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# TOWARD ENERGY SECURITY IN ASEAN: IMPACTS OF REGIONAL INTEGRATION, RENEWABLES, AND ENERGY EFFICIENCY

Yang Liu, Zhong Sheng,
and Dina Azhgaliyeva

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Yang Liu is a senior research fellow at the National University of Singapore. Zhong Sheng is a research fellow at the National University of Singapore. Dina Azhgaliyeva is a research fellow at the Asian Development Bank Institute.

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Please contact the authors for information about this paper.

Email: dazhgaliyeva@adbi.org

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

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**Abstract**

ASEAN countries share the common challenge of energy security, which consists of meeting rising demand for energy in a secure, affordable and sustainable manner. This paper extends the gravity model to estimate the effects of economic integration, renewable energy supply and energy efficiency on energy security. By extending the gravity model, our model specifications introduce a series of key variables to capture the deployment of renewable energy, energy efficiency and level of regional economic integration. Three measures are crucial to this task: ensuring renewable energy supply, energy efficiency improvements, and stronger economic integration. Using annual data across 440 countries over the period 1995–2016, we demonstrate the role of renewable energy supply, energy efficiency improvements and economic integration in bilateral energy trade. Based on our findings, policy recommendations are provided to help ASEAN decision makers prescribe future energy security policy.

**Keywords:** energy security, regional trade agreement, ASEAN, energy trade, renewable energy, energy efficiency

**JEL Classification:** F14, F15, Q43, Q42

# Contents

# 1. INTRODUCTION

The energy sector is undergoing a paradigm shift, toward a digitally enhanced, multi-directional and integrated system. The concept of energy security is also evolving with increasing renewable capacity and energy efficiency. Nonetheless, the ultimate goal of energy security is to maintain energy independence by reducing the ratio of energy consumption to energy production, regardless of whether the country is an importer or exporter of energy resources. Both energy endowment and domestic energy consumption can determine the level of energy trade for a country, alongside other geopolitical and geographic factors. This study focuses on global bilateral energy trade to measure energy security and investigate the multi-factor impacts of energy efficiency, renewables and cross-border integration.

Energy security is a context-dependent concept, and there is no unique and commonly accepted definition (Ang, Choong, and Ng 2015; Winzer 2012). In fact, the majority of the literature is constituted of country-specific and time-specific studies (Ang, Choong, and Ng 2015). Energy security can be defined as the reliable and sufficient supply or demand of energy at affordable prices (Aydin and Azhgaliyeva 2019; Yergin 2006). Metcalf (2014) deems energy security the ability of households, businesses, and governments to accommodate disruptions in supply in energy markets. Some literature emphasizes the availability and affordability of energy, such as access to sufficient energy sources, including infrastructure for energy transportation (Sovacool and Mukherjee 2011). Definitions of energy security are also contingent on whether the country is an energy exporter or energy importer (Aydin and Azhgaliyeva 2019; Tongsopit et al. 2016; Yao and Chang 2014).

With their total energy demand forecast to grow by almost two-thirds over the next two decades, the ten countries of the Association of Southeast Asian Nations (ASEAN) are set to become a significant game changer for the global energy landscape. The region is projected to become the fourth largest economy in the world by 2030. The population is set to rise by more than 10% to 690 million by 2020. Energy is essential to such economic growth. Investments in power generation capacity and infrastructure will be required to meet ASEAN's energy demand, which has grown by 60% over the past 15 years. The International Energy Agency (IEA) estimates that investments will continue to grow by another two thirds by 2040 (IEA 2017).

The ASEAN countries share the common challenge of energy security, which consists of meeting rising demand in a secure, affordable and sustainable manner. This study focuses on the ASEAN region to develop a better understanding of how and to what extent three pillars – reinforcing regional energy trade, ensuring investment in renewable energy supply, and improving energy efficiency – can help reinforce energy security in these emerging economies.

This paper investigates international (or cross-border) bilateral trade (trade), including import and export flows. There is a huge body of literature on the determinants of trade. In this study, we focus on the two most commonly traded fossil energy sources, namely crude oil and natural gas, and incorporate six determinants of energy trade accordingly. The existing literature largely concludes that distance and economic size are the two main determinants of bilateral trade. We go beyond the literature to study the determinants of energy trade from the perspective of energy efficiency, renewable energy deployment, and economic integration. The purpose of this paper is to rely on a robust methodology to reveal important empirical patterns related to energy trade across the world, and to develop a better understanding of the implications for ASEAN.

To this end, we use the theoretical framework of the augmented gravity model (Tinbergen 1962) to integrate sustainability, affordability and secure supply in the concept of energy security. Our empirical model introduces a series of key variables to capture the deployment of renewable energy, energy efficiency improvements and level of regional economic integration. Using annual data across 440 countries (218 energy-exporting and 222 energy-importing countries) over 22 years (from 1995 to 2016), we demonstrate the role of renewable energy supply, energy efficiency improvements and economic integration in bilateral energy trade for both energy-exporting and energy-importing countries. Based on the empirical results, policy recommendations are provided to help ASEAN policy makers prescribe future energy security policies.

The remainder of the paper is structured as follows. Section 2 reviews the literature on the determinants of bilateral trade and the gravity model. Section 3 provides stylized facts of energy trade, energy security renewable energy and energy efficiency in ASEAN countries. Section 4 presents the methodology and data. Section 5 discusses the results and key findings. Section 6 concludes with policy implications.

# 2. LITERATURE REVIEW

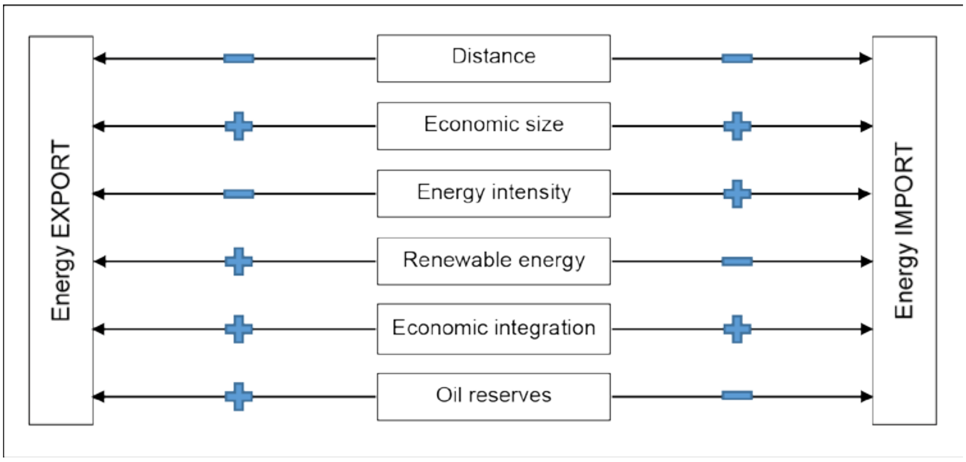
## 2.1 Energy Trade

Energy trade is important for energy security for both energy-exporting and -importing countries. The literature studying trade usually focuses on distance, gross domestic product (GDP) and economic integration as key determinants. In addition, the literature identifies renewable energy, energy efficiency and fossil fuel reserves as determinants of energy trade. Interestingly, the literature notes that the impacts of determinants of trade have the same direction on both imports and exports, hence the impacts on trade can be easily predicted, while the impacts of determinants of energy trade have different directions, rendering the overall impact on trade difficult to predict. In other words, the literature predicts that distance, GDP and economic integration have similar impacts on both exporters and importers, while renewable energy supply, energy efficiency and fossil fuel reserves have opposite impacts on exporters and importers. The determinants of energy trade and their impacts as suggested by the literature are discussed below and summarized in Figure 1 and Table 1.

Classical trade theory suggests that trade is proportional to the economic sizes of trading countries, i.e., their GDP (Tinbergen 1962). Bilateral trade is positively related to the incomes of both exporters and importers. The size of a country constrains the amount that it can trade. Countries with smaller GDP trade less, while countries with larger GDP tend to undertake more trade. Thus, GDP has a positive impact on trade.

Classical trade theory also suggests that bilateral trade is inversely proportional to the distance between exporters and importers due to transportation costs (Tinbergen 1962). Bilateral trade can be negatively related to the distance between exporters and importers owing to transportation costs. The greater the distance between an exporting country and an importing country, the higher the transportation costs. Thus, geographic distance has a negative effect on trade.

**Figure 1: Determinants of Energy Trade and Their Expected Impacts**




Source: Authors' own elaboration.

**Table 1: Determinants of Energy Trade and Their Expected Impact**

| N | Determinant | Exports | Imports | Trade |
|---|---|---|---|---|
| 1 | Distance | – | – | – |
| 2 | Economic size | + | + | + |
| 3 | Energy efficiency | + | – | +/– |
| 4 | Renewable energy | +/0 | – | +/– |
| 5 | Economic integration | + | + | + |
| 6 | Crude oil reserves | + | – | +/– |

Source: Authors' own elaboration.

Energy efficiency can reduce domestic energy needs and thus improve energy security (Ang, Choong, and Ng 2015; Vivoda 2010). Energy efficiency may improve energy security by reducing the amount of energy a country needs to function. Energy efficiency can reduce fossil fuel consumption (Ang, Choong, and Ng 2015; Nie and Yang 2016), and sustain energy security (Ben Jebli, Ben Youssef, and Ozturk 2016; Mathews and Tan 2014; Nie and Yang 2016). Energy efficiency is a key factor in facilitating energy security, because energy efficiency gradually helps a country move toward an end of energy demand growth (ASEAN Centre for Energy 2015). Energy efficiency can affect domestic energy consumption in both energy-exporting and -importing countries, and hence influence both energy exports and imports. Energy efficiency may substitute for the fossil fuel consumption that would have occurred without energy savings. In this sense, energy efficiency and fossil fuels can be considered substitutes to a certain degree. Energy efficiency is usually measured in terms of energy intensity, which is the energy required to produce each unit of output.

Energy security does not only comprise access to fossil fuels, but any energy source, including renewable energy (Mathews and Tan 2014; Nie and Yang 2016; Sovacool 2013; Valentine 2011). Renewable energy, akin to energy efficiency, can reduce fossil fuel requirements and thus improve energy security (Ang, Choong, and Ng 2015; Nie and Yang 2016; Valentine 2011). Renewable energy may reduce fossil fuel consumption (Ang, Choong, and Ng 2015; Nie and Yang 2016), and sustain energy security (Ben Jebli, Ben Youssef, and Ozturk 2016; Mathews and Tan 2014; Nie and Yang 2016). Share of renewables in the energy mix can affect energy demand for fossil fuels in both energy-exporting and -importing countries, thereby determining energy trade. However, the direction of impact – positive or negative – is not straightforward. Ben Jebli, Ben Youssef, and Ozturk (2016) provide empirical evidence highlighting the negative impact of renewable energy on energy imports, and lack of impact on energy exports.

Regional economic integration can positively affect energy trade due to there being fewer barriers to international trade (Sovacool and Mukherjee 2011). We consider three forms of economic integration: regional trade agreements (RTA), ASEAN, and Central Asia.

Crude oil proven reserves affect energy availability. Crude oil reserves are often used in measures of energy security, such as the reserves-to-production ratio (Kalyuzhnova 2005; Sovacool and Mukherjee 2011). Exporters with superior oil reserves can export more energy. Importers with more oil reserves can import less energy.

## 2.2 The Gravity Model

Patterns of bilateral trade flows between countries are commonly studied using the gravity model of trade flows. The gravity model was first proposed by Tinbergen (1962), and named as an analogy with the gravity equation in physics. Tinbergen's gravity model empirically reveals that bilateral trade flows between exporters and importers are proportional to the product of an index of their economic sizes (i.e., GDP), with measures of "trade resistance" determining proportionality, such as geographical distance, common borders, and cultural similarity (Helpman, Melitz, and Rubinstein 2008).

The gravity model has long been one of the most successful empirical models in economics (Anderson 2011; Anderson and van Wincoop 2003) and in policy research related to trade (United Nations Conference on Trade and Development and World Trade Organization 2012). Since Tinbergen's early work, the gravity model has been widely used to infer the trade flow effects of various institutional arrangements, such as tariffs and trade agreements (Baier and Bergstrand 2001; Carrere 2006; Estevadeordal, Frantz, and Taylor 2003; Rose 2004; Subramanian and Wei 2007), environmental policies (Costantini and Mazzanti 2012), corruption and imperfect contract enforcement (Anderson and Marcouiller 2002), and intellectual property rights (Smith 2001). However, the gravity model has been criticized for a lack of theoretical foundation (Anderson and van Wincoop 2003). A number of important studies provide the theoretical foundation of the gravity model. For instance, the Ricardian trade model that incorporates realistic geographic characteristics into general equilibrium to portray bilateral trade relations has been developed by Eaton and Kortum (2002). The Heckscher-Ohlin theory can account for the empirical success of the gravity model if differences in factor endowments are large (Evenett and Keller 2002). Anderson and van Wincoop (2003) provide a method that consistently and efficiently estimates a theoretical gravity model. In addition, regarding empirical estimation, under heteroskedasticity, ordinary least squares (OLS) estimation of the log-linearized gravity model would lead to biased estimates of the true elasticities (Silva and Tenreyro 2006).

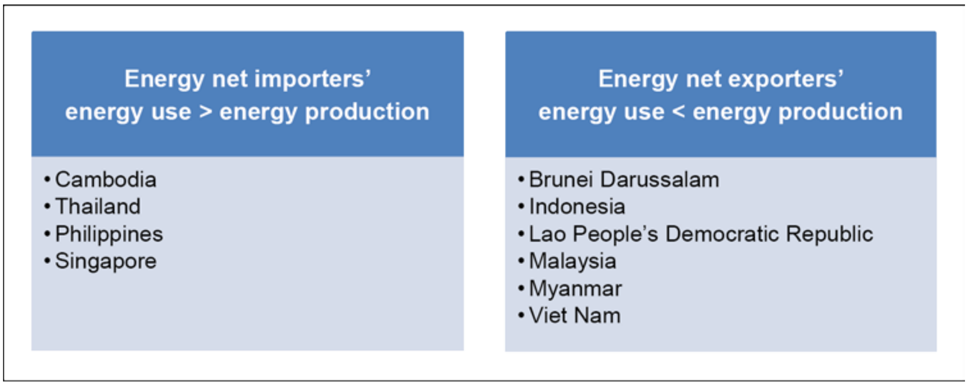
# 3. STYLIZED FACTS

The present analysis describes energy trade patterns in a systematic framework with comprehensive data coverage.

## 3.1 Energy Security

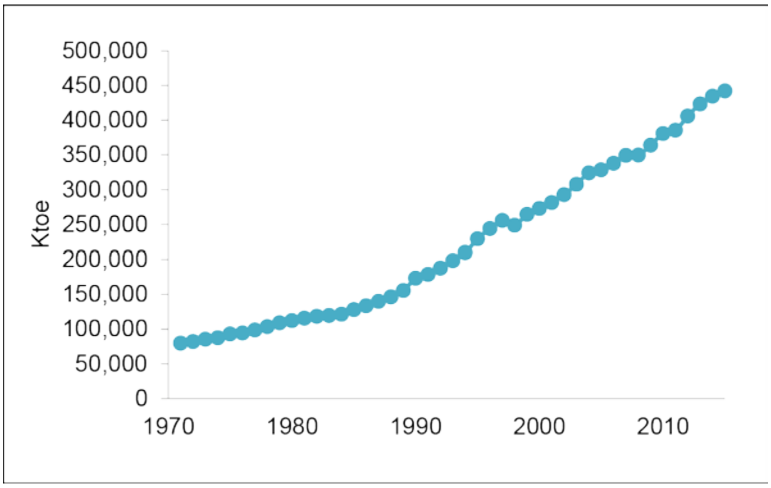
ASEAN includes both energy-exporting and energy-importing countries. Therefore, we need to consider the concept of energy security from both supply and demand perspectives (Figure 2). Energy importers may be concerned about security of supply, while energy exporters may rely on security of demand. Thus, bilateral energy trade is an essential factor that reflects energy security in this dynamic global context.

**Figure 2: Energy Net Exporters and Net Importers in ASEAN**




Source: Authors' elaboration using UNCTAD.

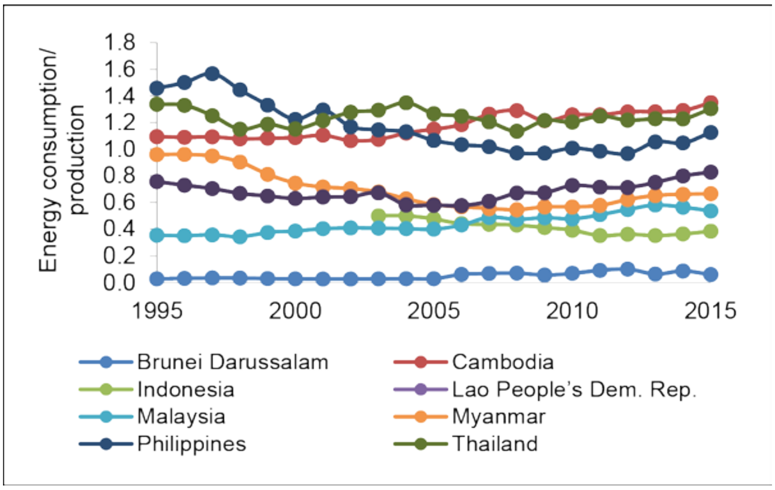
**Figure 3: Total Final Energy Use in ASEAN, 1971–2015**




Source: Authors' elaboration using IEA (2018).

Southeast Asia will play an increasingly important role in the future global energy landscape. The region is projected to see a 4% increase in energy demand on a yearly basis, amounting to around 7.5% of worldwide energy consumption by 2025. Today, ASEAN is the seventh largest economy in the world and the fifth largest investment destination. Strong economic growth and a rising population have fueled a 454% increase in total final energy demand over the period 1971–2015 (Figure 3). Although six of the ten economies are today energy net exporters, many of them would not be able to sustain self-sufficiency over the coming decade, as energy use tends to quickly surpass domestic energy production (Figure 4). It is consequently important to manage energy security to meet rising energy demand and sustain economic growth.

**Figure 4: Fraction of Energy Use to Energy Production in ASEAN**




Note: Singapore is excluded because its fraction of energy use to energy production is extremely high.

Source: Authors' elaboration using IEA (2018).

## 3.2 Energy Trade

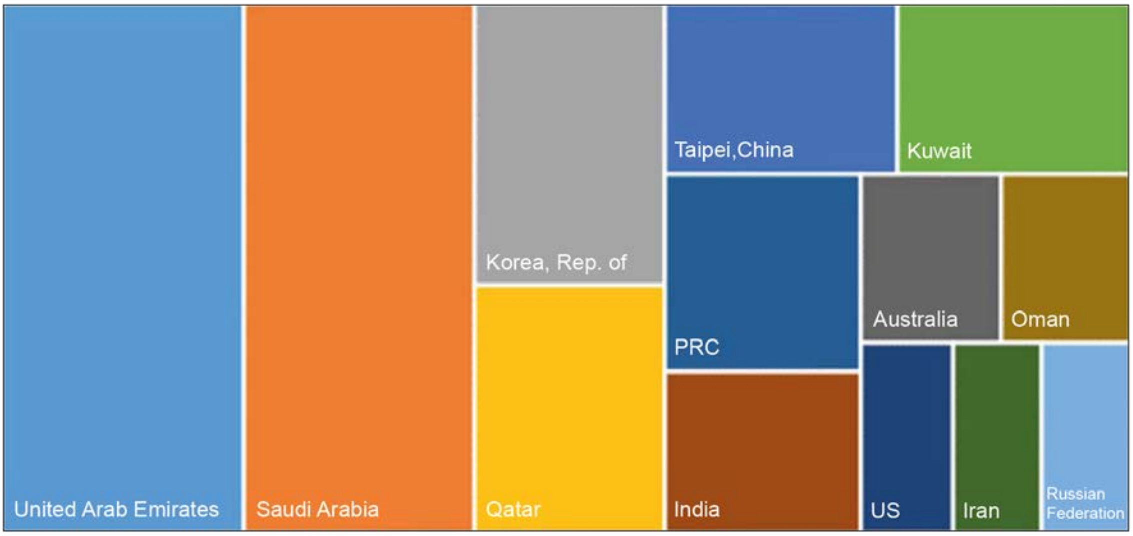
Southeast Asian countries trade energy in large part with non-ASEAN countries. The top ten importers of energy and energy products from ASEAN are Japan; the People's Republic of China (PRC); Australia; the Republic of Korea; Hong Kong, China; India; Taipei,China; the United States; New Zealand; and Bangladesh (Figure 5). The top thirteen exporters of energy and energy products to ASEAN are the United Arab Emirates; Saudi Arabia; the Republic of Korea; Qatar; Taipei,China; Kuwait; the PRC; India; Australia; Oman; the United States; Iran and the Russian Federation (Figure 6).

Although classical trade theory suggests that bilateral trade is closely correlated with the distance between exporters and importers owing to transportation costs, distance may not fully explain the energy trade activities of ASEAN countries, as most bilateral trade is conducted outside rather than within the region (UNCTAD 2018). This stylized fact impels us to identify other factors with more substantial impact on energy trade.

**Figure 5: Major Energy Importers from ASEAN, 1995–2016**


Source: Authors' elaboration using UNCTAD.

**Figure 6: Major Energy Exporters to ASEAN, 1995–2016**

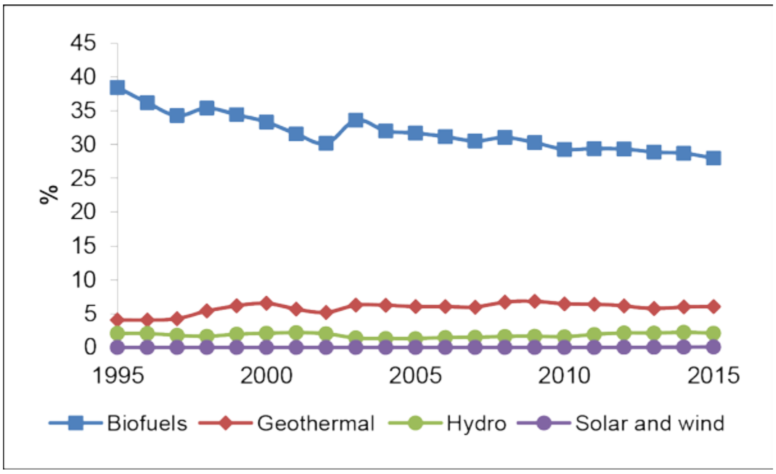



Source: Authors' elaboration using UNCTAD.

## 3.3 Renewable Energy and Energy Efficiency

So far, the majority of renewable energy in ASEAN takes the form of solid biomass, e.g., firewood and wood chips used in cooking. The application of advanced renewable energy technologies represents a relatively small share, with geothermal and hydro energy representing around 6% and 3% of total energy use, respectively. The share of solar and wind energy remains minimal, although ASEAN plans to achieve a 23% renewable energy share in total primary energy supply by 2025 (Figure 7).

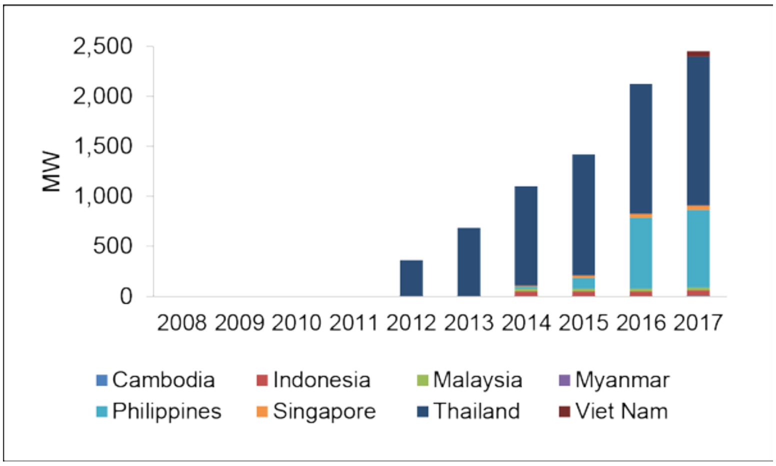
**Figure 7: Share of Renewable Energy in Total Energy Use in ASEAN**




Source: Authors' elaboration.

Geographically, ASEAN countries are closer to the equator, which provides enormous potential for solar energy. Countries like Thailand and the Philippines are pioneering the capture of such energy, followed by Malaysia, Singapore, Indonesia, and Viet Nam (Figure 8).

**Figure 8: Cumulative Installed Capacity of Solar Power in ASEAN**




Source: Authors' elaboration.

The ASEAN Plan of Action for Energy Cooperation (ASEAN Centre for Energy 2015) commits to reducing energy intensity to 20% by 2020 and 30% by 2025. An alternative way of viewing energy intensity improvements is that they deliver an energy productivity bonus, because an economy is able to produce more GDP for each unit of energy demand. In an efficient energy scenario, the IEA estimates that the energy intensity of ASEAN will decline by 1.9% per year until 2035, compared to 0.6% over the period of 1990–2011. In this case, energy demand in ASEAN can be cut by 15% (IEA 2017).

Table 2 summarizes specific energy efficiency and renewable energy targets for ASEAN countries.

**Table 2: Country-specific Energy Efficiency and Renewable Targets in ASEAN**

| Country | Energy Efficiency (EE) Targets | Renewable Energy (RE) Targets |
|---|---|---|
| Brunei Darussalam | • Reducing 25% EI by 2030 and 45% by 2035, based on the 2005 level;<br>• 63% energy saving by 2035, relative to BAU. | • 124 GWh RE (2017) and 954 GWh (2035) ~ 10% RE in power generation. |
| Cambodia | • Reducing energy consumption (TFEC) by 20% in 2035:<br>o Industry: up to 20% in garment factories and 70% in ice factories;<br>o Residential: up to 50%;<br>o Commercial: 20 to 30%;<br>• Rural electrification energy savings: up to 80%;<br>• Replacement of biomass use by 30–50%;<br>• 27% emission reduction by 2030 relative to BAU in energy industry and energy conservation. | • No specific RE target, but establishment of large hydro of 2,241 MW by 2020. |
| Indonesia | • Achieving 1% energy intensity reduction per annum up to 2025, and energy elasticity below 1 by 2025;<br>• Reducing energy consumption (TFEC) in 2025 by 17% in industry, 20% in transportation, 15% in households, and 15% in commercial buildings compared to BAU;<br>• Reducing final energy consumption in the commercial, industry, and residential sectors by 10% in 2030, based on the 2011 level;<br>• Reducing annual energy consumption by 1.4 ktoe by 2030 in the transportation sector. | • 23% RE share of TPES (around 92.2 Mtoe in 2025), including 69.2 Mtoe (45.2 GW) for electricity and 23 Mtoe for non-electricity;<br>• 31% RE share in 2030. |
| Lao PDR | • Reducing TFEC by 10% in 2030 compared to BAU. | • 30% RE share of total energy consumption by 2025 (approximately 1,479 ktoe), excluding large hydro (>15 MW capacity);<br>• 10% biofuel use in transportation sector by 2025. |
| Malaysia | • Reducing electricity consumption by 8% in 2025 compared to BAU;<br>• 35-45% emission intensity reduction in 2030. | • RE installed capacity of 2,080 MW (excluding large hydro) by 2020. |
| Myanmar | • Reducing electricity consumption by 20% in 2030 compared to BAU. | • 38% (8,896 MW) hydro, 20% (4,758 MW) of natural gas, 33% (7,940 MW) of coal and 9% (2,000 MW) of renewable sources in the energy mix by 2030–2031. |

| | |
|---|---|
| | • Increase hydropower generation by 9.4 GW by 2030, and use 30% RE sources for electricity generation. |

*continued on next page*

**Table 2** *continued*

| Country | Energy Efficiency (EE) Targets | Renewable Energy (RE) Targets |
|---|---|---|
| Philippines | • Reducing TFEC by 1% per year compared to BAU until 2040, equivalent to 33% reduction in energy demand;<br>• Reducing energy intensity (TFEC/GDP) by 40% in 2040 compared to 2005 level;<br>• 70% $CO_2$ emission reduction by 2030 relative to BAU scenario. | • 15.2 GW of RE installed capacity by 2030: Additional biomass capacity of 277 MW in 2015, additional wind capacity of 2,345 MW in 2022, additional hydro of 5,398 MW in 2023, additional ocean energy capacity of 75 MW in 2025, additional solar capacity of 284 MW in 2030, and additional geothermal capacity of 1,495 MW. |
| Singapore | • Reducing EI by 20% by 2020 and by 35% by 2030 based on the 2005 level. | • 350 MWp of solar power installation by 2020 and 10,140 tonnes/day by 2018 for waste to energy plant. |
| Thailand | • Reducing energy intensity (TFEC/GDP) by 30% in 2036 compared to the 2010 level;<br>• 20% GHG reduction by 2030 relative to BAU and up to 25% with assistance. | • 30% renewable in total energy consumption by 2036, in the form of electricity (20.11% in generation, approximately 19,684 MW), heat (36.67% of heat production, approximately 25,088 ktoe), and biofuels (25.04% i.e., 8,712.43 ktoe in transportation sector). |
| Viet Nam | • Reducing TFEC by 8% in 2020 compared to BAU;<br>• Reduce energy intensity of energy intensive industries by 10% by 2020. | • 21% RE of 60 GW installed capacity in 2020;<br>• 13% RE of 96 GW in 2025 and 21% RE of 130 GW in 2030, including 2.1% of wind;<br>• 15.5% hydro, 2.1% biomass, and 3.3% solar. |

Note: BAU = business as usual; TFEC = total final energy consumption.

Source: Authors' elaboration.

# 4. METHODOLOGY AND DATA

## 4.1 Dependent Variable

This paper considers the determinants (i.e., factors) that affect the bilateral trade flows of energy products instead of the total trade flows in the gravity model framework. We consider that the bilateral trade flows of energy products can reflect the status of energy security. There are some other potential measures of energy security, such as the fraction of energy consumption to energy production. However, due to a lack of data across countries over time (e.g., energy consumption and energy production), the use of bilateral trade flows of energy products seems more suitable, and should be viewed as a first step in researching energy security in a globalizing world. The dependent variable is cross-border bilateral *energy trade*, comprising import and export flows. It includes the trade of mineral fuels, lubricants and related materials. The energy trade was obtained across four categories of the Standard International Trade Classification (SITC) 3: (32) coal, coke and briquettes (coal), (33) petroleum, petroleum products and related materials (petroleum), (34) gas natural and manufactured (gas) and (35) electric current (electricity) (United Nations 2002). Data on exports and imports of coal, petroleum, gas and electricity were obtained from UNCTAD (2018) across 218 energy-exporting countries and 222 energy-importing countries over the period 1995–2016.

## 4.2 Independent Variables

Six determinants/independent variables of energy trade are included in the model: distance, GDP, energy efficiency, renewable energy supply, economic integration, and crude oil reserves. Below each independent variable is described in turn.

Geographical distance between energy-importing and -exporting countries, *distance*, is measured in kilometers. The data were obtained from the CEPII GeoDist database, which provides bilateral distance for most country pairs across the world (Mayer and Zignago 2011) and does not vary across years. The bilateral distances from country pairs not included in the CEPII GeoDist database are calculated using the great circle distance.

The sizes of economies are measured using real *GDP* in constant 2010 prices in US$. The data were obtained from the World Bank (2018) World Development Indicators database.

*Energy intensity* is included as a measure of energy efficiency. It is calculated as energy consumption per unit of real GDP in 2010 prices and measured in ktoe/2010 US$. The data on energy consumption were obtained from IEA (2018), while data on real GDP were obtained from the World Bank (2018).

Renewable energy supply, *renewables*, is measured as a share of renewable energy consumption over total energy consumption. Data on renewable energy consumption and total energy consumption were obtained from the IEA (2018).

Regional economic integration is measured using three binary variables: *RTA*, *ASEAN* and *Central Asia. RTA* equals one if trade occurred between an exporter and importer in the same regional trade agreement (RTA) in a given year, and zero otherwise. RTAs include free trade agreements and customs unions. The data on RTAs were obtained from the WTO Regional Trade Agreements Information System. *ASEAN* equals one if trade occurred between member states of ASEAN, and zero otherwise. ASEAN includes 10 member countries: Indonesia, Thailand, Singapore, Malaysia, the Philippines, Viet Nam, Myanmar, Cambodia, Brunei Darussalam, and the Lao PDR. *Central Asia* equals one if trade occurred between countries from the Central Asia region and zero otherwise. The Central Asia region includes five states: Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan.

*Oil reserves* refers to the amount of proven crude oil reserves. Data on oil reserves were obtained across countries and years from the Energy Information Administration (EIA 2018).

## 4.3 Augmented Gravity Model

Specifically, our basic model specification considers energy trade from the exporter $i$ to the importer $j$ in year $t$, $E_{ij,t}$, which is associated with their economic sizes, geographical distance, and other measures of "trade resistance":

$$\ln E_{ij,t} = a_0 + a_1 \ln GDP_{i,t} + a_2 \ln GDP_{j,t} + a_3 \ln Distance_{ij} + a^* \ln OT + \varepsilon_{ij,t},$$

where $GDP_{i,t}$ and $GDP_{j,t}$ are the GDP of exporter $i$ and importer $j$ in year $t$, respectively. $Distance_{ij}$ is the geographic distance between exporter $i$ and importer $j$. $OT$ is a set of other important factors of the exporters and importers that affect the bilateral trade of energy products, including the measure of energy intensity, share of renewable energy consumption, oil reserves, and institutional arrangements (e.g., dummy for regional trade agreement, dummy for energy trade within ASEAN, and dummy for energy trade within Central Asia). $a_0, a_1, a_2$ $and$ $a_3$ are coefficients. $a^*$ is a set of coefficients corresponding to the set of variables in $OT$. $\varepsilon_{ij,t}$ is the error term.

## 4.4 Data

We compiled various data sources across countries on energy trade, energy intensity, consumption of renewable energy, and institutional arrangements such as RTA and energy trade within ASEAN and Central Asia. We considered regional integration, reflected by the institutional coordination of trade and certain geopolitical and socio-economic groups. To do so, we introduced three dummy variables, namely the dummy for whether there is a regional trade agreement (RTA) between the trade partners, the dummy for whether the energy trade is within ASEAN, and the dummy for whether the energy trade is within Central Asia. The variables and data sources used in this paper are presented in Table 3. Summary statistics of exporters, importers and trade partners are presented in Table 4-5.

**Table 3: Definitions, Notes and Data Sources of Variables**

| Variable | Definition and Notes | Data Source |
|---|---|---|
| Energy trade from exporter to importer | Trade of mineral fuels, lubricants and related materials (Standard International Trade Classification (SITC) 3) in thousands of US dollars, including:<br>32 – Coal, coke and briquettes;<br>33 – Petroleum, petroleum products and related materials;<br>34 – Gas, natural and manufactured;<br>35 – Electric current.<br>See the classifications in UN (2002) | UNCTAD (2018) |
| Distance | Geographical distance between origin and destination countries | CEPII GeoDist (Mayer and Zignago 2011) and using great circle distance |
| GDP of exporter | In constant 2010 US$ | World Bank (2018) |
| GDP of importer | In constant 2010 US$ | World Bank (2018) |
| Energy intensity of exporter | Energy use (ktoe) per unit of GDP (constant 2010 US$) | Energy use data are from IEA (2018);<br>GDP data are from World Bank (2018) |
| Energy intensity of importer | Energy use (ktoe) per unit of GDP (constant 2010 US$) | Energy use data are from IEA (2018);<br>GDP data are from World Bank (2018) |
| RTA | Dummy for whether a RTA. Equals 1 if there is an RTA between exporter and importer | Own elaboration |
| ASEAN | Dummy for energy trade within ASEAN. Equals 1 if both exporter and importer are within ASEAN | Own elaboration |
| Central Asia | Dummy for energy trade within Central Asia. Equals 1 if both exporter and importer are within Central Asia | Own elaboration |
| Renewables of exporter | Share of renewable energy use (ktoe) to total energy use (ktoe) | IEA (2018) |
| Renewables of importer | Share of renewable energy use (ktoe) to total energy use (ktoe) | IEA (2018) |

| | | |
|---|---|---|
| Oil reserves of exporter | Proven reserves of crude oil (billion barrel) | EIA (2018) |
| Oil reserves of importer | Proven reserves of crude oil (billion barrel) | EIA (2018) |

Source: Authors' elaboration.

**Table 4: Summary Statistics of Exporters and Importers**

| Variable | No. | Mean | St. Dev. | Min. | 25% Q | Median | 75% Q | Max. |
|---|---|---|---|---|---|---|---|---|
| **Exporter** | | | | | | | | |
| Real GDP (constant 2010 mln. US$) | 4,041 | 319,000 | 1,240,000 | 29 | 5,200 | 20,900 | 156,000 | 16,900,000 |
| Oil reserves (billion barrel) | 2,003 | 14 | 41 | 0 | 0 | 0 | 4 | 300 |
| Energy intensity (US$/ktoe) | 3,631 | 7 | 6 | 0 | 4 | 5 | 8 | 58 |
| Share of renewable energy in energy use | 2,543 | 0 | 1 | 0 | 0 | 0 | 0 | 14 |
| **Importer** | | | | | | | | |
| Real GDP (constant 2010 mln. US$) | 4,171 | 309,000 | 1,220,000 | 23 | 4,450 | 18,800 | 147,000 | 16,900,000 |
| Oil reserves (billion barrel) | 4,330 | 6 | 29 | 0 | 0 | 0 | 0 | 300 |
| Energy intensity (US$/ktoe) | 3,739 | 7 | 6 | 0 | 4 | 5 | 8 | 58 |
| Share of renewable energy in energy use | 2,904 | 3 | 53 | 0 | 0 | 0 | 0 | 1,017 |

No. = number of observations, St. dev. = standard deviation, Q = quantile.

Note: Summary statistics are for 218 exporters and 222 importers over the period 1995–2016.

**Table 5: Summary Statistics of Trade Partners (Pairs of Exporters and Importers)**

| Variable | No. | Mean | St. dev. | Min. | 25% Q | Median | 75% Q | Max. |
|---|---|---|---|---|---|---|---|---|
| Energy exports (1,000 US$) | 173,942 | 189,281 | 1,560,723 | 0 | 24 | 513 | 13,984 | 1.21E+08 |
| Distance (kilometers) | 174,043 | 5,636 | 4,209 | 60 | 2,027 | 4,696 | 8,467 | 19,781 |

No. = number of observations, St. dev. = standard deviation, Q = quantile.

Note: Summary statistics are for 218 exporters and 222 importers over the period 1995–2016.

# 5. RESULTS AND DISCUSSIONS

This section presents the empirical findings of our augmented gravity model. The gravity model was extended in this paper to estimate the effects of economic integration, renewable energy supply and energy efficiency on energy security. Table 7 and Figure 9 show the regression results. Consistent with previous literature, geographical distance is found to be associated with lower bilateral trade flows of energy products (Helpman, Melitz, and Rubinstein 2008), and energy trade most often occurs between trade partners with larger economic sizes (Helpman, Melitz, and Rubinstein 2008). This finding is robust because the related coefficients are significant in all model specifications. The implication is that transport infrastructure matters to energy trade (as well as energy security): greater geographical distance is associated with larger transport costs.

The impact of energy intensity on energy trade is also as expected. The level of energy intensity has negative effects for exporters and positive effects for importers. Exporters with higher levels of energy intensity tend to export less energy. Importers with higher energy intensity tend to exhibit greater demand for energy imports. Energy exports are more sensitive to energy intensity than are energy imports ($|-0.375| > |+0.181|$).

The impact of renewables on energy trade is not consistent with the literature. The share of renewable energy in the energy consumption structure seems to have little effect on energy trade for exporters, while importers with larger shares of renewable energy tend to have more energy imports. The possible explanation is that importers with greater shares of renewable energy are also those with larger economic sizes.

The impact of oil reserves on energy trade is consistent with the literature. Oil reserves have significant but different effects for exporters and importers: countries that have rich oil reserves tend to export more and import less energy. However, exports are more sensitive to oil reserves than are imports ($|+0.305| > |-0.067|$).

The impact of economic integration on energy trade is consistent with the literature. Regional integration has a positive effect on energy trade, as all three coefficients measuring the impact of economic integration, i.e., *RTA*, *ASEAN* and *Central Asia,* are significant across all model specifications. Regional economic cooperation and coordination lead to further bilateral trade of energy products. However, compared to the Central Asia region, the impact magnitude of regional integration is much smaller in ASEAN ($2.073 < 5.538$). This shows the enormous potential of the energy trade for shared energy security across ASEAN countries with enhanced institutional collaboration. Recently, ASEAN saw the achievement of multilateral power trade under Phase 1 of the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project, the first trade taking place in January 2018. This is an important step toward enhancing ASEAN power grid connectivity.

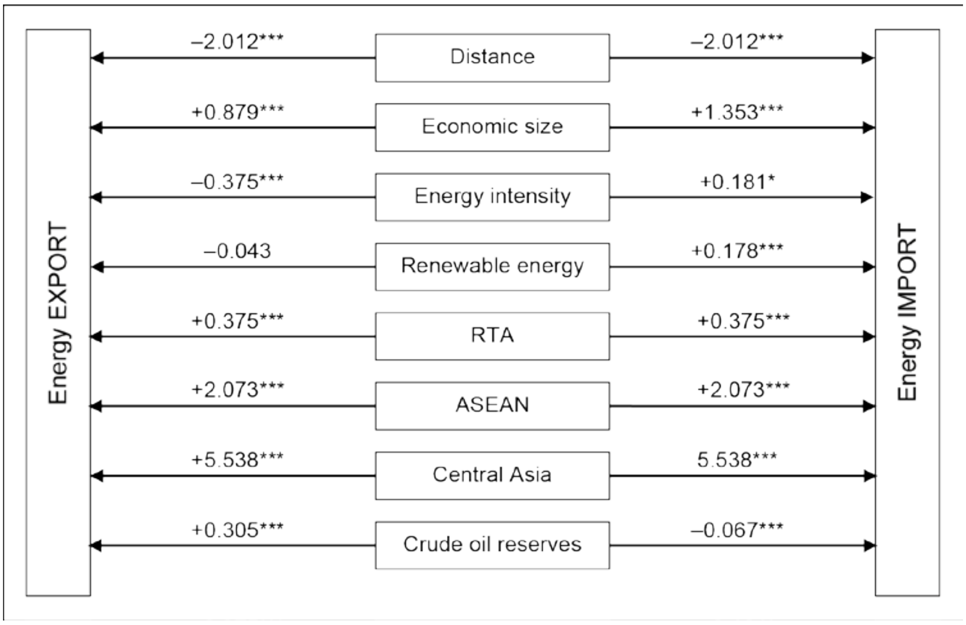
**Table 6: Regression Results of Augmented Gravity Model, 1995–2015**

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
|---|---|---|---|---|---|
| Distance | –1.501*** | –1.629*** | –1.717*** | –2.083*** | –2.012*** |
| | (0.0308) | (0.0388) | (0.0409) | (0.0609) | (0.0602) |
| GDP of exporters | 0.947*** | 1.075*** | 1.086*** | 0.874*** | 0.879*** |
| | (0.0147) | (0.0228) | (0.0228) | (0.0397) | (0.0396) |
| GDP of importers | 0.764*** | 1.025*** | 0.935*** | 1.348*** | 1.353*** |
| | (0.0136) | (0.0226) | (0.0227) | (0.0379) | (0.0378) |
| Energy intensity of exporters | | –0.067 | –0.086 | –0.345*** | –0.375*** |
| | | (0.0569) | (0.0581) | (0.0948) | (0.0945) |
| Energy intensity of importers | | –0.021 | –0.167** | 0.210* | 0.181* |
| | | (0.0515) | (0.0523) | (0.0847) | (0.0845) |
| Regional trade agreement | | 0.481*** | 0.450*** | 0.403*** | 0.375*** |
| | | (0.052) | (0.0564) | (0.0865) | (0.0869) |
| Share of renewables in exporters | | | 0.0202 | –0.035 | –0.043 |
| | | | (0.0151) | (0.0241) | (0.0238) |
| Share of renewables in importers | | | 0.0795*** | 0.186*** | 0.178*** |
| | | | (0.0157) | (0.0263) | (0.0261) |
| Oil reserves of exporters | | | | 0.308*** | 0.305*** |
| | | | | (0.0194) | (0.0193) |
| Oil reserves of importers | | | | –0.0635** | –0.0669*** |
| | | | | (0.0201) | (0.0201) |
| Exporters and importers within Central Asia | | | | | 5.538*** |
| | | | | | (0.451) |
| Exporters and importers within ASEAN | | | | | 2.073*** |
| | | | | | (0.417) |
| Constant | –25.41*** | –35.98*** | –35.60*** | –35.46*** | –37.36*** |

| | | | | | |
|---|---|---|---|---|---|
| | (0.571) | (1.06) | (1.165) | (1.81) | (1.81) |
| Number of observations | 162,943 | 125,827 | 103,133 | 51,711 | 51,711 |

Note: Dependent variable: energy trade from origin country to destination country (logs). Robust standard errors in parentheses; * p<.05, ** p<.01, *** p<.001.

**Figure 9: Results Overview**




Source: Authors' elaboration.

# 6. CONCLUSIONS AND POLICY IMPLICATIONS

The effects of regional integration, renewable energy supply and energy efficiency on energy security were estimated by extending the augmented gravity model. Using data from global energy trade across the period 1995–2015, this paper has shown that energy efficiency significantly contributed to enhancing energy security across the world by reducing energy demand in energy-importing countries, while greater efforts remain necessary in renewable energy deployment to reduce dependence on fossil fuel imports and exports.

ASEAN must consider energy efficiency improvement as a strategic approach to enhancing energy productivity. Energy is a vital input to the economy. Like labor, capital and other inputs, using energy more productively facilitates economic growth and protects the environment. This study confirms that energy efficiency change has a significant impact on energy trade.

Meanwhile, ASEAN needs to manage the structural change of its energy system by integrating energy efficiency and renewables across all sectors. The result of this study does not substantiate the role of renewable energy in enhancing energy security.

In the coming decades, ASEAN countries will encounter challenges in achieving economic growth and controlling energy demand. The region must continue its momentum in reducing the energy intensity of its economies. By 2016, ASEAN energy policies had already accomplished a 21.9% energy intensity reduction, exceeding its target for 2020, but remaining short of its 23% renewable target by 2025. ASEAN must perceive policies pertaining to energy efficiency and renewables as complementary tools to increase synergy within the policy mix. Indeed, even with its existing renewable capacity, controlling the region's energy demand growth will simply increase the share of renewables in the energy mix and help phase out fossil fuel sources.

Controlling energy consumption through energy efficiency measures is a cost-effective option compared with heavy investments in renewable energy infrastructure. Furthermore, as renewable energy technologies gradually become cheaper in the medium to long term, energy efficiency measures will help address ASEAN's low-carbon energy transition in the short term. Therefore, in order for ASEAN to achieve its renewable energy targets, maximizing the region's energy efficiency potential is essential.

The financial implications of integrating energy efficiency and renewables are essential for long-term investments in the energy systems of many emerging Southeast Asian economies, where forecast growth in electricity demand is very high. From an economic perspective, optimizing future energy infrastructure investments will rely on improvements in the asset utilization rate and enhancement of the efficiency level of the whole electricity system. Such increased efficiency will also afford the power system flexibility, strengthening its ability to respond rapidly to changes in supply-demand position, such as alterations in variable renewable energy generation output, generation failures, and variations in demand. Numerous countries with huge investments in renewable energy capacity have demonstrated concern for the implications of high renewable penetration on electricity grid stability. The flexibility of the energy system must be unlocked to circumvent any restrictions to variable renewables, enhancing their share of power generation. Current grid-edge innovations provide solutions to coordinating the utilization of supply-side and demand-side technologies, including dispatchable power plants, power storage and demand-side management, thereby enhancing the power system's flexibility. Today, ASEAN countries must review market rules to create an enabling environment for investment in such future-proof energy technologies.

Although energy efficiency can offer low-cost opportunities to reduce energy demand and associated emissions, unlocking energy efficiency's potential often faces specific barriers such as split incentives, lack of information, and behavioral change. The ASEAN Plan of Action for Energy Cooperation articulates four strategies to achieve this target. These include the harmonization of energy efficiency standards for energy-related products, enhancing private sector participation through energy service companies, developing green building codes, and increased participation of financial institutions in energy efficiency and conservation. Economic growth and improving living standards in ASEAN can involve both improving energy efficiency and rising energy consumption. In addition, expected energy savings are often taken back to some extent due to well-known rebound effects. In this rapid development context, more stringent energy efficiency targets must be in place to compensate for increased energy consumption without compromising economic growth and energy security.

Most ASEAN countries are still in the early stages of formulating regulatory policies for renewables and energy efficiency. Technological innovation and policy frameworks will continue to evolve. As energy security challenges increase, policy and regulatory changes are set to accelerate in the years to come. Policy coordination across ASEAN countries will be fundamental to unlocking the full potential of regional energy security.

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