Energy Security Analysis of Japan, South Korea, and Taiwan: A Mix Model Framework

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Abstract

Current energy consumption and how to mitigate the negative environmental effects alongside rising demand have become prominent issues in everyday discourse. Following this trend, the topic of energy security too has stepped back into the spotlight. This article aims to analyse the energy security situation of three East Asian countries, Japan, South Korea, and Taiwan. All three countries feature similar predicaments, being overly reliant on imports, having minuscule natural reserves, and also being high-tech and service-based economies. In this article the author attempts to determine similarities and differences from an energy security perspective. In order to assess these countries, a framework is created with thirty-five distinct indicators relating to energy security. Each indicator is then systematically compared with each of the three countries. The results are then presented in a table and with graphs to illustrate a comparison of each country's values. Through these results, the largest differences can be observed in energy efficiency and diversification of energy supply. The concluding remarks offer possible avenues for further studies and deliberate on lessons to be learned from these results.

Keywords: energy security, renewable energy, East Asia, energy intensity, sustainability, energy reserves, dependency

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Introduction

Energy has come to the forefront as one of the main issues of the twenty-first century, as news media, academia, corporations, politicians, and citizens are engaged in discussions of climate change and global warming. Questions concerning the makeup of the national power-grid and demand for a switch to renewable energies rest on ideas such as the "Green New Deal" in the USA, or the "Green Deal" proposed by the President of the European Commission. In Germany, renewable energy already accounted for the largest share of energy production in 2018, and China has become the leader in renewable capacity (Eckert 2019; IEA 2017: 3).

One effect of this turn to "green" energy is the decrease in dependency from energy imports, mitigating risks posed from disruptions to energy supplies (Ölz, Sims, and Kirchner 2007: 5). These considerations lie at the core of the topic of energy security. According to the Working Group on Asian Energy and Security at the Massachusetts Institute of Technology, energy security is built on three main tenets. It entails the reduction of foreign threats, prevention of supply crises, and minimising the effects of occurring supply crises (Lind 1997; Von Hippel et al. 2011: 6720). While these goals are shared among energy importing nations, their respective energy policies will nevertheless vastly vary depending on factors such as geographic location, quantity of natural resources, market forces, government intervention, price setting, and long term versus short term planning (Von Hippel et al. 2010: 75). As a recent example, the talks regarding Nord Stream 2, an additional pipeline between Russia and Germany, have sparked uncertainty in neighbouring countries, as they fear that Russia would be able to threaten supply cuts to Eastern Europe and use it as leverage without affecting supply to Germany. This has led to sanction warnings from the United States (Dettmer 2019; Gurzu 2019).

East Asia has already been hit with energy supply disruptions multiple times in the past. Most famous among them were the oil shocks of 1973 and 1979, which made clear that fuel supply was a matter of national security. The effects also caused Japan to refocus its economy away from heavy industries and towards technology intensive ones (Azad 2015: 63–64; Halloran 1974; Cheng 2009: 57; Mihut and Daniel 2013: 1046). In 2017, a massive power outage in the northern part of Taiwan caused millions in damages during a five-hour blackout. Part of the reason was found to be structural problems in the grid of the Taiwan Power Corporation. Shortly before the blackout, operational energy reserves shrank to one percent (Horwitz 2017; J. M. Yu 2017).

As ensuring energy security is vital to the uninterrupted economic activity within any given country, three common goals are reducing foreign threats, preventing supply crises, and minimising the effects of occurring supply constraints (Von Hippel et al. 2011: 6720). In addition to these three goals, energy policies nevertheless often vary from country to country, as geographic location and natural resources put different challenges on the various countries. Indigenous supply, strength of market forces,

governmental price setting, and long term versus short term planning further define energy security assessments (Von Hippel et al. 2010: 75).

The goal of this paper is to analyse the energy security performance of three East Asian countries, namely, Japan, South Korea, and Taiwan, and find out how the energy security situation differs between them. These three countries feature similar geographic properties, including location, deposits of natural resources, and island nation properties for all intents and purposes. Additionally, their economies are comparable, as they are high tech economies featuring a large service sector. To analyse the energy security performance, a framework based upon the work by Martchamadol and Kumar (2013) and Sovacool (2013) will be used to create a combined new framework with thirty-five indicators.

The final framework and its results shall provide the reader with insight into topics such as overall energy supply and reserves, energy efficiency in various economic sectors, and diversification towards alternative energy sources. The data provided shows stark differences in various metrics within the three measured countries, but only touches briefly on the reasons for these differences. Researchers may use the impetus provided to delve deeper into the specific metrics and find the reasons behind this variance. Additionally, the data provided by this paper may be used to further compare other similar or dissimilar countries in terms of energy security in order to test the flexibility of this framework. Further work could also use the data to distil a single energy security value, which could provide a simple tool to quickly compare the energy security of multiple countries.

Data used in this paper was generally taken from 2016 with exceptions made for data which was not available. In these cases, the next closest year was taken as the reference year. Translations are by the author unless otherwise specified.

State of the Art

Energy security is a term with no single definition. The Nautilus Institute for Security and Sustainable Development's (1998: 3–4) definition focuses on natural deposits, the distribution between market forces and government intervention in price setting, and long-term versus short-term planning. Moreover, it adds environmental protection and social and cultural risks that need to be considered. The Organisation for Economic Cooperation and Development (OECD) and IEA in 2014 released a report defining energy security as "the uninterrupted availability of energy sources at an affordable price" (2014: 13). Three core aspects of energy security are included in this sentence, namely affordability, availability, and accessibility. Affordability is guaranteed when social and economic activities are not severely disrupted (Deese 1979: 140). Availability is secured when the continuous and growing demand of energy can be satisfied (Khatib 2009: 112). Accessibility concerns itself with the possibility of extraction of

natural resources or generation of energy through other technologies (APERC 2007: 18). In the same paper, APERC has also included a fourth aspect, labelled acceptability. Elements include environmental and societal standards, which then stand in an inverse relationship with low energy costs (Kruyt et al. 2009: 2167).

Cherp and Jewell (2014: 416–418) have criticised the conceptualisation of energy security definitions in previous works and claim that even the "four A" concept is varying strongly between researchers. In an attempt to simplify these approaches, Ang, Choong, and Ng (2015b: 1081–1082) have surveyed more than a hundred energy security studies and extracted seven energy security themes: energy availability, infrastructure, energy prices, societal effects, environment, governance, energy efficiency. Frameworks which analyse energy security also differ widely in their approaches. The Global Energy Security Matrix, created by the OECD and the IEA (2009: 49) features seven dimensions and is designed as a template to determine the key improvement areas. The framework lacks the possibility to designate current energy security performance. The International Index of Energy Security Risk published by the Global Energy Institute (2016) provides a ranking based upon eight categories, among which twenty-nine metrics are considered. Its reliance on global data and trends as well as a special emphasis on fossil fuels and the lack of renewable energy data points do not lend itself to the analysis at hand. Vivoda (2010: 5261) created an Energy Security Assessment Instrument, which included eleven dimensions and forty-four indicators in total. As many of these indicators necessitate qualitative data, difficulties in direct comparisons emerge. In 2011, Sovacool expanded upon Vivoda's framework through interviews with international organisations and foundations working in the energy sector. The final framework offered presents twenty dimensions and 200 metrics overall (Sovacool 2011: 7476–7477). Another framework co-authored by Sovacool (Sovacool and Mukherjee 2011) features 320 simple and fifty-two complex indicators. Such frameworks are comprehensive in their span but are not suitable for analysis for the author's intended scope.

The chosen frameworks include Martchamadol and Kumar's (2013) "Aggregated Energy Security Performance Indicator (AESPI)" and Sovacool's (2013) "Assessing energy security performance in the Asia Pacific, 1990–2010." Martchamadol and Kumar's AESPI is an attempt to create a simple, comprehensive tool to analyse energy security performance, similar in concept to the Human Development Index or the Gross Domestic Product. Through its application, the energy security status of any given country should be easy to grasp and compare. For this purpose, Martchamadol and Kumar's framework consists of three dimensions: economic, societal, and environmental. Within these dimensions there are twenty-five indicators overall (Table 1). These indicators are based upon the Energy Indicators for Sustainable Development and were chosen by their usage rate. All metrics used are quantitative and economic sectors are split up to offer comparability. Renewable energies and carbon emissions are included, as are transmission and transformation losses. AESPI is also favourably

mentioned in multiple papers on energy security (Ang, Choong, and Ng 2015a: 315; Narula and Reddy 2015: 150; Ren and Sovacool 2014: 839; Tongsopit et al. 2016; Valdés 2018) and was used in an analysis of various EU member states by Smiech and Papiez (2014).

Sovacool's (2013) framework also features only quantitative data, which makes it feasible to combine key elements of both frameworks. It was specifically tailored to the Asia Pacific and contains metrics missing in AESPI, including pollution data, land use, water use, and fuel prices (Table 2). The countries chosen include the four largest energy consumers in Southeast Asia, namely China, India, Japan, and South Korea. In addition, ten ASEAN countries, Australia, and New Zealand have been added. The framework was created in a four-stage process, which started with a literature analysis and followed by expert interviews. In step three, energy planners were surveyed and the results of all previous stages were then used in the final stage to create a workshop in which dimensions, components, and metrics were determined.

The merging of those frameworks builds a more robust one, making it possible to easily compare countries' energy performances.

Table 1: Indicators for AESPI Formulation (Martchamadol and Kumar 2013: 663)

Indicator Number	Indicator Name	EISD category	Impact value relation*
1	Total Primary Energy per Capita	ECO – 1.1	Negative
2	Final Energy Consumption per Capita	ECO – 1.2	Negative
3	Electricity per Capita	ECO – 1.3	Negative
4	Total Primary Energy Intensity	ECO – 2.1	Negative
5	Final Energy Intensity	ECO – 2.2	Negative
6	Loss in Transmission	ECO – 3.1	Negative
7	Loss in Transformation	ECO – 3.2	Negative
8	Reserve Production Ratio (RPR) Crude Oil	ECO – 4.1	Positive
9	Reserve Production Ratio (RPR) Natural Gas	ECO – 4.2	Positive
10	Reserve Production Ratio (RPR) Coal	ECO – 4.3	Positive

11	Industrial Energy Intensity	ECO – 6	Negative
12	Agriculture Energy Intensity	ECO – 7	Negative
13	Commercial Energy Intensity	ECO – 8	Negative
14	Household Energy per Capita	ECO – 9.1	Negative
15	Household Electricity per Capita	ECO – 9.2	Negative
16	Transportation Energy Intensity	ECO – 10	Negative
17	Share of Capacity of Renewable Energy per Total Electricity Generation	ECO – 11	Positive
18	Share of Non-Carbon Energy per TPES	ECO – 12	Positive
19	Share of Renewable Energy per FEC	ECO – 13	Positive
20	Net Energy Import Dependency (NEID)	ECO – 15	Negative
21	CO_2 Emission per Capita	ENV – 1.1	Negative
22	CO_2 Emission per GDP	ENV – 1.2	Negative
23	Household Access to Electricity	SOC – 1	Positive
24	Share of Income Spent on Electricity	SOC – 2	Negative
25	Residential Energy per Household	SOC – 3	Negative

*Note that a positive impact value relation implies that a higher value indicator represents an improvement of energy security, while a negative indicator implies that a lower value represents an improvement.

Table 2: Energy Security Index (Sovacool 2013: 230)

Dimension		Component	Metric	Unit
Availability	1	Security of Supply	Total Primary Energy Supply	Thousand Tons of Oil Equivalent
	2	Production	Average Reserve to Production Ratio for the 3 Primary Energy Fuels (Coal, Natural Gas, and Oil)	Remaining Years of Production

	3	Dependency	Self Sufficiency	% of Energy Demand by Domestic Production
	4	Diversification	Share of Renewable Energy in Total Primary Energy Supply	% of Supply
Affordability	5	Stability	Stability of Electricity Prices	% Change
	6	Access	% Population with High Quality Connections to the Electricity Grid	% Electrification
	7	Equity	Households Dependent on Traditional Fuels	% of Population Using Solid Fuels
	8	Affordability	Retail Price of Gasoline/Petrol	Average Price in USD PPP for 100l of Regular Gasoline/Petrol
Technology development and efficiency	9	Innovation and Research	Research Intensity	% of Government Expenditures on Research and Development Compared to All Expenditures
	10	Energy Efficiency	Energy Intensity	Energy Consumption per Dollar of GDP
	11	Safety and Reliability	Grid Efficiency	% Electricity Transmission and Distribution Losses
	12	Resilience	Energy Resources and Stockpiles	Years of Energy Reserves Left
Environmental sustainability	13	Land Use	Forests Cover	Forest Area as Per Cent of Land Area
	14	Water	Water Availability	% Population with Access to Improved Water
	15	Climate Change	Per Capita Energy-Related Carbon Dioxide Emissions	Metric Tons of CO_2 per Person
	16	Pollution	Per Capita Sulphur Dioxide Emissions	Metric Tons of SO_2 per Person
Regulation & governance	17	Governance	Worldwide Governance Rating	Worldwide Governance Score

18	Trade and Connectivity	Energy Exports	Annual Value of Energy Exports in 2009 USD PPP – (Billions)
19	Competition	Per Capita Energy Subsidies	Cost of Energy Subsidies per Person (2009 USD PPP)
20	Information	Quality of Energy Information	% of Data Complete

Constructing the Framework

Indicators and Components

The first three indicators were chosen by Martchamadol and Kumar to measure energy consumption, energy usage, and energy efficiency on the demand side. The energy intensity indicators both assess the energy efficiency in relation to the economic output. Four indicators split up between economic sectors show this relation within the respective sectors. Transmission and transformation losses show the energy efficiency on the supply side. General supply availability is covered through reserve production ratio metrics for all common fossil fuels. "Net energy import dependency (NEID)" gives insight into the domestic energy market as well as general accessibility overview. Non-carbon energy, renewable energy, and renewable capacity indicators provide information on the state of renewable energy, with CO_2 metrics showing greenhouse gas emissions. Household and energy expense indicators were selected to gain insight into the energy efficiency, demand, affordability, as well as accessibility in the residential sector.

Sovacool's framework features five dimensions: *availability*, *affordability*, *technology development and efficiency*, *environmental sustainability*, and *regulation and governance* with four metrics each. The first dimension includes metrics on energy supply, energy dependency, renewable energies, and reserve production on fossil fuels. Within the *affordability* dimension, metrics are presented to provide information on energy access and costs. The third dimension gives insight into research intensity, energy intensity, and grid efficiency. The *environmental sustainability* dimension concerns water use, land use, and pollution metrics. The final dimension includes data on governance, subsidies, exports, and available information.

When combining and comparing the frameworks, per capita metrics are given preference over absolute metrics. More defined metrics are given preference over more general ones. And per AESPI's model, governmental metrics will not be in-

cluded. The author has chosen to merge such metrics and add those that are not duplicates. Sovacool's *availability* dimension features the same metrics within AESPI's framework. "Security of supply" equals "total primary energy per capita." "Production" matches AESPI's indicators eight, nine, and ten. Sovacool merges three kinds of fossil fuels into one component, but as per the author's definition, three separate indicators of Martchamadol and Kumar's framework will be used in its stead. Indicator twenty ("net energy import dependency") and the "dependency" component are equal in their metric. Both calculate the share of energy imports within the primary energy supply. Indicator nineteen and the component "diversification" overlap in presenting renewable energy share within energy supply.

Within the second dimension, *affordability*, components five ("stability") and eight ("affordability") are pricing metrics. Indicator twenty-four (income share spent on electricity) is the sole indicator within AESPI's framework to concern itself with pricing. Component six equals indicator twenty-three. The components "equity" and "stability" are not included and are added to the final framework. Component eight in Sovacool's work and indicator twenty-four are similar, in such as they both represent the affordability of energy. To keep a better level of differentiation, "affordability" is changed in name to "fuel pricing" in the final framework. Component five ("stability") will be included in this paper's constructed framework. Sovacool's framework used data from twenty years as a period of comparison. This paper's framework will use the same timeframe.

Component seven ("equity") will be renamed to "solid fuel usage" for clarity purposes. In Sovacool's third dimension, *technology development and efficiency*, component nine ("innovation and research") takes government expenditure into account. As per the definition of this paper's author, this component will therefore be disregarded. AESPI's indicators "final energy intensity," "loss in transmission," and "loss in transformation" contain the same metrics as components ten and eleven ("energy efficiency" and "safety and reliability"). The component "resilience" has no equivalent indicator and will thus be included in this paper's final framework.

Within the fourth dimension, *environmental sustainability*, the components "land use" and "water" are not found in AESPI and are added. The component "climate change" and the indicator twenty-one ("CO_2 emission per capita") feature the same metric and are merged. Component sixteen ("pollution") has no comparable indicator present in AESPI and is added in the final framework.

The final dimension, *regulation and governance*, features two components, "governance" and "competition," measuring government expenditures and performance. As with "innovation and research," this metric will not be included in the framework. The final components, "trade and connectivity" and "information," do not have comparable indicators in AESPI and will be included in the combined framework.

The final combined framework with all thirty-five indicators can be found below in Table 3.

Table 3: Final Combined Framework

Dimension	#	Indicator	Metric	Unit	Additional Notes
Availability	1	Supply	Total Primary Energy Supply (TPES) per Total Population	kgoe per Capita	
	2	Final Energy Consumption	Final Energy Consumption (FEC) per Total Population	kgoe per Capita	
	3	Electricity per Capita	Total Electricity Consumption per Total Population	kgoe per Capita	Electricity Consumption measured in kgoe
	4	Resilience	Total Reserves per FEC	Reserves in Years	Reserves and Stockpiles of Coal, Oil, Gas, and Uranium Divided by FEC
	5	Reserve Production (Oil)	(Proven) Reserves of Crude Oil per Crude Oil Production	Reserves in Years	
	6	Reserve Production (Natural Gas)	(Proven) Reserves of Natural Gas per Natural Gas Production	Reserves in Years	
	7	Reserve Production (Coal)	(Proven) Reserves of Coal per Coal Production	Reserves in Years	

Dimension	#	Indicator	Metric	Unit	Additional Notes
Availability	8	Dependency	Imported Energy as Share of TPES	Dependency in %	Total net imports (imports minus exports) of natural gas, solid fuels, and oil, including petroleum products
	9	Diversification	Share of Renewable Energy of TPES	Renewable Energy Share in %	Renewable Energy Generation in kgoe divided by TPES
	10	Exports	Value of Total Energy Exports	Value in USD	
Efficiency and Technology	11	Primary Energy Intensity	TPES per GDP	kgoe per USD	
	12	Final Energy Intensity	FEC per GDP	kgoe per USD	
	13	Transportation Energy Intensity	FEC of the Transportation Sector per GDP of the Transportation Sector	kgoe per USD	
	14	Commercial Energy Intensity	FEC of the Commercial Sector per GDP of the Commercial Sector	kgoe per USD	

Dimension	#	Indicator	Metric	Unit	Additional Notes
Efficiency and Technology	15	Agriculture Energy Intensity	FEC of the Agriculture Sector per GDP of the Agriculture Sector	kgoe per USD	
	16	Industrial Energy Intensity	FEC of the Industrial Sector per GDP of the Industrial Sector	kgoe per USD	
	17	Household Consumption	Residential Energy Consumption per Total Number of Households	kgoe per Households	
	18	Household Energy	Residential Energy Consumption per Total Number of Households per Average Members of Households	kgoe per Capita	
	19	Household Electricity	Residential Electricity Consumption per Total Number of Households per Average Members of Households	kWh per Capita	
	20	Grid Efficiency 1 (Loss in Transmission)	Reported Data (Annualied)	Transmission Loss in %	
	21	Grid Efficiency 2 (Loss in Transformation)	$\left(1-\left(\frac{FEC}{TPES}\right)\right)\times 100$	Transformation Loss in %	

Dimension	#	Indicator	Metric	Unit	Additional Notes
Affordability	22	Access	Households with Electricity Access per Total Number of Households	% of Households with Access to Electricity	
	23	Solid Fuel Usage	Percentage of Population Using Solid Fuels	Percentage of Solid Fuel Dependent Households	Solid Fuels include Biomass, Wood, Charcoal, Straw, Crops, Agricultural Waste, Dung, Shrubs, and Coal
	24	Electricity Pricing	$\frac{(EC/Cap/Year) \times EP)}{\frac{GDP}{Cap}} \times 100$	Income Pay Expenditure for Electricity in %	EC = Electricity Consumption Cap = Capita EP = Electricity Price
	25	Stability	% Change in Electricity Prices over Five-Year Intervals	Change in %	Five-Year Intervals over the Last 20 Years
	26	Fuel Pricing	Average Price in USD PPP for 100l of Regular Gasoline/Petrol	Price in USD	Actual Prices Paid by Final Consumers for Ordinary Gasoline inclusive of all Taxes and Subsidies
Environmental Sustainability	27	Land Use	Forest Cover of Land Mass in %	% of Total Land Mass	Excludes Tree Stands in Agricultural Production Systems and Trees in Urban Parks and Gardens
	28	Water	Access to Improved Water among Population	% of Population with Access	Improved Water includes Household Connections, Public Standpipes, Boreholes, Protected Wells and/or Spring and Rainwater Collection

Dimension	#	Indicator	Metric	Unit	Additional Notes
Environmental Sustainability	29	Climate Change 1 (CO_2 per Capita)	Fossil Fuel Type by Total Consumption of that Fuel by Carbon Emission Factor of that Fuel per Total Population	tCO_2 per Capita	
	30	Climate Change 2 (CO_2 per GDP)	Fossil Fuel Type by Total Consumption of that Fuel by Carbon Emission Factor of that Fuel per GDP	$kgCO_2$ per USD	
	31	Renewable Capacity	Renewable Electricity Generation Capacity in MW per Total Generation Capacity	% of Renewables within Total Electricity Generation Capacity	
	32	Non-Carbon Energy	Hydro Primary Energy Supply (PES) plus Nuclear PES plus Renewable PES per TPES	% of Non-Carbon Energy within TPES	Excludes Waste Energy Generation
	33	Renewables	Renewable Energy Consumption per FEC	% of Renewables within FEC	
	34	Pollution	Sulphur Dioxide Emissions per Total Population	SO_2 Emission per Capita	SO_x Emissions used as Substitute
Information	35	Quality of Information	Missing Data points per Total Data Points	% of Data Complete	

Definitions

In various indicators, data is presented in kilograms of oil equivalent or tons of oil equivalent (kgoe/toe). This value is defined by Eurostat as a normalised unit of energy, which should equal to the energy which can be extracted from one kilogram of crude oil. The standard nominal energy value equals 41,868 kilojoules per kilogram or 41,868 gigajoules per ton (Eurostat 2013).

The term "total primary energy supply" is defined by the OECD (2018b) as "energy production plus energy imports, minus energy exports, minus international bunkers, then plus or minus stock changes." The IEA (2019) further defines international bunkers as both aviation and marine bunkers, which need to be considered. Calculating the total primary energy supply features two distinct models. The partial substitution method converts all energy generated, no matter its source, to the amount necessary to produce this energy through a thermal energy plant. The second method used is the physical energy content one. Thereby the primary energy source is the primary energy equivalent (IEA 2019). To exemplify the partial substitution method, heat is a thermal power plant's primary energy source. A nuclear power plant's primary energy source is also heat, but as the desired energy value is electricity for both thermal and nuclear power plants, energy values are then calculated by using a thirty-three per cent efficiency assumption. In the case of hydropower, however, the primary energy source is electricity. The power generation here is assumed to be close to a hundred per cent efficient and no further calculations need to be considered. Therefore, using the partial substitution method yields overly large numbers in the case of nuclear power, and reduced numbers in the case of hydropower in comparison to the physical energy content method. Based upon Japan's and South Korea's own data (KEEI 2017; METI 2016a), both use the partial substitution method, which means that further calculations are required in some areas to get the correct energy values for certain metrics, especially hydropower and nuclear power.

Eurostat (2012) defines "final energy consumption" as "the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself." Similarly, "final electricity consumption" does not include own use electricity, as well as transmission or distribution losses. It solely focuses on electricity that reaches the end consumer. It is calculated using imports minus exports. Differences in total amount produced and/or imported to the total amount consumed are assumed to be losses in transmission or distribution (Central Intelligence Agency 2018; EEA 2010).

Another term frequently used within the framework is energy intensity. It is defined as the expended energy unit per unit of the Gross Domestic Product (GDP). In other terms, it shows how much energy needs to be used in an economy to increase the economic output. A higher energy intensity shows that more energy is required

per unit of GDP, whereas a lower energy intensity indicates that less energy is required. Factors influencing energy intensity are abundant and can range from better and more energy efficient technology being used to a refocusing of the economy on sectors which need little energy but produce high economic output. Even geographic situations, climate, country size, or the occurrence of natural disasters can influence the energy intensity. Paradoxically then, longer commutes or higher energy expenditures can also lower energy intensity if the economic output of the action increases GDP disproportionally (Bhatia 2014: 16–17).

Most indicators use per capita metrics instead of absolute ones. As per the United Nations Statistics division, the *de jure* population number, meaning all residents, will be used (UN 2008: 122).

The GDP is a metric used throughout this paper and is defined by the OECD (2018a) as:

> Expenditure on final goods and services minus imports: final consumption expenditures, gross capital formation, and exports less imports. 'Gross' signifies that no deduction has been made for the depreciation of machinery, building and other capital products used in production. 'Domestic' means that it is production by the resident institutional units of the country. The products refer to final goods and services, that is, those that are purchased, imputed or otherwise, as: final consumption of households, non-profit institutions serving households and government; fixed assets; and exports (minus imports).

In addition, the concept of purchase power parity (PPP) will be utilised to equalise currencies based on their purchasing power in their home countries (OECD 2019b).

Transmission and transformation losses are energy losses that occur during the electricity generating and delivering process. Transmission losses include heat generated in power lines and transformers, as well as variable losses in cables and power lines. Transformation losses include losses that are incurred via the transformation of one energy form to electricity (Council of European Energy Regulators 2017: 10–11).

Renewable energy is defined by Twidell and Weir (2006: 7) as "energy obtained from natural and persistent flows of energy occurring in the immediate environment." These flows of energy are continually replenished and either directly or indirectly obtained from the sun. Direct cases include thermal, photo-chemical, and photo-electric energy. Indirect includes hydropower, wind, and photosynthetic energy in biomass. Other flows of energy include geothermal and tidal energies (Ellabban et al. 2014: 749). Solar energy is differentiated between photovoltaic, concentrating solar power, and solar thermal heating and cooling. Photovoltaic systems convert solar energy into electricity through semiconductors. Concentrating solar energy is a technique which bundles solar rays and uses the energy to heat a liquid, solid, or gas which is then further used for electricity generating purposes. Solar thermal heating and cooling uses thermal energy or heat exchangers to offer heating or cooling depending on needs (ibid.: 754).

Hydropower is energy of flowing water converted to electricity through turbines. There are three types of hydropower plants, which include Run-of-River, storage, and pumped storage plants. Run-of-river plants use natural elevation differences and the resulting downstream flow of water to power turbines and produce electricity. Storage and pumped storage plants rely on a reservoir of water which, either naturally or through pumps, is accumulated and then emptied through turbines when required (Ellabban et al. 2014: 752).

Wind turbines provide electricity, but wind power can also be used mechanically in windmills, and in wind pumps for drainage or water. Wind turbine farms exist on- and offshore with offshore farms yielding higher wind resources but come at the cost of more expensive infrastructure (Ellabban et al. 2014: 755).

Biomass is defined as organic material from plants, crops, and trees which store energy through photosynthesis. Biomass can then be converted into heat, electricity, fuels, or other types of energy. Geothermal energy production requires the tapping of the stored heat energy in earth's interior crust. This can be in the form of rock, trapped steam, or liquid water. Renewable marine energy stems from tidal differences, ocean currents, salinity gradients, or ocean thermal energy conversion. These technologies are currently mostly still in their infancy (Ellabban et al. 2014: 750–751).

The burning of waste produces thermal energy. Waste energy is typically not considered renewable, but since waste is continuously being produced, some researchers have begun including thermal waste processing into the renewable energy umbrella (Moya et al. 2017: 293).

AESPI includes the non-carbon energy metric, which is based upon an indicator of the APERC. It separates hydro and nuclear energy from other (renewable) energy sources (APERC 2007: 52).

Carbon emission metrics require information about carbon emission factors for various fossil fuels. These factors are averaged within the data of the British Department for Business, Energy and Industrial Strategy and the Department for Environment, Food and Rural Affairs (BEIS and DEFRA) (BEIS and DEFRA 2018).

Improved water sources differentiate between piped and non-piped water.The former are generally found in tap water, while the latter include boreholes, protected wells and springs, rainwater, and packaged water (UNICEF and WHO 2017: 12).

Another metric present is forest cover, which is defined by the Food and Agriculture Organization (FAO) as "land spanning more than 0.5 hectares with trees higher than 5 meters and canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use" (FAO 2012: 3).

As energy intensity is also measured within different economic sectors, these sectors need to be defined. The U.S. Energy Information Administration defines (USEIA) the commercial sector as "an energy consuming sector that consists of service-provid-

ing facilities and equipment of businesses" (USEIA 2018b). This definition is expanded upon by Griffith et al. (2007: 4), by excluding industrial, residential, and agricultural activities. For the purpose of this paper, the sector will include all public and private economic activities and exclude agricultural, industrial, manufacturing, transport, and residential activities.

The transportation sector is defined by including all energy used to transport people or goods by road, rail, air, marine, or pipeline ways. Not included are vehicles whose main purpose is not transport but localised work (e.g., cranes, bulldozers, farming vehicles) (Atabani et al. 2011: 4587; USEIA 2018b).

The agricultural sector includes several sub-sectors, such as gathering, production, post-harvest processing, crop farming, livestock management, agro-forestry, and fishing and aquaculture (FAO 2018).

In many definitions, the industrial sector is often combined with agriculture, forestry, and fishing (Abdelaziz, Saidur, and Mekhilef 2011; BusinessDictionary 2018; Office of Energy Efficiency 2008; USEIA 2018b; Zhang 2003). As this paper aims to separate agriculture from other industries, the author will use solely manufacturing, mining, and construction activities as the point of reference.

Country Case Analysis

Japan

With 456 million tons of oil equivalent being consumed in 2017, Japan ranks number five globally (BP 2018a: 8). With domestic resources being extremely scarce, the import of energy is the main source of fuel. Fossil fuels account for ninety per cent of primary energy (METI 2018: 1). Domestic oil production does not produce enough yields on either on- or offshore projects. Therefore, crude oil is instead imported and refined domestically (Petroleum Association of Japan 2015: 8; Thorarinsson 2018: 13–15). Coal has increasingly become more expensive to produce within Japan during the second half of the last century. As domestic prices tripled imported materials, the last coal mine was closed in 2002, with only small-scale projects recently opening in Hokkaido. Japan features the highest efficiency rate of coal powered plants worldwide (Hirao 2002; USEIA 2017: 16).

Liquefied Natural Gas (LNG) has become the main electricity production resource. Japan has also become the largest importer of LNG worldwide with eighty-four million tons in 2016 (ITA 2018a; METI 2018: 8).

Nuclear power in Japan has drastically been reduced after the Tohoku earthquake of 2011 and the subsequent accident at the Fukushima Daiichi Nuclear Power Plant. Reactors were only slowly restarted. Although Japan officialy has thirty-seven nuclear

power plaints, nuclear power accounted for just one per cent of all electricity generation by 2014, and only nine reactors had been restarted by 2018 (Komiyama and Fujii 2017: 595; USEIA 2017: 17; WNA 2018b).

By 2017, renewable energy made up 15.6% of all energy generation, with hydropower leading among the various types. The last decade has seen a strong rise of PV systems, but the continuous reduction of feed-in-tariffs by the government has led to a stark decrease in new installations (ITA 2018b; Japan for Sustainability 2017). Japan ranks third globally in unused geothermal energy reserves, but land use issues hamper expansion (ITA 2016: 3).

South Korea

As the ninth largest energy consumer worldwide, South Korea features scarce natural resources and relies on imports for ninety-eight per cent of its fossil fuels (BP 2018a: 8; USEIA 2018a: 1). While oil and gas fields are being explored, the daily production of 165 barrels of crude oil in 2016 is miniscule in comparison to the overall consumption. The domestic production is accounting for less than one per cent of total demand (KEEI 2017: 6; KNOC 2018). Private coal mines still operate but are also unable to satisfy domestic demand (KEEI 2017: 6; KCC 2019).

Up to date twenty-five nuclear reactors have been constructed in South Korea. Two reactors have been permanently shut down and ten more are scheduled to shut down in the near future (Korea Hydro and Nuclear Power 2018; MOTIE 2017a: 35; WNA 2019).

Among renewable energies, more than half is produced from waste incineration. Solar energy reached a third of total renewable capacity in 2016 and, together with wind energy, constitutes the major focus of expansion. Hydropower is limited by seasonal fluctuations and makes up around only five per cent of all renewable energy (Alsharif, Kim, and Kim 2018: 7; KEEI 2017: 6, 45; Materia 2017: 6).

Taiwan

In 2016, total energy consumption of 114 million toe ranks Taiwan at number twenty-two among energy consumers worldwide (BP 2018b). Natural resources are scarce, and energy is mostly imported in the form of fossil fuels (USEIA 2016). Oil and gas exploration in Taiwan has not yielded major results and domestic production is miniscule (ibid.). Coal mines have been slowly shut down since the 1970s and after three major accidents in 1984. There are no active coal mines currently (S. Yu 2002; Wu 2000: 150). LNG imports in Taiwan are securing the majority of electricity generation and are overall the fifth largest worldwide (BEMEA 2018i; CEIC 2019; IGU 2017). Nuclear power plants started operating in 1978. These first plants were shut down in 2018, but two other plants continue to operate. In a 2018 referendum, the

continuing use of nuclear power was approved by the public with a fifty-nine per cent majority (WNA 2018c). Renewable energies have increased in the last decade and solar energy saw a doubling of its capacity between 2012 and 2015 (BEMEA 2013; IEA PVPS 2018: 3). Both offshore and onshore wind turbines are being pursued, and geothermal energy is being tested for its potential (ITRI 2019; Pan and Kao 2017; Tsai and Hsu 2018). The lack of capacity for large scale hdyropower projects and environmental concerns caused hydropower to only slowly increase since 1962 (Chang 2017: 61).

Indicator Analysis

Indicator 1

Japan

The first indicator, *supply*, is adding all indigenous production of coal, crude oil, natural gas, nuclear fission, hydroelectric, and other renewable energy sources. Imports and exports of energy are considered and stock changes as well as international bunkers are added. Overall, the Ministry of Economy Trade and Industry's (METI) data shows that 194,145,500 tons of coal were supplied. After transforming this value into tons of oil equivalent, the final value of the coal supply is 119,636,808.54 toe (APS 2018; METI 2016a; United Nations Department of Economic and Social Affairs Statistics Division 2016: 24). Crude oil and oil products add up to 192,449,700 kilolitres and transform to 181,125,574.56 toe (APS 2018; IEA 2018d; METI 2016a). Natural gas measured 4,809,908,064 MBTU (British Thermal Units in millions). Converting that value leads to a result of 121,207,644 toe (IEA 2018d; IGU 2012; METI 2016a). Nuclear power yields an additional 148,965 Terajoule (TJ) of energy, which equals 3,558,803 toe (IEA 2018d; METI 2016a). No imports, exports, bunkers, or stockpile changes need to be taken into account when considering nuclear power generation and renewable energy. Not counting hydropower, renewables accounted for 803,760 TJ or 19,197,487.3 toe. Hydropower by itself produced 650,844.56 TJ or 15,545,141.9 toe (IEA 2018d; METI 2016a). In addition, waste energy, also tracked by the METI, adds 13,962,164.4 toe through incineration (IEA 2018d; METI 2016a). When all added up, these values result in a total energy supply of 474,233,623.7 toe. The per capita consumption is calculated by using the de jure total population of Japan. With the Statistics Bureau of Japan measuring 126,933,000 people in 2016, the per capita supply results in 3.73609 toe/cap or 3,736.09 kgoe/cap (SBMIC 2018: 10).

South Korea

Total primary energy supply in South Korea is based upon data from the Korea Energy Economics Institute (KEEI). Coal and coal products, including production, imports, and stock changes made up 81,872,000 toe. Oil and petroleum products include no domestic production and amount to overall 119,108,000 toe. Natural gas features a small domestic production and, coupled with imports and stock changes, amounts to a total of 45,518,000 toe. Nuclear power produced the equivalent of 34,181,000 toe, hydropower 1,400,000 toe, and all remaining renewable sources produced 13,575,000 toe in total (KEEI 2017: 50–51). The total supply therefore amounts to 294,654,000 toe. Considering the population of 51,269,554 persons, the per capita primary consumption is 5.74715 toe or 5,747.15 kgoe per capita (KOSIS 2018c).

Taiwan

Total coal imports, divided into various coal products, measured the equivalent of 38,683,440 toe (BEMEA 2018i: 29). Among crude oil and products, 8,500,000 kl were produced domestically, with the overall supply reaching 49,526,500 kl. After conversion, this equals 43,492,680 toe (ibid.). Natural gas domestic production and imports measured 369,800,000 cubic meters and LNG made up 33,594,550 cubic meters (BEMEA 2018h: 29). Converted into tons of oil equivalent, the number is 18,081,180 toe. Nuclear energy accounted for 8,252,190 toe, hydropower for 564,570 toe, solar energy for 97,380 toe, wind energy for 125,370 toe, and solar thermal energy for 100,890 toe (BEMEA 2018h: 29; 2018i: 29). The TPES adds up to 110,962,800 toe. Official data puts the number of residents in Taiwan at 23,539,816, which in turn means the per capita value of total primary energy supply is 4.71383 toe/capita or 4,713.83 kgoe/capita (Department of Household Registration Affairs 2019).

Indicator 2

Japan

Final energy consumption is calculated through the addition of all economic sectors, as laid out in the framework. The industrial sector, including agriculture, fishery, mining, construction, and manufacturing consumed a total of 137,842,027 toe. The commercial sector accounted for 50,998,590.8 toe. Residential data added another 45,788,836.3 toe and the transportation sector 74,604,542.8 toe. Combined with the non-energy sector—usage of primary materials for other uses than energy generation—the total consumption adds up to 356,718,424.13 toe (IEA 2018d; METI 2016a). Divided by the total population, the per capita value is 2,810.28 kgoe/cap.

South Korea

Final Energy Consumption, being calculated from the industry, transportation, residential, commercial, and public sector, is the second indicator. The industry sector accounted for 138,469,000 toe, the transportation sector for 42,714,000 toe, the residential sector for 21,256,000, the commercial sector for 17,005,000 toe, and the public sector for 6,237,000 toe (KEEI 2017: 50–51). Overall, this totalled to 225,681,000 toe and a per capita value of 4.40158 toe or 4,401.85 kgoe.

Taiwan

Between the different economic sectors, the industrial sector consumed 23,986,890 toe, the agricultural sector consumed 596,430 toe, the transportation sector accounted for 12,515,040 toe, the commercial sector consumed 5,335,650 toe, and the residential sector 5,880,612 toe (BEMEA 2018h: 30; 2018i: 30). Including non-energy use, the total consumption adds up to 71,163,552 toe, which measured against the population is 3,023.11 kgoe per capita.

Indicator 3

Japan

Total electricity production amounted to 1055.53 terawatt hours (TWh). The agriculture, fishing, mining, construction, and manufacturing sector consumed 345.36 TWh, the commercial sector 317.66 TWh, the residential sector 269.27 TWh, and the transportation sector 17.43 TWh. Overall this amounts to 949.79 TWh (METI 2016a). The discrepancy between production and consumption is assumed to be losses in transmission or distribution. When converted into tons of oil equivalent, the resulting value is 81,667,239.9 toe, and distributed among the population this results in a per capita consumption of 643.38 kgoe.

South Korea

The electricity generated in 2016 was 540,441 gigawatt hours (GWh), while the total usage was measured at 497,039 GWh, with the differences expected to be various losses. This value equals 42,745,000 toe and results in a per capita value of 833.73 kgoe of consumed electricity.

Taiwan

The total of all electricity produced required 48,584,430 toe, whereas total electrical output was 22,725,810 toe. The electricity consumed by end users finally amounted to 20,345,580 toe (BEMEA 2018h: 30; 2018i: 30). Divided by the total population, per capita electricity consumption was 864.3 kgoe.

Indicator 4

Japan

To assess this indicator, all proven natural reserves and all stockpiles need to be considered. Coal stockpiles amounted to 137,864,240 toe in 2015 (Koji 2016). Petroleum stockpiles in Japan exist as both a national and a private stockpile. Added together, they amount to 74,692,371.26 toe (JOGMEC 2016: 2). Similarly, liquefied petrolum (LP) is being stored in national and private stockpiles, with the overall amount being 3,193,879 toe (Hofstrand 2008; JOGMEC 2017). LNG is not stockpiled strategically, but reprocessing facilities hold a voluntary stock of about twenty days reserve. This equals around 5,805,000 toe (Qatar Petroleum 2018; Vivoda 2014: 74). According to the Japanese Nuclear Regulation Authority, nuclear stockpiles are divided into enriched, depleted, and natural uranium. As all current operating reactors in Japan are light-water ones, the author assumes that all natural uranium will be enriched before usage (NRA 2015; URENCO 2019; WNA 2018b). Japan possesses its own enrichment facility at Rokkasho (Japan Nuclear Fuel Limited 2018). After taking these calculations the total tonnage of enriched material reaches 23,435 tons. With an energy density of 3,900 GJ/kg, the total energy of this stockpile is equal to 2,069,418,171 toe (WNA 2018a).

South Korea

Stockpiles in South Korea include coal, petroleum, LP gas, and uranium. No LNG stockpiles exist, but LNG storage tanks at terminals feature a significant stock. Overall these stocks total 587,253,353.42 toe (APS 2018; Doshi and Six 2017: 19–20; Hofstrand 2008; IAEA/NEA 2016: 106; IEA 2014: 300; Im 2016; MOTIE 2016: 3; 2017b: 7; Park and Chung 2014: 296; USEIA 2018a: 10). In addition, natural reserves of coal, petroleum, and uranium amount to 543,723,315.41 toe (BP 2018b; IAEA 2019; KNOC 2018; Xu and Bell 2017). The overall stockpile and natural reserve value is 1,331,865,175.56 toe, which divided by the FEC results in a reserve of 5.9 years for the resilience indicator.

Taiwan

Coal stockpiles in Taiwan amounted to 2,250,000 toe, crude stockpiles made up 14,418,880 toe, and LPG stockpiles 265,118 toe (BEMEA 2018f; 2018h: 30; Hofstrand 2008; Kwon and Hong 2015: 15). LNG stockpiles measure ten days' worth of supply, which amounts to a total of 547,740 toe (C. Hsu 2017). As for fissile nuclear material, no data could be found by the author. Natural reserves of coal are estimated at around one hundred million tons, crude oil at 347,324 toe, and natural gas at 5,500,000 toe (N.A. 1997: 271; Xu and Bell 2017). There are no naturally occurring uranium deposits in Taiwan (Russian Federation Foreign Intelligence Service 1995). These stockpiles and reserves total 84,951,303 toe, or when measured against FEC, 1.19 years.

Indicators 5–7

Japan

Natural coal reserves in Japan are estimated at 347-359 million tons or 242,837,000 toe (BP 2018b; USEPA and CMOP 2015: 162). Oil reserves have been estimated at forty-five million barrels, which converts to 6,567,067 toe (ENI 2018: 5; Xu and Bell 2017). Natural gas was found to have reserves of around 18,450,000 toe. According to the IAEA/NEA, the natural recoverable uranium sits at around 6,600 tons. Enriching this uranium would lead to a total energy value of 93,149,899 toe (URENCO 2019; WNA 2018a). To calculate the resilience indicator, the total energy reserves of 2,759,722,355.37 toe are divided by the final energy consumption for a value of 7.75 years of reserves. Reserve production for the three major fossil fuels is calculated by dividing current production by total reserves. For oil, the average daily production is estimated at around four million barrels a year (ENI 2018: 10). This leads to a reserve production of 11.25 years. Natural gas production was found to be around one hundred million cubic feet (USEIA 2017: 9). Using that value, the reserve production is 7.38 years. On coal, Japan only has very limited production of 1.2 million tons a year (Kushiro Coal Mine Co. Ltd. 2019). Considering current reserves, this would lead to a reserve production of 677.35 years. Similarly to the BP statistical review, the author will deem this coal production negligible (BP 2018b).

South Korea

Reserve production for each individual fossil fuel amounted to 1.6 years in the case of oil, 71.58 years in the case of natural gas, and 191.76 years in the case of coal (BP 2018b; KNOC 2018; Xu and Bell 2017). Natural gas and coal numbers are inflated because of miniscule production.

Taiwan

Considering the small domestic production of 8,500 kl in 2016, the total oil reserves could sustain a production of forty-four years (BEMEA 2018a: 2; Xu and Bell 2017). Natural gas reserves of 6,226,000,000 cubic meters would last 19.36 years under current production (IGU 2012; Xu and Bell 2017). Coal reserves are not being mined, so no reserve production can be calculated (BEMEA 2018j; S. Yu 2002).

Indicator 8

Japan

Fuel imports amounted to 416,414,949.29 toe overall (METI 2016a). Considering the TPES of 474,233,623.7 toe, the dependency ratio sits at 87.8%. When including nuclear energy in this calculation, dependency rises to 88.55% (METI 2016a).

South Korea

Calculating dependency based upon imports and exports compared to TPES shows a final import value of 255,664,000 toe contrasted to the TPES 294,654,000 toe. The energy import dependency is calculated at 86.76%. (KEEI 2017: 6, 23; 2018: 100) When nuclear fissile material is included in this calculation as imported energy, the number rises to 98.36% (KEEI 2017: 53).

Taiwan

Total imports minus exports amounted to 99,300,420 toe which, measured against TPES, leads to an import dependency of 89.48% (BEMEA 2018h: 29). Including nuclear material as imported energy increases this value to 96.92%.

Indicator 9

Japan

Renewable energy, including hydropower and waste energy recovery, totals 48,704,793.6 toe (METI 2016a). Measured against TPES, the diversification indicator is 10.27%.

South Korea

Overall renewable energy in South Korea, consisting of solar energy, hydropower, biomass energy generation, waste recovery, wind energy, fuel cells, geothermal, and tidal energy produced 14,975,200 toe (KEEI 2017: 27, 45). In relation to TPES, this equals a diversification indicator of 5.08%.

Taiwan

Hydropower, wind, solar PV, solar thermal, biomass, and waste energy combined produced 2,453,310 toe in 2016. This value equals 2.21% of TPES (BEMEA 2018h: 29; 2018i: 29).

Indicator 10

Japan

Export data shows that the export volume of coal and oil products measures 9,372,170,034 USD (UNSD 2019b).

South Korea

Energy exports in 2016 amounted to 487,716,000 barrels of petroleum products or 67,481,000 toe (KEEI 2017: 23; 2018: 100). The value of these exports was estimated at 26,679,036,921 USD (UNSD 2019b).

Taiwan

Mineral product exports made up 9,192,000,000 USD in 2016 (Department of Statistics Ministry of Economic Affairs 2019).

Indicator 11

Japan

Primary energy intensity calculation divides TPES by total GDP. The OECD puts the GDP value at 5,245,730,500,000 USD (OECD 2019a). The resulting division leads to a primary energy intensity of 0.0904 kgoe/USD or 3.78 MJ/USD (IEA 2018d).

South Korea

Using South Korea's GDP for 2016 and adjusting for PPP, the number is 1.903 trillion USD (KOSIS 2019; OECD 2018a; 2019b). Measured against the TPES, the resulting primary energy intensity is 0.1548 kgoe/USD.

Taiwan

Taiwan's GDP in 2016 was 1,135,322,899,814 USD according to official statistics (DGBAS 2019). When dividing TPES by this value, the primary energy intensity results in 0.0977 kgoe/USD.

Indicator 12

Japan

In contrast to primary energy intensity, final energy intensity is calculated by using the FEC instead of the TPES. The resulting calculation leads to a final energy intensity of 0.068 kgoe/USD or 2.84 MJ/USD (IEA 2018d).

South Korea

Taking the GDP value and dividing by FEC yields a result of 0.062 kgoe/USD as the final energy intensity.

Taiwan

Final energy intensity, utilising FEC and dividing by the previously established GDP, results in 0.11859 kgoe/USD.

Indicators 13–16

Japan

The energy intensity of the various economic sectors is calculated by dividing energy expenditure within that sector by its share of GDP. The transportation sector consumed 74,604,542.8 toe and accounted for 26,963 billion Yen or 264,343,137,254 USD PPP (METI 2016a; OECD 2019b; SBMIC 2019). The energy intensity is therefore 0.28 kgoe/USD or 11.8 MJ/USD (IEA 2018d). The commercial sector used 50,998,590.8 toe and accounted for 2,749,283,452,676 USD PPP, which yields an energy intensity of 0.018 kgoe/USD or 0.753 MJ/USD (IEA 2018d; METI 2016a; OECD 2019b; SBMIC 2019). Within the agricultural sector, 8,930,209.23 toe were

expended, while its share of the GDP was 60,724,509,803 USD PPP (ibid.). The resulting intensity is 0.14 kgoe/USD or 5.86 MJ/USD. The industrial sector measured a consumption of 137,842,027 toe. The GDP share amounted to 1,405,421,568,627 USD PPP (ibid.). The energy intensity equals 0.098 kgoe/USD or 4.1 MJ/USD.

South Korea

The energy intensity in the transportation sector was calculated at 0.622 kgoe/USD, using the total expenditure of 42,714,000 toe and its portion of GDP at 68,668,482,986 USD (KEEI 2017: 34; KOSIS 2018b). The commercial sector amounted to 954,412,034,084 USD of total GDP and used 22,242,000 toe. This results in an energy intensity of 0.0243 kgoe/USD (KEEI 2017: 51; KOSIS 2018b). The agricultural sector made up a respective 36,692,173,913 USD of GDP and consumed 2,719,000 toe, which leads to an energy intensity of 0.074 kgoe/USD (ibid.). The final industrial sector accounted for 610,836,125,442 USD in 2016 and used an overall 135,750,000 toe. This results in an energy intensity value of 0.222 kgoe/USD (ibid.).

Taiwan

The energy intensity within the transportation sector is measured by the total energy consumed in that sector and share of GDP. Consumption adds up to 12,515,040 toe, while GDP share was 2.92% or 33,151,428,674 USD (BEMEA 2018h: 30; 2018i: 30; DGBAS 2017). Through division of these values, energy intensity is 0.37 kgoe/USD.

Commercial sector data shows that the sector made up 678,468,964,929 USD of total GDP and consumed 5,335,650 toe (BEMEA 2018h: 30; 2018i: 30; DGBAS 2017). This leads to a energy intensity value of 0.0078 kgoe/USD.

Within the agricultural sector, 596,430 toe were consumed in 2016. Its share of GDP amounted to a total of 20,322,279,906 USD (BEMEA 2018h: 30; 2018i: 30; DGBAS 2017). The energy intensity therefore results in 0.0293 kgoe/USD.

The industrial sector accounted for 403,493,758,593 USD and used 23,986,890 toe in energy (BEMEA 2018i: 30; 2018h: 30; DGBAS 2017). Dividing energy expenditure by economic output yields a result of 0.059 kgoe/USD.

Indicator 17

Japan

Household energy consumption in Japan was calculated by using total residential energy expenditure and dividing it by the total households. Dividing 45,788,836.3 toe of consumption by 53,332,000 households yields a result of 858.56 kgoe per household (SBMIC 2018: 11).

South Korea

Household energy consumption measured 21,256,000 toe and with the number of households in 2016 being 19,837,665, the average per household consumption is 1071.49 kgoe (KEEI 2017: 51; KOSIS 2018c).

Taiwan

The department of household registration put the numbers of households at 8,561,383 in 2016 (DHRA 2019). Total household consumption meanwhile amounted to 5,880,612 toe, which puts household consumption at 686.87 kgoe (BEMEA 2018h: 30; 2018i: 30).

Indicator 18

Japan

Dividing this household energy consumption by the average number of household members of 2.33 leads to a per capita household consumption of 368.45 kgoe per capita (SBMIC 2018: 11).

South Korea

Per capita household consumption is calculated by using the average number of household members of 2.58. This leads to a per capita household consumption of 414.59 kgoe.

Taiwan

The average number of household members was 2.75, which leads to a per capita household consumption of 249.77 kgoe (DHRA 2019).

Indicator 19

Japan

The total residential electricity consumption amounted to 269,278,500,000 kWh in 2016 (METI 2016a). Divided by the total amount of households and average members per household, the per capita consumption is 2,166 kWh.

South Korea

The household electricity indicator uses the total consumption of 66.173 GWh within the residential sector. Divided by the total amount of households and average members per household, the per capita consumption is 1,292.91 kWh (KEEI 2017: 51).

Taiwan

Total residential electricity consumption amounted to 47,332,400 MWh (BEMEA 2018h: 29). Divided by total households and average household members shows a per capita consumption of 2,010 kWh.

Indicator 20

Japan

Grid efficiency, measured as the loss in transformation, was assessed by the Federation of Electric Power Companies of Japan and was reported at five per cent in 2016 (FEPC 2017: 23).

South Korea

The Ministry of Trade, Industry and Energy shows a transmission loss of 3.593% for 2016 (EPSIS 2019).

Taiwan

Transmission losses accounted for 8,684.6 GWh out of a total produced 255,420.1 GWh, which represent 3.4% (BEMEA 2018k).

Indicator 21

Japan

The loss in transformation is calculated according to the formula (1-(FEC/TPES))×100. Using the previously assessed values of FEC and TPES, the resulting value shows transformation losses at 24.78%.

South Korea

Using the formula given to calculate the loss in transformation, (1–(FEC/TPES))×100, the resulting value is 23.4%.

Taiwan

By using this indicator's formula and inserting FEC and TPES, loss in transformation in 2016 was 35.86%.

Indicator 22

Japan

According to the World Bank and the Federation of Electric Power companies of Japan data, one hundred per cent of households in Japan have access to electricity.

South Korea

Electricity access, tracked by the World Bank, shows a value of one hundred per cent in South Korea (WB 2019).

Taiwan

Electricity access in Taiwan was measured at ninety-nine per cent (World Energy Council 2015).

Indicator 23

Japan

Solid fuel usage in Japan is only estimated by the WHO (2013) and through a model by Rehfuess, Mehta, and Prüss-Üstün (2006: 373). Both models classify Japan as a high income country, which puts solid fuel usage below five per cent. For this paper, the rate will be considered as negligible.

South Korea

The model of the WHO is applied for the solid fuel indicator, which estimates solid fuel usage of countries with per capita GDP exceeding 10,500 USD to be below five per cent (WHO 2013).

Taiwan

Modeling through Rehfuess, Mehta, and Prüss-Üstün's model predicts that, with a per capita GDP of 48,299 USD PPP, Taiwan's solid fuel usage is expected to be below five per cent (Rehfuess, Mehta, and Prüss-Üstün 2006: 373).

Indicator 24

Japan

Electricity pricing is dependant on yearly consumption per capita, price per kWh, and GDP per capita. Per capita consumption has been establied at 2,166 kWh. The IEA energy prices and taxes report calculated the price of one kWh at 27.239 Yen in 2016 (IEA 2018a: 175). After accounting for PPP, the rate equals 0.26 USD (OECD 2019b). Per capita GDP can be calculated at 41,326.76 USD. Using these values to fill in this indicator's formula, the result is 1.36%.

South Korea

As for the electricity pricing indicator, the International Energy Agency shows that average kWh prices in 2016 were 138.16 Won, including all applicable taxes (IEA 2018a: 182). Converted to USD PPP, the price was 0.16 USD (OECD 2019b). Measured against per capita GDP of 37,059.03 USD and inserting these values into this indicator's formula, the result shows 0.55%.

Taiwan

The average price per kWh in 2016 was 0.1431 USD PPP (BEMEA 2018b). With GDP per capita at 48,299 USD PPP and an average consumption per capita of 2,010 kWh, the yearly electricity expenditure makes up 0.59% of per capita GDP.

Indicator 25

Japan

Electricity price fluctuations for the stability indicator between 1996 and 2016, split into five-year intervals and starting from 1996, are: -3.5%, -5.5%, 2.45%, 9.92% (IEA 2018a: 176).

South Korea

The varying prices for electricity between 1996 and 2016, again split into five-year intervals and starting from 1996, are: +16.6%, -6.3%, +3%, +1.9% (IEA 2018a: 183).

Taiwan

Between 1997 and 2016, measured in five-year intervalls, electricity prices have fluctuated by: +5.71%, +17.3%, +44.1%, -16.8% (BEMEA 2018b; IMF 2019).

Indicator 26

Japan

Taking all taxes into account, the cost for one hundred litres of regular unleaded petrol was 12,060 Yen in 2016 (IEA 2018a: 174). Accounting for PPP, this equals to 118.23 USD as the fuel pricing indicator (OECD 2019b).

South Korea

In South Korea, one hundred litres of petrol, including applicable taxes, were 140,264 Won or 162.61 USD PPP (IEA 2018a: 181; OECD 2019b).

Taiwan

One hundred litres of unleaded gasoline, including all taxes, cost 218.12 USD PPP in 2016 (BEMEA 2018g; 2018c; IMF 2019).

Indicator 27

Japan

For the land use indicator, the total land mass in Japan is 37.8 million ha, of which 25.08 million ha are forests. The resulting forest cover is 66.34% (FAJ 2017: 25).

South Korea

With a total land mass of 10,036,372 ha, the forest cover of 6,326,285 ha equals to 60.03% of the total for indicator twenty-seven (Korea Forest Service 2018: 20).

Taiwan

The total land size of Taiwan is 3,591,500 ha, of which forest size was 2,1002,400 ha in 2016 (FBCOA 2016a; 2016b). This shows a forest coverage of 58.53%.

Indicator 28

Japan

According to the WHO/UNICEF Joint Monitoring Programme for Water supply, Sanitation and Hygiene (2017), the overall access to improved water for indicator twenty-eight in Japan is 98.94%.

South Korea

In 2016, the access to improved water in South Korea was at 99.59% (WHO/UNICEF Joint Monitoring Programme for Water Supply Sanitation and Hygiene 2017).

Taiwan

The Taiwan Water Corporation serves 97.2% of designated and 92.5% of actual population (TWC 2017: 16). The difference is believed to be based on Taiwan's remote islands not being served (Taipei Times 2013). A Stantec survey (2017) puts the water access at ninety-four per cent. As no other data could be found, the latter value is used for this indicator.

Indicators 29–30

Japan

Both climate change indicators require the calculation of total carbon dioxide emissions in 2016. By using the carbon emissions per fuel type data and total expenditure of each fuel type, the total value of all emissions is calculated at 1,321,201,600.22 tons of CO_2 (BEIS and DEFRA 2018; METI 2016a). Dividing it by the total population yields 10.4 tons of CO_2 per capita. Dividing total emissions by GDP yields a result of 0.25 kg CO_2 per USD.

South Korea

The total carbon emissions, calculated by using each fossil fuel's carbon emission factor and total usage, was 834,997,105.77 tons of CO_2 (BEIS and DEFRA 2018; KEEI 2017: 50–51). The per capita value therefore is 16.28 tons of CO_2. Considering the 2016 GDP, emissions results in 0.43 kgCO_2 per USD for indicator thirty.

Taiwan

Multiplying each fossil fuel with its corresponding carbon emission factor adds up to a total of 285,780,693.34 tons of CO_2 (BEIS and DEFRA 2018; BEMEA 2018h: 30; 2018i: 30; IEA 2018d; Juhrich 2016: 46). Divided by the total population, the per capita carbon emission in 2016 amounted to 12.14 tons of CO_2. Measured against the 2016 GDP, the carbon emissions amounted to 0.25 kgCO_2/USD.

Indicator 31

Japan

The renewable capacity is based upon the overlying total generation of 335,636 MW on average, including autoproducer capacity. As renewables accounted for 92,132.082 MW, their capacity equals to 27.45% of the total (METI 2016b; UNSD 2019a).

South Korea

Renewable energy generation capacity amounted to 13,965.29 MW and includes hydropower, solar, wind, and tide generation, biomass, landfill gas, and waste burn generation, as well as product gas and fuel cells (KEPCO 2017: 30–43). When compared to the total generation capacity of 105,865.55 MW, this represents 13.19% (KEPCO 2018: 28).

Taiwan

Total renewable capacity in Taiwan, including hydropwer, solar PV, biomass, and waste amounted to 726.6 MW. Measured against the total capacity of 7,345.1 MW, it represents 14.7% (BEMEA 2018d).

Indicator 32

Japan

Using data from all non-carbon energy sources (geothermal, nuclear, photovoltaic, water, wind) for indicator thirty-two, the total overall generation is valued at 33,673,002.62 toe (Fu et al. 2015; IEA 2018b; 2018d; Patel 2017). Divided by TPES, this represents 7.1%.

South Korea

Based upon non-carbon emitting sources, hydropower, nuclear power, and renewables, the total energy produced measured 37,648,000 toe (KEEI 2017: 45). Compared to the TPES, this equals 12.77%.

Taiwan

Overall, all non-carbon energy producers generated 9,140,400 toe, which represents 8.23% of TPES (BEMEA 2018i: 30).

Indicator 33

Japan

Measured against the FEC, renewables overall produced 43,266,145.25 toe in 2016, which equals to 12.12% (IEA 2018d).

South Korea

When combining all renewable energy production, including waste energy, the total electricity generated equals 4,365,219.25 toe and heat energy 4,524,839.97 toe, using the partial substitution method (IEA 2018c). These values combined make up 3.93% of FEC.

Taiwan

Total renewable energy production in 2016 equalled 2,983,860 toe (BEMEA 2018i: 30). When compared with FEC, the renewable generation amounts to 4.19%.

Indicator 34

Japan

Data from 2012 shows total sulphur oxide emissions of 406,735 tons, which calculated against the total population is 3.2 kg of SO_x emissions per capita per year as our pollution indicator (MENV 2017).

South Korea

Total SO_x emissions in South Korea in 2015 were 351,900 tons (KOSIS 2018a). Measured against the total population, the per capita value was 6.86 kg of SO_x.

Taiwan

Sulphur oxide emissions measured 103,000 tons according to 2010 data (Department of Air Quality and Protection and Noise Control 2019). Divided among the population, this represents 4.37 kgSO_x per capita.

Indicator 35

Japan – South Korea – Taiwan: As all indicators could be filled, the quality of information indicator shows one hundred per cent.

Results

All results can be seen in Table 4 to easily compare data points. Significant differences can be seen in both energy supply and energy consumption. The per capita supply was highest in South Korea, being 53.8% higher than Japan's and 21.9% higher than Taiwan's. On the consumption side, South Korea's per capita consumption is surpassing Japan's by 56.6% and Taiwan's by 45.6%. On overall electricity consumption, Taiwan leads among the three countries observed by 34.3% compared to Japan and 3.4% compared to South Korea. Japan shows the highest level of diversification, where renewables provide more than ten per cent of TPES, while South Korea sits at 5.08% and Taiwan at 2.21%.

Looking at the varying energy intensity values, Japan shows the lowest primary energy intensity, but Taiwan features the lowest final energy intensity. This is also visible by comparing the various economic sectors' energy intensity, where Taiwan shows the lowest value in all sectors except transportation. South Korea generally has the highest energy intensity except in the agricultural sector, whereas Japan eclipses both other countries.

Per capita carbon emissions were fifty-six per cent higher in South Korea compared to Japan. Taiwan was also 16.7% higher than Japan. Measured against GDP, South Korea showed an increase of seventy-two per cent per USD, while Taiwan and Japan featured the same value. Renewable capacity in Japan was twice the value of South Korea and Taiwan. The difference is largely based upon Japan's large PV installation of 42,000 MW, which dwarfs South Korea's 3,716 MW and Taiwan's 1,245 MW.

South Korea shows the highest value of non-carbon energy generation due to its nuclear power generation, while Japan had to reduce its nuclear output since the 2011 earthquake. Overall renewable energy generation was highest in Japan. In numbers, it was 245% higher than South Korea's and 189% larger than Taiwan's.

Table 4: Final Results

Dimension	#	Indicator	Results		
			Japan	South Korea	Taiwan
Availability	1	Supply	3,736.09 kgoe/cap	5,747.15 kgoe/cap	4,713.83 kgoe/cap
	2	Final Energy Consumption per Capita	2,810.28 kgoe/cap	4,401.85 kgoe/cap	3,023.11 kgoe/cap

	3	Electricity per Capita	643.38 kgoe/cap	833.73 kgoe/cap	864.3 kgoe/cap
	4	Resilience	7.75 years	5.9 years	1.19 years
	5	Reserve Production (Oil)	11.25 years	1.6 years	44 years
	6	Reserve Production (Natural Gas)	7.38 years	71.58 years	16.36 years
	7	Reserve Production (Coal)	–	191.76 years	–
	8	Dependency (Including Nuclear Power)	87.8% (88.55%)	86.76% (98.36%)	89.48% (96.92%)
	9	Diversification	10.27%	5.08%	2.21%
	10	Exports	9,372,170,037 USD	26,679,036,921 USD	9,192,000,000 USD
Efficiency and Technology	11	Primary Energy Intensity	0.0904 kgoe/USD	0.1548 kgoe/USD	0.0977 kgoe/USD
	12	Final Energy Intensity	0.068 kgoe/USD	0.11859 kgoe/USD	0.062 kgoe/USD
	13	Transportation Energy Intensity	0.28 kgoe/USD	0.62 kgoe/USD	0.37 kgoe/USD
	14	Commercial Energy Intensity	0.018 kgoe/USD	0.024 kgoe/USD	0.0078 kgoe/USD
	15	Agriculture Energy Intensity	0.14 kgoe/USD	0.074 kgoe/USD	0.0293 kgoe/USD
	16	Industrial Energy Intensity	0.098 kgoe/USD	0.222 kgoe/USD	0.059 kgoe/USD

	17	Household Consumption	858.56 kgoe/household	1071.49 kgoe/household	686.87 kgoe/household
	18	Household Energy	368.48 kgoe/cap	414.59 kgoe/cap	249.77 kgoe/cap
	19	Household Electricity	2,166 kWh/cap	1,292.91 kWh/cap	2,010 kWh/cap
	20	Grid Efficiency 1 (Loss in Transmission)	5%	3.593%	3.4%
	21	Grid Efficiency 2 (Loss in Transformation)	24.78%	23.4%	35.86%
Affordability	22	Access	100%	100%	99%
	23	Solid Fuel Usage	<5%	<5%	<5%
	24	Electricity Pricing	1.36%	0.55%	0.59%
	25	Stability	1996–2001: –3.5% 2001–2006: –5.5% 2006–2011: +2.45% 2011–2016: +9.92%	1996–2001: +16.6% 2001–2006: –6.3% 2006–2011: +3% 2011–2016: +1.9%	1997–2001: +5.71 2001–2006: +17.3% 2006–2011: +44.17% 2011–2016: –16.8%
	26	Fuel Pricing	118.23 USD	162.61 USD	218.12 USD
Environmental sustainability	27	Land Use	66.34%	63.03%	58.53%

	28	Water	98.94%	98.6%	94%
	29	Climate Change 1 (CO_2 per Capita)	10.4 tCO_2/cap	16.28 tCO_2/cap	12.14 tCO_2/cap
	30	Climate Change 2 (CO_2 per GDP)	0.25 $kgCO_2$/USD	0.43 $kgoeCO_2$/USD	0.25 $kgCO_2$/USD
	31	Renewable Capacity	27.45%	13.19%	14.7%
	32	Non-Carbon Energy	7.1%	12.77%	8.23%
	33	Renewables	12.12%	3.93%	4.19%
	34	Pollution	3.2 $kgSO_x$/cap	6.86 $kgSO_x$/cap	4.37 $kgSO_x$/cap
Information	35	Quality of Information	100%	100%	100%

Conclusion

Based on frameworks from Sovacool et al. (2013) and Martchamadol and Kumar (2013), the central aim of this paper was to establish differences in energy security. Through a combined framework, consisting of five dimensions and thirty-five indicators, each indicator was established with data from 2016 or the next closest date available. The three chosen countries, namely Japan, South Korea, and Taiwan, were then individually analysed along these thirty-five indicators.

During the analysis, some indicators were found to yield only inconclusive results. Indicators like electricity access and improved water access do not provide any new insight when comparing similarly developed economies. Reserve production values show unrealistic values as the ease of access to these natural resources is not considered. Future research is needed to improve or replace such indicators and provide an even more robust framework.

Looking at the results, Japan shows the lowest supply and lowest consumption among the three analysed countries. While Japan also shows the lowest primary energy intensity, indicating that it is the most efficient country measured based on energy supply, Taiwan has the lowest final energy intensity. This indicates that Taiwan is the most efficient country overall when accounting for transformation losses. This

is also visible looking at the energy intensity of the various economic sectors, according to which Taiwan is far ahead of Japan and South Korea.

Natural reserves for all fossil fuels in all three countries have been shown to be miniscule or difficult to access. But while Japan's and South Korea's resilience ratings show that their reserves could last several years, Taiwan only has stock for about one year. All three countries are nevertheless highly reliant on imports of fossil fuels of around 87–90% of the total energy supply. This number increases even further for Taiwan and South Korea when considering fissile nuclear material as imported.

Comparing these three countries, large variations in energy intensity are visible. Particularly large differences could be observed in the agricultural sector. Taiwan's energy intensity was calculated to be sixty per cent lower than South Korea's and eighty per cent lower than Japan's. While this paper did not explore the underlying reasons for this difference, these results could pave the way for research into contract farming as it is mainly practiced in Taiwan compared to more family or coop-style farming as adopted in Japan and South Korea. Differences in which type of crop is farmed and different climates could also prove to be some of the many factors from which these results stem.

The industrial energy intensity showed South Korea doubling the value of Japan and tripling Taiwan's. What is driving this difference is another opening for further analysis. Expert interviews on the industrial sector could provide a gateway for such research. South Korea sports large industries in the shipbuilding, steelmaking, and car manufacturing. A deeper look into these sectors could show higher energy use and explain the corresponding energy intensity.

Overall, adapting strategies from Taiwan to reduce intensity, Japan and South Korea would be able to conserve energy and require less energy imports in total without changing their supply makeup. Additionally, as the industrial sector is shown to be the least energy efficient, while the commercial sector is the most efficient, a further shift to an even larger commercial sector within the economy would improve energy security as well.

The other way to improve energy security is provided by investing in and expanding heavily on renewable energy sources. As renewable energy production currently is supplying energy first and foremost domestically, its replacement of oil and gas ultimately decreases the dependency on imports. In addition, they also reduce carbon emissions and pollution levels. Japan shows the highest amount of renewable capacity at twenty-seven per cent and produces the highest amount of renewable energy among the measured countries at twelve per cent. Japan also sports the lowest per capita CO_2 and SO_x emissions. All three countries find it difficult to expand their hydropower generation based on geographic conditions and, in recent years, opposition against dam building has made it politically difficult as well. Expansion of solar and wind energy therefore seem the natural path for these countries. But even if such expansions are undertaken in large scale, the question of load balance remains, and solutions need

to be found. Nuclear energy shares many qualities with renewable energies but remains politically tough to propagate. The absence of carbon emissions and the possibility to hoard fissile materials to provide energy for multiple years makes it an attractive choice for resource poor nations. Nevertheless, no natural uranium deposits and the lack of enrichment facilities show the difficulties for these countries to consider nuclear energy as a truly viable alternative.

As energy is necessary for all economic activities and everyday life to continue, any disruption in its supply is a tremendous risk. Especially in Japan, South Korea, and Taiwan, imports are reliant on free passage through open seas. Tensions in the Middle East or the South China Sea could quickly escalate to large scale supply constraints for any of these three countries. Change in energy supply cannot occur in a short time frame, but it can be planned. All three countries have put plans into motion to increase the share of renewable energy, but it is not obvious if these plans are enough for the coming years. Japan has reduced its subsidies for PV, while Taiwan is only slowly testing offshore wind farms. The increasing importance of climate change topics in modern politics and the accompanying wish to stop the reliance on fossil fuels could prove to be a boon for domestic energy security as well. The possibility to kill two birds with one stone is one that should not be wasted.

ABBREVIATIONS

AESPI	Aggregated Energy Security Performance Indicator
APERC	Asia Pacific Energy Research Centre
APS	American Physical Society
BEMEA	Bureau of Energy/Ministry of Economic Affairs
BEIS	British Department for Business, Energy and Industrial Strategy
CMOP	Coalbed Methane Outreach Program
DEFRA	Department for Environment, Food and Rural Affairs
DGBAS	Directorate General of Budget Accounting and Statistics Executive Yuan
DHRA	Department of Household Registration Affairs
EEA	European Environment Agency
EPSIS	Electric Power Statistics Information System
FAJ	Forestry Agency Japan
FAO	Food and Agriculture Organization
FBCOA	Forestry Bureau/Council of Agriculture
FEC	Final Energy Consumption
FEPC	Federation of Electric Power Companies of Japan
GDP	Gross Domestic Product
GWh	Gigawatt hours
IAEA	International Atomic Energy Agency
IAEA/NEA	International Atomic Energy Agency / Nuclear Energy Agency

IEA	International Energy Agency
IEA PVPS	International Energy Agency Photovoltaic Power Systems Programme
IGU	International Gas Union
IMF	International Monetary Fund
ITA	International Trade Administration
ITRI	Industrial Technology Research Institute
JOGMEC	Japan Oil, Gas and Metals National Corporation
KCC	Korean Coal Corporation
KEEI	Korea Energy Economics Institute
KEPCO	Korea Electric Power Corporation
kgoe/toe	kilograms of oil equivalent / tons of oil equivalent
KNOC	Korea National Oil Corporation
KOSIS	Korean Statistical Information Service
kWh	kilowatt hour
LNG	Liquefied Natural Gas
LP	Liquefied petroleum
MBTU	British Thermal Units in millions
MENV	Ministry of the Environment
METI	Ministry of Economy Trade and Industry
MOTIE	Ministry of Trade, Industry and Energy
NEID	Net Energy Import Dependency
NRA	Nuclear Regulation Authority
OECD	Organisation for Economic Cooperation and Development
PPP	Purchase Power Parity
SBMIC	Statistics Bureau – Ministry of Internal Affairs and Communications
TJ	Terajoule
TPES	Total Primary Energy Supply
TWC	Taiwan Water Corporation
TWh	Terawatt hours
UN	United Nations
UNICEF	United Nations Children's Fund
UNSD	United Nations Statistics Division
USEIA	U.S. Energy Information Administration
USEPA	U.S. Environmental Protection Agency
WB	World Bank
WHO	World Health Organisation
WNA	World Nuclear Association

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