI.

The database used in this paper is constructed by combining energy consumption data from the Energy Balances (International Energy Agency, 2018) with economic data obtained from the World Development Indicators database (World Bank, 2018). Data on Brent crude oil prices as well as coal prices are sourced from the BP statistical review of World Energy (BP, 2018).

4.1 Empirical model and data

It is plausible to form a long-run relationship between EI and its factors in a linear logarithm form. The empirical model for this study follows directly from Adom and Kwakwa (2014), Adom (2015b), Rudenko and Raschetova (2018). It is represented by Equation (1) as follows:

$$\ln(\mathrm{EI})_t = \alpha + \beta_1 \ln(\mathrm{OIL})_t + \beta_2 \ln(\mathrm{IND})_t + \beta_3 \ln(\mathrm{FDI})_t + \beta_4 \ln(\mathrm{TR})_t + \beta_5 \ln(\mathrm{AE})_t + \beta_6 \ln(\mathrm{FIN})_t + \varepsilon_t \qquad (1)$$

where EI is EI, AE is a share of alternative and nuclear energy, IND is industry value-added, FDI is foreign direct investment, TR is trade openness, FIN is domestic credit to the private sector and OIL is a real price of Brent crude oil.

EI is measured as the kilogram of oil equivalent of energy use per 1,000 constant PPP GDP. PPP GDP is gross domestic product converted to international dollars using PPP rates. An international dollar has the same purchasing power over GDP as the US dollar has in the United States. Data are in constant 2011 international dollars. Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

The energy price (OIL), being one of the most critical factors in terms of energy consumption, is measured as the price of Brent crude oil per barrel in terms of constant 2018 US dollars. According to IEA data (IEA, 2018), oil constitutes almost 30% of the total primary energy supply in Indonesia, which fact makes crude oil prices quite an important factor. We include this variable to show the energy-saving impact of oil prices. The general position of the literature is that higher prices of energy will cause EI to fall.

Industry value added (IND) includes value added in industries belonging to ISIC divisions 10–45 and including manufacturing (ISIC divisions 15–37). It comprises value added in mining, manufacturing, construction, electricity, water and gas. This determinant is measured as a percentage of GDP. It is considered as a high energy-intensive activity than any others, so the authors assume that the higher this share in the economy is, the higher the EI is. Typically, industry-oriented economies are more energy-intensive than agriculture and services (Mimouni and Temimi, 2018).

FDIs are the net inflows of investment to acquire a lasting interest in or management control over an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital and short-term capital, as shown in the balance of payments. The FDI variable, as used in this study, is measured as the net inflow of FDI as a percentage of GDP. Generally, the effect of FDI on EI has been established to be positive. Foreign investments, imports and international aid foster the transfer of energy-saving technology and leads to lower EI (the amount of energy used per unit of output). This transmission of knowledge and improvement in energy efficiency is usually achieved when countries employ new technologies, import less energy-intensive goods and foster better management practices (Mimouni and Temimi, 2018).

Trade openness (TR) is the sum of exports and imports of goods and services measured as a share of gross domestic product. This determinant shows the extent of openness of the economy. The current study uses trade openness and FDI as channels for technological diffusion. Trade openness contributes to the development of local competition, which in turn leads to the introduction of energy-saving technologies. Albeit, there is an agreement on the roles of FDI and trade in reducing EI; their specific roles are not evident in the literature. The effects of imports on energy use depend on their structure, which is affected by a country's comparative advantage, the level of its economic development and the environmental regulations in place (Grossman and Krueger, 1991; Copeland and Taylor, 1994; Antweiler *et al.*, 2001; Cole, 2006; Sadorsky, 2011; Salim *et al.*, 2017).

Alternative and nuclear energy (AE) is zero-carbon energy that does not produce carbon dioxide when generated. It includes hydropower and nuclear, geothermal, solar power, among others. It is measured as a percentage of total energy use. In the current study, a share of alternative and nuclear energy is a new, not previously analysed variable. The authors suppose that the higher this share is, the less EI of the country is. Indonesia belongs to the group of countries with a growing share of the consumption of fossil fuels. The reduction of this share will allow decreasing the amount of primary energy used. Development of alternative and nuclear energy in Indonesia will reduce the EI of production, as well as provide energy to territories cut off from the centralized power supply. As a rule, these territories use coal and petroleum products for providing energy. Current energy strategy of Indonesia does not include the construction of any nuclear power plants. Government efforts are aimed at the development of nuclear energy roadmap (IAEA, 2018).

Domestic credit to the private sector (FIN) as a share of GDP refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of nonequity securities and trade credits and other accounts receivable, which establish a claim for repayment. Financial development describes the effects of cumulative capital (vintage capital) on EI. A more extensive stock of capital fosters "learning by doing" and leads to more energy efficiency. On the other hand, energy-intensive industries are usually capital intensive. As a result, an increase in accumulated capital may generate a surge in EI. Hence, the impact of accumulated capital on EI is ambiguous depending on which effect prevails (Mimouni and Temimi, 2018).

Determining the relationship between dependent and independent variables in this study, especially EI and a share of alternative energy sources, raises some endogeneity apprehensions. To address these, we use the recent econometric techniques that are more robust to serial correlation and endogeneity problems (Adom, 2015b).

4.2 Econometric methodology

Most economic time series are integrated of degree one and difference stationary. Applying a regression to the levels of those $I(1)$ series leads to a spurious correlation, particularly when the variables involved exhibit long-run trend movement. The cointegration concept has been introduced to take care of such a non-stationarity of the variables and investigate the existence of a long-run equilibrium relationship among them. If these variables are cointegrated as defined by Engle and Granger (1987), then the task of describing these long-run relations reduces to the problem of estimating cointegrating vectors (Stock and Watson, 1993). Although Engle and Granger (1987) as well as Johansen (1991) propose basic approaches to test the existence of cointegration between variables of interest and estimate the co-integrating vector, there are alternative methods of estimating the long-run parameters where there is only one cointegrating relationship. The Phillips and Hansen's (1990) fully modified least squares (FM-OLS), Park's (1992) canonical cointegrating regression (CCR) as well as Stock and Watson's (1993) dynamic least squares (DOLS) are among the usual alternatives. As mentioned in Adom (2015b), the alternative approaches are known to be more robust to serial correlation and endogeneity compared to the Johansen or ARDL approach. Hence the methods produce consistent and robust estimates of the long-run parameters especially for a small sample size solving the defects of the simple OLS approach.

Determining the long-run relationship between selected variables and Indonesia's EI we undertake the following steps. The first step is to examine the stationarity properties of the chosen variables using unit root tests. Once the existence of a unit root has been established, the issue arises whether there exists a long-run equilibrium relationship between variables. Given that each variable is non-stationary, we examine whether the series exhibit a common deterministic trend using parameter instability test (Hansen, 1992). After confirming the cointegration of the variables, we employ FM-OLS, CCR and DOLS techniques to estimate the long-run cointegration vector.

Before testing for cointegration, we determine the order of integration of each series $I(d)$ of variables included in equation (1). The most common testing procedures used for such purposes are the Dickey–Fuller (DF), Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests (Dickey and Fuller, 1979; Said and Dickey, 1984; Phillips and Perron, 1988). However, these unit root tests (DF, ADF and PP) have relatively low power to reject their null hypothesis. A great advantage of the PP test is that it is non-parametric, it does not require to select the level of serial correlation as in ADF. It rather takes the same estimation scheme as in the DF test, but corrects the statistic to conduct for autocorrelations and heteroscedasticity. The main disadvantage of the PP test is that it is based on asymptotic theory. Hence it works well only in large samples that we are indeed missing in Indonesia's case. Moreover, any sort of structural break in the series is likely to cause a failure to reject, even if the series is stationary before and after the structural break. To deal with low power of ADF and PP tests, more powerful tests such as Elliott, Rothenberg, Stock's (ERS) DF-GLS test have been devised (Elliott *et al.*, 1996). Their test is like the ADF test but has the best overall performance in terms of small-sample size and power, dominating the ordinary DF test. To confirm the findings of the DF-GLS test we also consider the KPSS test of Kwiatkowski *et al.* (1992), which has the more natural null hypothesis of stationarity ($I(0)$), where a rejection indicates non-stationarity ($I(1)$ or $I(d)$). Using a longer time series is not feasible due to known structural breaks, institutional changes and the like. A problem common with the classic unit root tests is that they are particularly susceptible to breaks in the structure of a relationship. So, we consider Zivot–Andrews (Zivot and Andrews, 1992) endogenous structural break test that is a sequential test which utilizes the full sample and uses a different dummy variable for each possible break date. Since all series in this study depict upward or downward trend, we employ the tests for a unit root in time series, assuming constant with the trend.

We proceed to check the cointegration relationship between selected variables for EI function referring to Hansen's Instability test as well as to Johansen multivariate test. Cointegration implies that albeit series may be non-stationary, there is as a systemic co-movement among variables over the long run. Hansen (1992) outlines a test of the null hypothesis of cointegration against the alternative of no cointegration. He notes that under the alternative hypothesis of no cointegration, one should expect to see evidence of parameter instability.

Based on the existence of a cointegration relationship among the variables, we therefore estimate the long-run relationships using the Phillips and Hansen's (1990) fully modified least squares (FM-OLS), Park's (1992) canonical cointegrating regression (CCR) as well as Stock and Watson's (1993) dynamic least squares (DOLS) model. All three methods are superior to the OLS as they take care of small sample bias and endogeneity bias. Moreover, the OLS estimates may suffer from serial correlation, heteroskedasticity since the omitted dynamics are captured by the residual so that inference using the normal tables will not be valid even asymptotically.

Consider the $n+1$ dimensional time series vector process (y_t, X_t'). The generating mechanism for it is the cointegrated system in its triangular form:

$$y_t = X_t'\beta + D_{1t}'\gamma_1 + u_{1t} \tag{2}$$

$$X_t = \Gamma_{21'}' D_{1t} + \Gamma_{22'}' D_{2t} + \epsilon_{2t} \tag{3}$$

$$\Delta\epsilon_{2t} = u_{2t} \tag{4}$$

where X_t are n stochastic regressors, $D_t = (D_{1t}', D_{2t}')'$ are deterministic trend regressors and $u_t = (u_{1t}', u_{2t}')'$ is strictly stationary with zero mean and finite covariance matrix $\sum$. In the general case, whenever $\sum$ is not block-diagonal and/or the u_t, process is weakly dependent, the ordinary least square estimate of β is consistent but not efficient. The approach by FM-OLS and CCR techniques is to use a transformation process to produce a consistent and efficient estimator.

Fully modified least squares (FM-OLS) regression is a semi-parametric method designed by Phillips and Hansen (1990) to eliminate the problems caused by the long-run correlation between the cointegrating equation and stochastic regressors innovations. The estimator is asymptotically unbiased and uses the transformation of both the data and the estimates. If we let u_{1t} be the residuals obtained from Eq. (2), then we can obtain let u_{2t} indirectly as $\Delta\epsilon_{2t} = u_{2t}$ from the levels regressions Eq. (3) or directly from the difference Eq. (5)

$$\Delta X_t = \widehat{\Gamma}_{21'}\Delta D_{1t} + \widehat{\Gamma}_{22'}\Delta D_{2t} + u_{2t} \tag{5}$$

If we let $\widehat{\Omega}$ and $\widehat{\Lambda}$ be the long-run covariance matrices computed using the residuals $u_t = (u_{2t}', u_{2t}')$. Then we may define the modified data (Eq. 6) and an estimated bias correction term (Eq. 7)

$$y_t^+ = y_t - \widehat{\omega}_{12}\widehat{\Omega}_{22}^{-1}u_2 \tag{6}$$

$$\widehat{\lambda}_{12}^+ = \widehat{\lambda}_{12} - \widehat{\omega}_{12}\widehat{\Omega}_{22}^{-1}\widehat{\Lambda}_{22} \tag{7}$$

y_t^+ and $\widehat{\lambda}_{12}^+$ are the correction terms for endogeneity and serial correlation, respectively. The FM-OLS estimator (θ_{FM}) is given by

$$\theta_{\mathrm{FM}} = \begin{bmatrix} \beta \\ \widehat{\gamma}_1 \end{bmatrix} = \left(\sum_{t=2}^{T} Z_t Z_t' \right)^{-1} \left(\sum\nolimits_{t=2}^{T} Z_t y_t^+ - T \begin{bmatrix} \widehat{\lambda}_{12}^{+'} \\ 0 \end{bmatrix} \right) \tag{8}$$

where $Z_t = (X_t', D_t')'$.

Contrary to the FM-OLS, the CCR estimator is based only on a transformation of the data in the cointegrating regression that removes the second-order bias of the OLS estimator. The first step is to obtain estimates of residuals $u_t = (u_{1t}^{'}, u_{2t}^{'})^{'}$ and corresponding consistent estimates of the long-run covariance matrices $\widehat{\Omega}$ and $\widehat{\Lambda}$. Unlike FMOLS, CCR also requires a consistent estimator of the contemporaneous covariance matrix $\sum$. Following Park (1992), to obtain consistent and efficient estimate of β we transform the $(y_t, X_t^{'})$ using

$$X_t^* = X_t - \left(\widehat{\Sigma}^{-1}\widehat{\lambda}_2\right)^{'} u_t \tag{9}$$

$$y_t^* = y_t - \left(\widehat{\Sigma}^{-1}\widehat{\lambda}_2\overline{\beta} + \begin{bmatrix} 0 \\ \widehat{\Omega}_{22}^{-1}\widehat{\omega}_{21} \end{bmatrix}\right)^{'} \widehat{u}_t \tag{10}$$

The CCR estimator is defined as ordinary least squares applied to the transformed data

$$\theta_{\text{CCR}} = \begin{bmatrix} \widehat{\beta} \\ \widehat{\gamma}_1 \end{bmatrix} = \left(\sum_{t=1}^{T} Z_t^* Z_t^{*'}\right)^{-1} \sum_{t=1}^{T} Z_t^* y_t^* \tag{11}$$

Stock and Watson (1993) have proposed to estimate β running the following regression:

$$y_t = X_t^{'}\beta + D_{1t}^{'}\gamma_1 + \sum_{j=-q}^{r} \Delta X_{t+j}^{'}\delta + v_{1t} \tag{12}$$

Termed dynamic OLS (DOLS), the method takes care of endogeneity by adding the leads and lags of X_t so that the resulting cointegrating equation error term is orthogonal to the entire history of the stochastic regressor innovations. Under the assumption that adding q lags and r leads to the differenced regressors soaks up all of the long-run correlation between u_{1t} and u_{2t} least-squares estimates of $\theta = (\beta', \gamma')'$ have the same asymptotic distribution as those obtained from FM-OLS and CCR.

The selection of the methods is precisely discussed by Montalvo (1995) who notes that the CCR estimator shows less bias than the OLS and the fully modified estimators in small samples using Monte Carlo simulations. The DOLS estimator has better sample properties rather than the CCR estimator. So, the parametric DOLS is preferred to the non-parametric FM-OLS in that the latter (unlike the former) imposes additional requirements that all variables should be integrated of the same order (i.e. $I(1)$) and that the regressors themselves should not be cointegrated.

5. Results

5.1 Baseline model

The focus of this study is to explore the long-run relationship among EI and its factors (estimation of Eq. (1)). The first step is to examine the time series by unit root tests and identify the order of integration of each variable. We employ the PP, DF-GLS, KPSS and Zivot–Andrews tests for a unit root in time series, assuming constant with the trend. Table 3 reports the results for the level and the first difference of each variable. The tests show that all variables are non-stationary at levels, but they are stationary at their first differences at a 10% level of significance, and hence the time series are integrated of order one, $I(1)$. The optimal lag length is determined by the Schwarz information criterion (SIC). Although the dates of the structural break, according to Zivot–Andrews test, are different for our variables, most of the dates are concentrated around the Asian financial crisis (1997) and the Global financial crisis (2008). EI, industry value-added, trade openness and domestic credit to the private sector have breaks during or soon after the Asian financial crisis. Economic

Variables	PP	DF-GLS	KPSS	ZA
EI	−0.86	−1.00	0.22***	−3.43 (0) [2003]
D.EI	−4.70***	−4.85***	0.08	−5.25*** (0) [1999]
AE	−1.43	−1.57	0.21***	−4.23* (0) [2003]
D.AE	−5.48***	−5.33***	0.07	−4.49** (2) [2008]
IND	−1.08	−1.65	0.23***	−3.55 (2) [2009]
D.IND	−5.86***	−5.65***	0.07	−7.01*** (1) [1997]
FDI	−2.11	−2.00	0.12*	−2.47 (0) [2000]
D.FDI	−3.79*	−4.01***	0.08***	−4.11* (0) [2012]
OIL	−1.79	−1.64	0.12*	−2.68 (0) [2012]
D.OIL	−4.10***	−4.26***	0.17**	−5.55*** (0) [2012]
TR	−2.62	−2.87	0.19**	−4.82** (0) [2000]
D.TR	−7.94***	−7.56***	0.06	−7.25*** (0) [1999]
FIN	−1.43*	−1.40	0.19**	−2.94 (0) [2002]
D.FIN	−4.03***	−4.22***	0.07	−4.38* (0) [2000]

Source(s): Author's calculations
Note(s): 1. D.Y denotes first differencing of time series Y, 2. ***, **, * indicate 1%, 5 and 10% significance levels, respectively, 3. () represents the optimum lag length, 4. [] represents the year of a break in trend, 5. All tests are conducted with the model of both intercept and trend orientation

Table 3.
Unit root tests

instability in the region diminished both the importance of capital access and the role of cross-border operations. The remaining breaks are concentrated around 2008–2012; oil prices, FDI and the share of alternative energy sources had breakpoints mainly because oil prices peaked during that period.

Next, we use the Hansen Parameter Instability test to determine the cointegration relationship. The results of the test statistics are presented in Table 4. Taking into consideration the 5% significance level, we cannot reject the null hypothesis of cointegration, so the Hansen parameter instability test shows that there is a long-run equilibrium relationship. We find existence of cointegration relationships between EI and its factors: a share of alternative and nuclear energy, industry value-added, trade openness, FDI net inflows, domestic credit to the private sector and real prices of crude oil. Thus, the chosen factors can be treated as the long run forcing variables explaining EI in Indonesia.

When interpreting the results from tests that take no cointegration as the null hypothesis we should be very mindful. In particular, a rejection by such a test does not imply that all the units of the panel are cointegrated, the average is so, but a single unit may not (Streimikiene and Kasperowicz, 2016). So, we perform the Johansen multivariate test. Table 5 shows the

Series: EI AE IND FDI OIL TR FIN
Null hypothesis: series are cointegrated
Cointegrating equation deterministic: Const
Additional regressor deterministic: @TREND

Lc statistic	Stochastic Trends (m)	Deterministic Trends (k)	Excluded Trends ($p2$)	Prob.*
0.144	6	0	0	>0.2

Source(s): Author's calculations
Note(s): *Hansen (1992) Lc ($m2 = 4, k = 0$) p-values, where $m2 = m - p2$ is the number of stochastic trends in the asymptotic distribution

Table 4.
Cointegration test – Hansen parameter instability

result for the Trace and Maximum eigenvalue test. The Trace test indicates that there are three cointegrating equations. This is confirmed by the Maximum eigenvalue test, which also shows three cointegrating equations. By implication, the short-term path of these variables may diverge, but in the long run there is convergence in their path.

The results of co-integration test support the existence of long-run equilibrium relationships among the model's variables. Hence, the next step is to estimate the long-run cointegrating vector between EI and its factors. We employ the FM-OLS, CCR and DOLS methods taking deterministic trend and constant into account. The DOLS estimator values are determined following the assumption of one lag and one lead in the change of the regressors. Table 6 summarizes the results of the FMOLS, CCR and DOLS estimators of Eq. (1) for Indonesia.

For the chosen variables the FM-OLS, CCR and DOLS estimators produce similar results in terms of the sign and statistical significance, whereas the magnitudes of the estimated coefficients are slightly different. We find a positive relationship between EI, globalisation (trade openness and FDI), industrialisation (industry value added). The FM-OLS results suggest that a 1% increase in trade openness increases EI by 0.3%, a 1% increase in FDI increases EI by 0.02% and a 1% increase in industry value added increases EI by 0.4%. In case of FDI and industrialisation FM-OLS, DOLS and CCR estimators produce similar results in terms of the sign, but the statistical significance is different for each method – for DOLS FDI and industrialisation are not significant variables, while for FM-OLS and CCR they are

Table 5. Cointegration test – Johansen multivariate test

Hypothesized no. of CE(s)	Trace test	Maximum eigenvalue test
None	201.01***	56.65***
At most 1	144.36***	46.84***
At most 2	97.52***	42.22***
At most 3	55.30	21.83

Source(s): Author's calculations
Note(s): *** Indicates 1% significance level

Table 6. Long-run estimates: baseline model

Dependent variable: energy intensity (ln)
Sample (adjusted): 1991–2016
Cointegrating equation deterministic: Const
Additional regressor deterministic: @TREND
Long-run covariance estimate (Prewhitening with lags = 2 from AIC maxlags = 2, Bartlett kernel, Newey–West automatic bandwidth = 1.9861, NW automatic lag length = 2

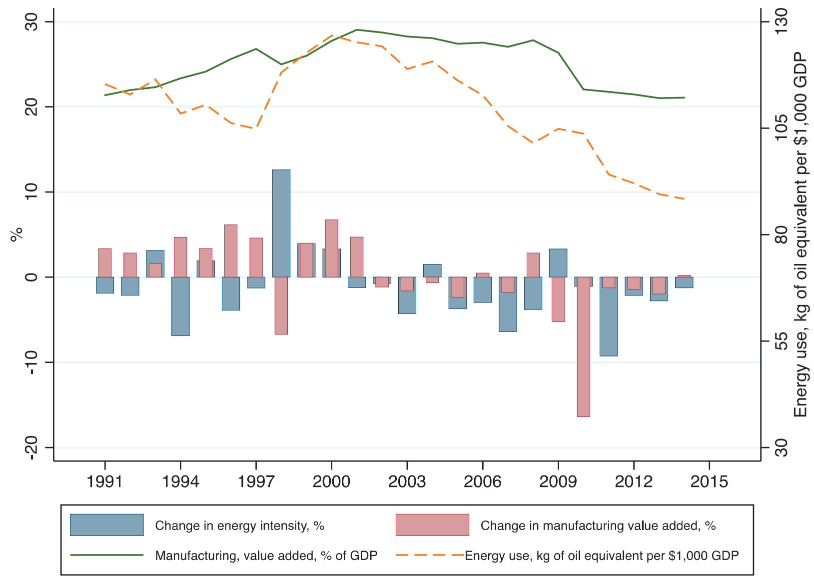
Variable	FM-OLS	DOLS	CCR
Const	3.358*** (0.089)	3.980*** (1.008)	3.465*** (0.056)
Ln(AE)	−0.176*** (0.004)	−0.214*** (0.04)	−0.191*** (0.002)
Ln(IND)	0.399*** (0.024)	0.395 (0.27)	0.316*** (0.013)
Ln(FDI)	0.018*** (0.001)	0.005 (0.015)	0.032*** (0.00)
Ln(OIL)	−0.062*** (0.004)	−0.052 (0.038)	−0.074*** (0.002)
Ln(TR)	0.300*** (0.008)	0.166* (0.09)	0.395*** (0.008)
Ln(FIN)	−0.246*** (0.006)	−0.256*** (0.065)	−0.28*** (0.005)
Adjusted *R*-squared	0.887	0.993	0.842
Lon-run variance	0.0005	0.0027	0.0004

Source(s): Author's calculations
Note(s): ***, **, * indicate 1%, 5 and 10% significance levels, respectively

significant. The effect of real prices of crude oil, financial development and alternative energy consumption on EI is negative and statistically significant. The result is robust in two out of three regression models. This result makes a conviction of energy efficient technological development of Indonesia, what means that a significant substitution of fossil fuels by alternative energy sources would decries the EI of the Indonesian economy. In sum, we find that high prices of crude oil together with financial development and alternative energy sources have negative and statistically significant impact on EI in the long run.

5.2 Robustness check

We provide a set of robustness checks for the effect of chosen factors on EI in Indonesia. First, we employ alternative measurements of the industrial structure. The industrialisation is a complex factor that can be measured using different indicators. In the first robustness check, we adopt manufacturing value added (MAN) to replace industry value added variable. Indonesian manufacturing sector (measured by the ratio of manufacturing value added to the GDP) has fluctuated as an inverted U-shaped curve (Figure 6). However, its EI (measured by energy consumption per unit of GDP, its inverse stands for energy efficiency) follows a declining trend. Although this trend was temporarily reversed after the Asian Financial crisis 1998–2000, its decline rate is fluctuating dramatically. Thus, clarifying the possible effects of manufacturing structure on EI and providing evidence for determining the possible direction for the decline rate of EI is our motivation. Second, we consider possible structural breaks in the data. The EI series displays some fluctuations especially in the late-1990 that reflect the period of the Asian financial crisis. As such, our econometric modelling accounts for such a break which is necessary to avoid misleading statistical inferences. The current study employs ZA unit root test that accounts for a possible single structural break and reveals significant break dates that resonate with Indonesia's economic development (Table 3). Third, for a more rigorous analysis, we also duplicate the regressions through the use of coal



Source(s): Data from the World Bank (2018)

Figure 6.
Energy intensity and manufacturing sector in Indonesia

prices instead of oil prices as a substitute variable for energy prices. Indonesia is the fifth-largest coal producer in the world and one of the largest coal exporters. Moreover, Indonesia had a substantial increase in coal consumption (43.3 MTOE in 2016 against 12.1 MTOE in 2000), which made coal, at 19% in country's energy mix, the third-largest energy source. We measure coal prices in terms of the Asian prices as the average of the monthly marker (BP, 2018) in constant 2018 US dollars (deflated using the Consumer Price Index for the US).

Table 7. Long-run estimates: robustness check 1

Dependent variable: energy intensity (ln)
Sample (adjusted): 1991–2016
Cointegrating equation deterministic: Const
Additional regressor deterministic: @TREND
Long-run covariance estimate (Prewhitening with lags = 2 from AIC maxlags = 2, Bartlett kernel, Newey–West automatic bandwidth = 1.8132, NW automatic lag length = 2

Variable	FM-OLS	FM-OLS	DOLS	CCR
Const	4.203*** (0.053)	5.334*** (0.013)	5.205*** (0.034)	5.131*** (0.493)
Ln(AE)	−0.191*** (0.001)	−0.212*** (0.001)	−0.234*** (0.031)	−0.233*** (0.02)
Ln(MAN)	0.192*** (0.013)	0.024*** (0.001)	0.141 (0.112)	0.152*** (0.01)
Ln(FDI)	0.003*** (0.000)	0.001*** (0.000)	0.010 (0.021)	0.011 (0.012)
Ln(OIL)	−0.021*** (0.000)	−0.071*** (0.000)	−0.051 (0.042)	−0.052*** (0.030)
Ln(TR)	0.243*** (0.001)	0.262*** (0.001)	0.192*** (0.063)	0.183*** (0.082)
Ln(FIN)	−0.201*** (0.000)	−0.321*** (0.001)	−0.322*** (0.071)	−0.301*** (0.061)
D(1999)		−0.212*** (0.001)	−0.163*** (0.050)	−0.142*** (0.070)
Adjusted R-squared	0.879	0.905	0.920	0.930
Lon-run variance	0.0001	0.0004	0.0015	0.0006

Source(s): Author's calculations
Note(s): ***, **, * indicate 1%, 5 and 10% significance levels, respectively

Table 8. Long-run estimates: robustness check 2

Dependent variable: energy intensity (ln)
Sample (adjusted): 1991–2016
Cointegrating equation deterministic: Const
Additional regressor deterministic: @TREND
Long-run covariance estimate (Prewhitening with lags = 2 from AIC maxlags = 2, Bartlett kernel, Newey–West automatic bandwidth = 4.3386, NW automatic lag length = 2

Variable	FM-OLS	DOLS	CCR
Const	4.579*** (0.051)	4.182*** (0.852)	3.975*** (0.784)
Ln(AE)	−0.279*** (0.002)	−0.264*** (0.036)	−0.246*** (0.036)
Ln(IND)	0.457*** (0.014)	0.407* (0.232)	0.490* (0.244)
Ln(FDI)	0.021*** (0.000)	−0.002 (0.011)	−0.006 (0.012)
Ln(COAL)	−0.111*** (0.002)	−0.042 (0.036)	−0.059 (0.035)
Ln(TR)	0.151*** (0.004)	0.149* (0.079)	0.112 (0.138)
Ln(FIN)	−0.371*** (0.006)	−0.285*** (0.055)	−0.260*** (0.061)
D(1999)	−0.114*** (0.003)	−0.155** (0.055)	−0.137 (0.098)
Adjusted R-squared	0.847	0.899	0.898
Lon-run variance	0.0007	0.0021	0.0011

Source(s): Author's calculations
Note(s): ***, **, * indicate 1%, 5% and 10% significance levels, respectively

The results given in Table 7 and Table 8 show that the sign and significance of the estimated coefficients are broadly consistent with our benchmark results in Table 6. The relationship between globalisation, industrialisation and EI remains significantly positive, while the effect of energy prices, consumption of alternative energy sources and financial development on EI is negative.

6. Discussion

The estimated coefficient of the FDI effect on EI shows a 0.03% growth of EI with a per cent increase in FDI. A full circle of scholars studies this effect (Mielnik and Goldemberg, 2002; Hübler and Keller, 2010; Sadorsky, 2010; Mimouni and Temimi, 2018), but the results are mixed. Hübler and Keller (2010) and Sadorsky (2010) find that FDI does not affect EI in the samples of 60 and 22 countries, respectively. Ertugrul *et al.* (2014) display that investments lead to an increase in energy consumption in the case of Indonesia, Malaysia and Thailand. Mielnik and Goldemberg (2002) reveal a positive effect of FDI on EI while Mimouni and Temimi (2018) describe an inverted-U-shaped relationship among low-, middle- and high-income countries. According to them, FDI leads to more energy efficiency in middle-income countries, like Indonesia. However, our results show the opposite: one of the reasons for this might be the fact that Indonesia attracts foreign investment mainly to manufacturing, mining and quarrying.

The effect of trade openness on EI is positive and statistically significant. The increase of trade openness by 1% is expected to raise EI by 0.39% approximately. Sadorsky (2011) as well as Mimouni and Temimi (2018) reach similar results for imports in Middle East countries and middle-income countries respectively. The findings of Hübler and Keller (2010) do not confirm the existence of the effect of trade openness on EI in the sample of 60 developing countries for the 1975–2004 period. Herrerias *et al.* (2013) mark opposite results based on Chinese provinces for the period from 1985 to 2008.

Each 1% of the growth in industry value added is expected to increase EI by 0.32%. Our results are very close to conclusions made by Poumanyvong and Kameko (2010) as well as Adom and Kwakwa (2014). In opposite, Lin and Moubarak (2014) show the negative relationship between changes in industrial structure and EI in China.

We find that the impact of domestic credit for the private sector is negative and statistically significant. It affects R&D expenditure, increasing the technological level of the national economy and spurring the development of energy-saving projects. The positive influence of financial development on the decline of EI in par with energy prices is proved by Fisher-Vanden *et al.* (2004). The provision of credits for the private sector for the development of renewable energy may produce a synergistic effect in reducing EI. Investments in the development of renewables might mitigate the downward trends in the fossil fuels, increase production by extension of infrastructure in addition to reducing of greenhouse gas emissions and supporting of energy security (Kurniawan and Managi, 2018). Furthermore, the need for state support of renewables also caused by the entrenched fossil fuels in Indonesia energy mix (Mormann, 2011). Domestic credit to the private sector can ease transition to the consumption of renewable energy sources, as an access to capital can stimulate business to upgrade production lines in order to achieve higher energy efficiency. Moreover, easier access to capital may attract foreign companies to start local entities and transfer new technologies to the country.

The effect of crude oil price on EI is negative and statistically significant. A 1% increase in crude oil price is expected to reduce EI by 0.07% approximately. Rudenko and Rastchetova (2018) show the effect to be 0.26 for Russia, Lin and Moubarak (2014) estimate it to be 0.916, Adom (2015a, b) find the price effect for Nigeria to be 0.383 and for South Africa to be 0.127. The relatively low oil price elasticity can be explained by the fact that Indonesia has always subsidized oil prices for domestic retail fuel consumers, with selling energy products at a discounted price well below the world market parity prices (Rafiq and Salim, 2011). Fuel subsidies have cost the government from 7% and 27% of its annual public expenditures between 2005 and 2014. High international oil prices before the second half of 2014 and increasing fuel imports made energy subsidies expensive, weighing heavily on Indonesia's budget. In 2014, the government overshot its budgeted amount by 17% after spending 20 billion US dollars on fuel subsidies, according to Indonesia's Ministry of Finance data (IISD, 2011, 2015).

The effect of alternative energy consumption on EI is negative and statistically significant. The estimated coefficient shows that for every 1% expansion in green energy reduces EI by 0.19% approximately. The potential of development of wind, geothermal, solar energy, biomass and small hydropower stations depends on the region. With around 30% of the total primary energy supply from renewable resources, Indonesia is one of the leaders in the Asia–Pacific region. Indonesia is a significant consumer of traditional biomass and waste in its residential sector, particularly in the more remote areas that lack connection to the country's energy transmission networks. In 2016, biomass and waste (which includes firewood and charcoal) consisted of nearly 24% of total primary energy supply, although its share has declined since the year of 1990, but now the government is trying to use this source of energy more efficiently as a source of fuel for power plants. Increasing energy efficiency and substantially increasing the share of renewable in the overall energy mix, Indonesia can substantially reduce the carbon intensity (Salim and Rafiq, 2012).

However, renewable energy in Indonesia, excluding biofuels and waste, is not used enough even though it may be one of the main factors in the reduction of energy costs per unit of GDP. Due to coal demand boom, the Indonesian government has not stimulated the consumption of renewable energy sources. As a result, there was a rapid decrease in renewable energy in the energy mix of Indonesia in recent years, which was being driven mainly by increasing coal dependency despite increasing electricity generation from geothermal sources. Nasruddin *et al.* (2016) note that Indonesia being traversed by the world's ring of fire holds one of the immense geothermal potential, estimated about 40% of the world's geothermal energy potential. However, less than 8% of the overall energy mix is dominated by geothermal sources, and only 4.5% is being utilised as electrical energy in the country (Mohammadzadeh Bina *et al.*, 2018). The government of Indonesia must increase the capacity for geothermal power plants. It is planned by 2025 that the total installed power from geothermal power plants is 9500 MW (Nasruddin *et al.*, 2016).

Photovoltaic energy generation also has significant potential (Hermato and Narindro, 2019). Like the others, this sector requires state participation to overcome the geographic asymmetry of foreign investments expressed in the more excellent investment attractiveness of locations with reliable access to electricity due to less risk as noted by Kennedy (2018). Moreover, government support, coupled with the declining of prices, can provide an opportunity to ensure off-grid electricity generation for urban citizens and rural areas. It is important to note that the above advantage of renewables relevant especially for archipelago countries, such as Indonesia: a lot of islands force to develop independent one-island grid and make local energy sources more important (Erinofiardi *et al.*, 2017; Kurniawan and Managi, 2018).

The transition from fossil fuels to cleaner forms of energy takes time and coal provides a low-cost source of power for economic development in Indonesia. The government should provide price competitiveness of alternative energy sources compared with fossil fuels through emissions tax or subsidies to generating companies, or public guarantees for both local and foreign investors balancing interests of all stakeholders in terms of energy tariffs. Another option to attract business to alternative energy sector is to provide preferential tax regime. Moreover, subsidies and low interest loans for greenfield projects can make prices from non-fossil sources of energy more competitive. Substitution of coal to gas is another way to more efficient energy use, it is already proven that energy produced by gas power plants is much cleaner (Li *et al.*, 2013).

7. Conclusion

This study examines the impact of six key determinants (i.e. a share of alternative and nuclear energy, industry value added, trade openness, FDI net inflows, domestic credit to the private sector and real prices of crude oil) on the trend and mode of EI in Indonesia. Using most recent time series data over a 27-year period from 1990 to 2016, we find that, for Indonesia, its EI is positively determined by globalisation and industrialisation, and negatively by alternative energy consumption, crude oil prices and financial development. The long-run analysis, based on FM-OLS, DOLS and CCR shows that energy mix structure, as well as industry value-added and financial development, has a significant impact on EI in the country.

7.1 Implications for theory and practice

The study adds to the academic literature in the following ways. First, despite a significantly increased in recent years number of studies on EI, a careful review of the literature indicates that there are some profound gaps. For example, what is the relationship between financial development and EI? Are alternative energy sources more efficient sources of energy in terms of EI? This study effectively addresses these questions. Second, to the author's knowledge, this paper is the first one trying to investigate the impact of the energy transition on EI in Indonesia. It extends the research period to the year of 2016, which attracted little attention due to the lack of reliable data. Last, the paper contributes to the existing literature by using the cointegration methodology to estimate equations that is becoming a standard practice in energy economics. Moreover, our findings serve to aid the government and policymakers in prioritizing improvements in the sphere of energy policy. An important policy implication, regarding Indonesia, that arises from our study, is that, for the country to be able to decrease its EI, it must be able to develop its financial market and zero carbon energy sources, mainly geothermal energy with its huge potential. International experience to establish the regulatory conditions and investment climate necessary for the deployment of alternative energy sources is required. In line with Paramati *et al.* (2016) we argue that policymakers in Indonesia should initiate effective public–private-partnership investments in clean energy projects by providing lucrative incentives, which, in turn, will encourage both domestic and foreign investors to invest more in zero carbon energy projects.

7.2 Limitations and future research directions

The present paper points out a promising area for future research. We focus mainly on six key determinants of EI: energy consumption structure, trade openness, FDI, financial development, industrialisation and crude oil prices. We do not try to rule out other possible determinants of EI. We consider the determinants of EI using time series data, while an ideal analysis would be based on panel-level data. Rather, we hope that this study will stimulate more comparative studies across emerging and advanced countries that will model and explore the impact of other determinants on EI. Another limitation is that the study covers only the time period from 1990 to 2016. This fact might limit the efficiency of estimated cointegration models. Hence, future research can be carried out by extending the timeframe of the study, to quarterly or monthly data.

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