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Abbreviations

AESPI	Aggregated Energy Security Performance Indicator
ASEAN	Association of Southeast Asian Nations
BEMEA	Bureau of Energy/Ministry of Economic Affairs (Taiwan)
EEA	European Environment Agency
GDP	Gross Domestic Product
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IMF	International Monetary Fund
ITA	International Trade Association
ITRI	Industrial Technology Research Institute
KCC	Korean Coal Corporation
KEEI	Korea Energy Economics Institute
KNOC	Korea National Oil Corporation
KOSIS	Korean Statistical Information Service
LNG	Liquefied Natural Gas
METI	Ministry of Economy, Trade and Industry (Japan)
NEA	Nuclear Energy Agency
NRA	Nuclear Regulation Authority
NTD	New Taiwan Dollar
OECD	Organisation for Economic Cooperation and Development
TPES	Total primary energy supply
FEC	Final energy supply
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNSD	United Nations Statistics Division
UNICEF	United Nations Children’s Fund
USD	United States Dollar
USEIA	United States Energy Information Administration
WHO	World Health Organization
WNA	World Nuclear Association

Physical Units

BTU	British Thermal Units (Around 1.055 Joule)
kgCO_2	kilograms of carbon dioxide
tCO_2	tons of carbon dioxide
ha	hectares
m/s	meters per second
kgoe	kilograms of oil equivalent
toe	tons of oil equivalent (1.000 kgoe)
kl	kiloliter (1.000 liters)
kloe	kiloliters of oil equivalent (around 0,9 toe)
boe	barrels of oil equivalent (around 158 liters of oil equivalent)
MJ	Megajoule (1.000.000 joule)
GJ	Gigajoule (1.000 MJ)
TJ	Terajoule (1.000 GJ)
MW	Megawatt (1.000.000 Watts)
GW	Gigawatt (1.000 MW)
kWh	kilowatt hour (the energy equivalent of 1.000 watts per hour)
MWh	Megawatt hour (1.000 kWh)
GWh	Gigawatt hour (1.000 MWh)
TWh	Terawatt hour (1.000 GWh)

The fundamental object of contention in the life-struggle,
in the evolution of the organic world, is available energy.
– Ludwig Boltzmann

1. Introduction

The topic of energy is ubiquitous in news and media. Renewable energy is at the center of current climate change discussions, offered as a carbon neutral solution to counteract global warming. In Germany, the last coal mine just recently closed and nuclear power plants are to be phased out until 2022 (World Nuclear Association [WNA], 2019a). Renewables in Germany are internationally touted as a success, after they accounted for the largest share in electricity production, ahead of coal in 2018 (Eckert, 2019). In the United States, talks have entered the airwaves of a “Green New Deal”, a proposal of which one point includes meeting national energy demands with only clean, renewable, and zero-emission energy, even if it is highly unlikely to pass soon (Rizzo, 2019). China is the global leader in renewable capacity, representing half of the global demand for photovoltaic electricity expansion (International Energy Agency [IEA], 2017b, p. 3). Nonetheless, while the focus rests on climate change, the topic of energy and security is rarely mentioned in these contexts.

Since renewable energy does not rely on imported carbon based energy, it has the potential to aid countries to become independent from foreign fossil fuels and mitigate risks from conflicts or other disruptions blocking access to vital energy supplies (Ölz, Sims, & Kirchner, 2007, p. 5). Such a subject lies at the core of the talks on Nord Stream 2, an expansion to an existing pipeline between Russia and Germany through the Baltic Sea, which has caused international disputes with the United States issuing sanction warnings against Germany (Dettmer, 2019). Poland and Ukraine have been strong critics of the pipeline, fearing Russia is using Nord Stream 2 as a bypass to strong-arm Eastern European countries without cutting gas deliveries to Germany (Gurzu, 2019).

In Japan, during the first oil crisis in 1973, the country expected cuts to its oil supply by about 30%. Japan suffered an economic downturn and entered recession in 1974. It was made obvious to policymakers that fuel supply was a matter of national security (Mihut & Daniel, 2013, p. 1046). It also fueled the call to refocus the Japanese economy away from heavy industries and on technology-intensive ones (Cheng, 2009, p. 57). South Korea[1] was no less affected by the first and second oil shocks of 1973 and 1979 (Azad, 2015, pp. 63–64; Halloran, 1974). Again, the oil shocks proved to demonstrate how energy supply and national security are intertwined. Today, Japan and South Korea remain highly dependent on imports of fossil fuels. While coal and natural gas imports are being diversified, sourcing of crude oil has remained greatly reliant on the Middle East (Korea Energy Economics Institute [KEEI], 2017, p. 6; Ministry of Economy, Trade and Industry [METI], 2018a, p. 3). In 2011, the Tohoku earthquake in Japan caused massive disruptions to the energy supply, after the shutdown of all nuclear power plants followed the accident at the Fukushima Daiichi plant. Without the nuclear power plants, only some of which have been restarted by today, Japan was forced to increase its share of fossil fuels for its electricity generation, which meant further imports since domestic supplies are not able to compensate (McCurry, 2015; U.S. Energy Information Administration [USEIA], 2017, p. 1). Both countries have shifted their electricity generation away from oil and towards liquified natural gas and coal (KEEI, 2017, p. 6; METI, 2018a, p. 8).

In Taiwan[2], a massive power outage in the northern half of the island caused the country's energy supply situation to come into the spotlight in 2017. While the five-hour blackout, which caused an estimated three million USD in damages, was partly blamed on human error, structural problems within the state-run Taiwan Power Corporation were mentioned. Operating electricity reserves dwindled from 6% to 1% one week before the blackout (Horwitz, 2017; J. M. Yu, 2017). With imports of energy making up an overwhelming majority of Taiwan's supply, solar and wind power have been pushed strongly and are set for drastic increases if the governmental roadmaps can be fulfilled (Industrial Technology Research Institute [ITRI], 2019; International Energy Agency Photovoltaic Power Systems Programme [IEA PVPS], 2018, p. 3)

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[1] Within this thesis, the Republic of Korea will be abbreviated as "South Korea" or "Korea".

[2] "Taiwan" will be used as a pars pro toto for the Republic of China throughout this thesis.

Without a stable energy supply, no state can prosper. All modern technology and transportation rely on either fossil fuels or electricity. As seen in the cases of Japan and South Korea, disruptions to these supplies are so impactful, they are considered risks to national security. In short, energy security issues are paramount to the continuation of economic activity and everyday life.

The Working Group on Asian Energy and Security at the Massachusetts Institute of Technology outlined three goals of energy security (Lind, 1997). These are summarized by Von Hippel et al. (2011, p. 6720) as follows: Firstly, this entails reducing foreign threats, followed by trying to prevent any supply crises and finally, minimizing the effects of such crises, once they have occurred. But even if these goals are shared by energy importing nations, there are still vast differences in energy policy, depending on factors such as geographic location and the occurrence of natural resources. Thus, energy security thinking depends on attributes such as quantity of the indigenous resource supply, the strength of market forces in contrast to governmental intervention in price setting and long term versus short term planning (Von Hippel, Hayes, Williams, Savage, & Suzuki, 2010, p. 75).

The topic of this thesis will focus on energy security. Japan, South Korea, and Taiwan have been chosen by the author, as all three countries are highly reliant on imports of fossil fuels, having little to no natural resources. All are high-tech economies and geographically located in the same region. While Japan and Taiwan are island nations, South Korea's only land border is with North Korea, through which trade is severely limited. In this thesis, the term energy security is elaborated upon at first, with varying definitions being considered. Then, a framework with multiple indicators is established in order to empirically measure energy security. Terms that span throughout the course of this thesis are defined and Japan, South Korea, and Taiwan are individually assessed using these metrics. The results will be presented and then compared with each other. These metrics range from energy supply and consumption, to economically efficient use of energy, and the share of renewable energy within the electrical grid. The framework is based upon the work of Martchamadol and Kumar (2013), researchers at the School of Environment, Resources and Development in Thailand, which have designed an aggregated energy security performance indicator. Furthermore, the work of Benjamin K. Sovacool

(2013), current director of the Danish Center for Energy Technology and professor of social sciences at Aarhus University, who analyzed energy security performance in the Asia Pacific, is used in conjunction with Martchamadol and Kumar's work.

This thesis tries to answer the question in what way the energy security situation in Japan, South Korea, and Taiwan currently differs. All data used in reference to the framework was taken from 2016. Whenever data from that year was not available, the next closest year with available data was used for reference. Translations within this thesis have been performed by the author unless otherwise stated. The author would also like to specify that while being aware of the first law of thermodynamics, words like *consume, expend, use, etc.* will be used in conjunction with the term "energy" throughout the thesis for readability purposes.

2. State of the Art

2.1. What is Energy Security?

To conceptualize the term "energy security", its many varying definitions should be considered. In a summary for the Pacific Asia Regional Energy Security Project, the effort to construct a framework suitable for energy security analysis leads to the following concept,

> There are three main differences that help to distinguish the way that policy-makers in different countries think about energy security: 1) the degree to which a country is rich or poor in energy resources, 2) the degree to which market forces are allowed to operate as compared to the use of government intervention to set prices, and 3) the degree to which long-term versus short-term planning is employed. In addition to the usual focus on security of energy supply, a new, comprehensive energy security concept must address the disparate challenges of environmental protection, the risks associated with advanced technologies, the management of energy demand, social and cultural risks and concerns, and international relations/military risks (Nautilus Institute for Security and Sustainable Development, 1998, pp. 3–4)

In this report, many of the common indicators later used in energy security frameworks are already visible. While supply-side, economic, and technical considerations are common, the inclusion of environmental, social, and cultural dimensions extends to many modern frameworks, as provided later in this chapter.

In a joint report by the Organisation for Economic Cooperation and Development (OECD) and International Energy Agency (IEA) (2014) defines the term energy security as “the uninterrupted availability of energy sources at an affordable price” (ibid., p. 13). This short sentence encompasses three major aspects that are considered vital. Affordability, availability, and accessibility. Energy is deemed affordable when regular social and economic activities are not severely disrupted (Deese, 1979, p. 140). Availability concerns itself with the continuous access to resources and energy to meet current domestic and growing future demand (Khatib, 2009, p. 112). Accessibility is established when energy is available and can be accessed, either through extraction in the case of fossil fuels or through technology in the case of renewable energy sources. As an example, energy can be available in form of oil and gas reserves, but access can be hindered by political instabilities, technological or geographical constraints that make accessing these reserves difficult (Asia Pacific Energy Research Centre [APERC], 2007, p. 18). All three aspects need to be fulfilled to ensure the energy security of any given state.

Energy security is often split between short-term and long-term energy security, as the IEA, in its report, mentions (IEA, 2011, p. 9). The IEA model of short-term energy security (MOSES) centers on domestic volatility, production, transformation and distribution of energy, while external factors are mostly relegated to the import of energy (ibid., p. 10). Short-term indicators used in MOSES range from crude oil and other fossil fuels, to biomass, hydropower and nuclear power. Risk and resilience of these primary energy sources are to be assessed, primarily in terms of production, supply and import dependence. In addition, the International Energy Program requires IEA member states to hold 90 days’ worth of oil in supply for emergency supply disruptions. These emergency stocks may be held through stocks specifically for emergency purposes as well as stocks held for commercial use, including refineries, ports and tankers. Stocks may also be stored outside the countries’ borders if bilateral agreements between the two states are signed. The only countries that are exempt from these statutes are net oil exporting IEA countries, namely Canada, Denmark, and Norway (OECD/IEA, 2014, pp. 29–31).

Long term energy security focuses more strongly on the availability of supply of primary energy sources or energy carriers, which often concentrate on exhaustible fuels such as oil, natural gas and coal (Jansen & Seebregts, 2010, p. 1654). This supply-based view mainly corresponds with the goals of “1. reducing vulnerability to foreign threats or pressure, 2. preventing a supply crisis from occurring and 3. minimizing the economic and military impact of a supply crisis once it has occurred” (Von Hippel et al., 2011, p. 6720). When multilateralism, international cooperation and market trust are high, concerns over dependence on other regions are low. The focus then shifts towards topics such as production capacity, production costs and physical availability (Kruyt, Van Vuuren, de Vries, & Groenenberg, 2009, p. 2167).

Expanding upon the definitions by the OECD/IEA, researchers have begun to include aspects of environmental protection in the umbrella term of energy security. A fourth aspect to the aforementioned affordability, reliability and accessibility is the term *Acceptability* as proposed in 2007 by the Asia Pacific Energy Research Centre (APERC) in regard to environmental standards and societal elements. These environmental challenges, however, lead to higher energy-system costs and are therefore in an inverse relationship with low energy costs (Kruyt et al., 2009, p. 2167).

Cherp and Jewell (2014, pp. 416–418) specifically target this idea of the “four As” and claim that previous work was often complacent in trying to find specific definitions for energy security by ascribing a certain impracticality to conceptualization. According to them, this failure to conceptualize energy security has led to various strongly differing definitions now being circulated. Other researches have followed up upon these various definitions and attempted to uniformize these approaches. Ang et al. (2015b, pp. 1081-1082) have surveyed 104 energy security studies, ranging from peer-reviewed papers, national and international reports to business associations.

From these, the most common factors have been distilled into seven major energy security themes:

1. Energy availability
2. Infrastructure
3. Energy prices
4. Societal effects
5. Environment
6. Governance
7. Energy efficiency

Energy availability concerns itself with supply side diversification to mitigate risks of import disruptions. This diversification can take various forms ranging from *source diversity*, which stands for the import from many different countries, to *spatial diversity*, describing the spread of energy facilities across the country's landmass. Furthermore, *energy mix diversity*, the balance of different energy types, and *technology diversity*, especially regarding intermittent energy sources such as many renewables, are mentioned under this umbrella term (ibid., p. 1081).

Infrastructure is a key in providing stable energy supply, encompassing transformation, distribution and transmission facilities. Reliable infrastructure with spare capacity prevents shortages and blackouts. With advanced computer systems being used as a supervisory tool, it is increasingly exposed to cyber-security risks, however (ibid. p. 1081).

Energy prices define the affordability of energy supplies. Various dimensions to be considered include price level and volatility, competition in energy markets and U.S. Dollar exchange rates (ibid., p. 1082).

Societal effects include the topic of energy poverty and access to adequate energy supply for social and economic welfare. *Environmental aspects* can be incorporated in this category but also form their own classification that concerns itself with carbon emissions, air pollution and environmental damages caused by energy generating facilities or during transportation (ibid., p 1082).

Forward looking *governance* prevents short term energy supply disruptions and effective infrastructure planning averts long term issues. Subsidies and taxes, energy diplomacy through foreign policy, and information gathering are also key components of good governance (ibid., p. 1082).

As the final factor, Ang et al. have placed *energy efficiency*. Improving technologies lead to less energy consumption and thereby improve energy security. A concept directly related to energy efficiency is energy intensity, which is defined as the "energy 'consumed' per unit of activity or output" (International Atomic Energy Agency [IAEA], United Nations Department of Economic and Social Affairs [UNDESA], IEA, Eurostat, European Environment Agency [EEA], 2005, p. 157). In more direct terms, Kemmler and Spreng define energy intensity as the "ratio of total energy consumption to economic output", measured in GDP (Kemmler & Spreng, 2007, p. 2469). Ang et al. state that "lowering the energy intensity of an economy can improve energy security by reducing the amount of energy it needs to function" (Ang et al., 2015b, p. 1082). By looking at energy intensities in conjunction with energy efficiency in specific economic sectors instead of the whole economy, errors in attributing energy efficiency can be avoided (Kemmler & Spreng, 2007, p. 2469).

2.2. Energy Security Analysis – Various Approaches

Considering these differing approaches to define energy security, multiple approaches to forming a framework of measurement have been made with one of the most prominent being the Global Energy Security Matrix by the OECD and IEA (2009, p. 49) (Appendix 1). Based upon data from seventeen OECD countries, a matrix focusing on key areas for improvement in the energy security sector was compiled. Featuring seven dimensions, it provides a general template for improving energy security in any given country and offers suggestions on which areas to improve within these dimensions. Reading the various dimensions and each accompanying area for improvement, it becomes clear that this framework offers no direct way to assess the current energy security situation of a given country. Therefore, such a framework, while useful for shaping the concept of what encompasses the term "energy security", is not sufficient as a basis for this paper.

Another approach is offered via the International Index of Energy Security Risk, by the Global Energy Institute (2016) published by the U.S. Chamber of Commerce (Appendix 2). It provides a list of 25 nations, which are ranked according to their energy security risk level. The framework used to decide on these rankings is based upon eight categories: *Global Fuels, Fuel Imports, Energy Expenditures, Price and Market Volatility, Energy Use Intensity, Electric Power Sector, Transportation Sector* and *Environmental*. Among these categories a total of 29 metrics are considered. This approach offers a more suitable framework to properly assess the energy security situation in any given country and resembles the frameworks by authors like Von Hippel (2011), Vivoda (2010), and other researchers who have analysed energy security (Brown, Wang, Sovacool, Louis, & Agostino, 2014; Löschel, Moslener, & Rübbelke, 2010; Mükusch, 2011; Narula & Reddy, 2016). In addition, the weighting of each category in percentage points and the data required to measure the metrics being clear and concise, make this a suitable framework to analyze energy security.

For the purpose of this paper, however, some features are lacking. It relies on global trends and global data in addition to being strongly focused on petroleum. Additionally, renewable energy is discussed just tangentially and topics such as domestic (reserve) production are included only indirectly. Economic sectors and their respective energy consumption and energy intensities are not discussed with the exception of the transportation sector. As the focus with the International Index of Energy Security Risk lies on a more global comparison, the author has decided against it. Another framework which is more country-specific is required.

In adaptation to the works of Von Hippel et al. (2011), who created a conceptual framework, spanning six dimensions of energy security risks and 29 issues across those, Vivoda (2010, p. 5261) has created an Energy Security Assessment Instrument expanding the matrix to eleven dimensions, each with associated attributes. These include the *energy supply* itself, *demand management*, *efficiency*, *economic* as well as *environmental* dimensions. Furthermore, he includes *human* and *military security* aspects, the *domestic sociocultural – political* as well as the *international* dimension. The final two dimensions compromise *technological* and *policy* aspects. All dimensions featured within the framework are further defined by 44 quantitative and qualitative attributes and indicators in total. As some of these energy security dimensions rely heavily on qualitative measurements, a direct comparison between two countries becomes difficult. This paper strives to provide a simple way to assess differences in energy security at a glance, which Vivoda's framework does not offer and will therefore be disregarded.

Sovacool (2011) in turn builds his framework upon the work by Vivoda (2010), but strives to offer "more comprehensive approach" (Sovacool, 2011, p. 7472). The dimensions identified are sourced through interviews with international organizations and foundations working in the energy sector. Special emphasis was put on the inclusion of Asian experts on the topic. The resulting framework encompasses 20 dimensions of which each features at least 6 indicators or metrics, culminating in 200 metrics overall (ibid., pp. 7476–7477). Furthermore, another framework, which Sovacool co-authored, also categorized 20 dimensions, 320 simple and 52 complex indicators, many of which are distinct from the previously mentioned work (Sovacool & Mukherjee, 2011). While such a framework is certainly comprehensive, the expansive nature does not lend itself to be considered by the author for this thesis. Rather, a framework which offers a wide variety of metrics, while not being overburdening, is more applicable to the scope at hand.

For this thesis the author has chosen to primarily focus on Martchamadol and Kumar's (2013) framework, titled the "Aggregated Energy Security Performance Indicator (AESPI)" and include elements from Sovacool's (2013) "Assessing energy security performance in the Asia Pacific, 1990-2010". In their paper, Martchamadol and Kumar show that energy security indicators are either of two types. First are disaggregated indicators like the *Shannon-Wiener Index* (SWI), *Net Energy Import Dependency* (NEID), *Geopolitical Market Concentration Risk* (GMC), *Market Liquidity* (ML) and others. In contrast to these, aggregated indicators are based on the combination of multiple indicators. Examples of these include the Oil Vulnerability Index (OVI), made up of seven indicators concerning oil market and supply risk or the Energy Development Index (EDI), built from four indicators, both representing a more complete review of performance (Martchamadol & Kumar, 2013, p. 654).

According to Martchamadol and Kumar (2013, pp. 654–655), a review of past studies on energy security reveals that four factors are recurring throughout the field. These include institutional, social, environmental and economic factors. Institutional factors contain eleven indicators, social factors contain seven, environmental contain eight and economic factors contain 68 indicators. Previous works like the Energy Sustainability Index (ESI) by Doukas et al. (2012) and the Energy Indicators for Sustainable Development (EISD) (IAEA; UNDESA; IEA; Eurostat; EEA, 2005) address specific criteria and are used to measure different objectives and dimensions. These analyses, however, lack a holistic study of the overall energy security of a county, province or country since they often deal with paired relations such as energy-economy, energy-social, or energy-environment. Large numbers of indicators make these sets unwieldy and difficult to use effectively.

With the creation of AESPI, it was the authors' intention to be comparable in application to the Human Development Index or the Gross Domestic Product as an easy to grasp status overview of any given country's energy security situation, past, present and future. AESPI consists of 25 indicators based on the Energy Indicators for Sustainable Development (EISD) and chosen by their most common usage rate in other energy security analysis works and the availability of historical data (Table 3) (Martchamadol & Kumar, 2013, pp. 662–663).

AESPI features solely quantitative metrics. It presents the necessary input data and demonstrates equations to calculate these values. The various economic sectors are calculated independently, offering a way to compare efficiency within these sectors and to other countries. Household energy and electricity are measured to compare the energy demands of any given population, with the relation of energy pricing and income being taken into account. Renewable energies and carbon emissions are included in multiple indicators, with consideration to the difference of renewables and non-carbon energy. AESPI is also a framework which takes both transmission and transformation losses into account. All these indicators offer clear metrics, which make a comparison between multiple countries feasible and simple.

Valdés (2018) calls the methodology behind AESPI detailed and transparent, based upon a discussion of various energy security definitions. Tongsopit et al. (2016), who discuss energy security within the Association of Southeast Asian Nations (ASEAN), review AESPI as being comprehensive, and Paraventis et al. (2018) praise the possibility to assess current and future energy security trends. It was used by Smiech and Papiez (2014) to analyze the energy security of EU member states between 2000 and 2010. Furthermore, the framework is discussed in multiple papers on the topic of energy security (Ang, Choong, & Ng, 2015a, p. 315; Narula & Reddy, 2015, p. 150; Ren & Sovacool, 2014, p. 839). For these reasons, the author has chosen Martchamadol and Kumar's framework as the main framework for this thesis.

Sovacool's (2013) framework is similar to AESPI in its various metrics and also features only quantitative data. This makes it possible to combine this framework with AESPI and fill in gaps that may exist in either framework, as Sovacool includes pollution data, water and land use as well as fuel prices and price stability among others. It was also created with a focus of the Asia-Pacific in mind, which, given the countries analyzed in this thesis, is an additional benefit (Table 2).

By merging these two frameworks, the author strives to create a more robust one which still offers a simple way to compare the energy security performance of multiple countries. The following chapter will establish the framework used for this thesis.

3. Constructing a Framework

3.1. Indicators and Components

AESPI is built upon three overarching categories of indicators. Economic considerations make up 80% of the total. The remaining five indicators fall under environmental and social dimensions (Table 1). “Total primary energy per capita”, “final energy consumption per capita”, and “electricity per capita” were selected by Martchamadol and Kumar to measure overall energy consumption and energy usage. Also included is an assessment of energy efficiency on the demand side. “Total primary energy intensity” and “final energy intensity” were chosen to represent energy efficiency in relation to economic productivity. “industrial energy intensity”, “agriculture energy intensity”, “commercial energy intensity”, and “transportation energy intensity” were then further selected to show this productivity in the respective sectors (Martchamadol & Kumar, 2013, p. 663.).

“Loss in transmission” and “loss in transformation” represent the energy efficiency policy on the supply side (ibid.).

“Reserve production ratio (RPR) of fossil fuel (e.g. crude oil, natural gas, coal)” show the availability of supply (ibid.).

“Residential energy per household”, “household energy per capita”, “household electricity per capita”, “household access to electricity”, and “share of income pay to electricity” were selected to reflect on the efficient use and to quantify demand of energy in the residential sector as well as the quality of life, energy affordability and accessibility (ibid.).

“Share of non-carbon energy per total primary energy consumption (TPES)”, “share of renewable energy per final energy consumption (FEC)”, “share of capacity of renewable energy per total electricity generation”, “CO_2 emission per capita” and “CO_2 emission per GDP” were included to display environmental acceptability (ibid.). “Net energy import dependency (NEID)” was chosen to indicate the status of the energy import market (ibid.).

The comparison to Sovacool’s (2013) work is not only presenting additional insight, but is particularly relevant to this thesis as it concerns itself with the Asia-Pacific region. In his paper, eighteen countries were selected, including the four largest energy consumers China, India, Japan, and South Korea. The remaining countries compromise the ten countries currently in ASEAN, as well as Australia and New Zealand due to their diverse energy imports and proximity to ASEAN. Sovacool utilized a four-stage process by which the framework was created. Beginning with literature analysis, research interviews were then conducted with energy experts. The following step included a survey with energy planners and the final stage was creating an international workshop to determine the dimensions, components and metrics to be used. Sovacool turned all metrics unidirectional, meaning that higher values correspond with better energy security scores, which were made empirical and relative. Sovacool describes the system as “empirical in that scores were based on real-world performance of countries observed within a particular metric for a given year, and relative in that we took the best and worst scores for those countries and used those to create our range of scoring points” (Sovacool, 2013, p. 229).

Sovacool establishes five dimensions, *availability*, *affordability*, *technology development and efficiency*, *environmental sustainability*, and *regulation and governance*. Each dimension is divided into four components and associated metrics and units for calculation (2013, p. 230).

The *availability* dimension includes “security of supply”, “production”, “dependency”, and “diversification” components. These components feature metrics such as the total primary energy supply, the reserve production of three primary energy fuels, the energy demand measured against domestic production, and share of renewable energy (ibid.).

The *affordability* dimension includes “stability”, “access”, “equity”, and “affordability” as components, which deal with access, expenses and prices for end consumers. Metrics include retail price of gasoline, percentage of households dependent on traditional solid fuels, and electricity price stability (ibid.).

The *technology development and efficiency* dimension includes the components “innovation and research”, “energy efficiency”, “safety and reliability”, and “resilience”. This dimension focuses on the effective use of the current energy supply and improving upon it. Metrics measure the research intensity or government expenditure on research and development, the overall energy intensity, the transmission and distribution losses, and total fossil fuel reserves in years (ibid.).

The fourth dimension, *environmental sustainability,* encompasses “land use”, “water”, “climate change”, and “pollution” as its components, focusing on ecological considerations and carbon emissions. Metrics used in this dimension are forest cover as percentage of land area, access to improved water sources, total per capita emissions of carbon dioxide, and sulfur dioxide emissions (ibid.).

The final dimension is *regulation and governance*. Its components include “governance”, “trade and connectivity”, “competition”, and “information”. The focus lies on governmental influence on the energy market and energy exports. The metrics presented here include the worldwide governance score, which is based on six categories, the annual value of energy exports in USD, the per capita energy subsidies, and the quality of information (ibid.).

While his work’s 20 components offer certain overlap between the two frameworks, there are enough differences to warrant a closer look. To prevent mixing up both frameworks in the following chapter, when talking about AESPI, the term *indicator* will be used, while regarding Sovacool’s work, the term *component* will be used.

Table 1 Indicators for AESPI Formulation (Martchamadol & Kumar, 2013, p. 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

(Table created by author)

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

Table 2 Energy Security Index (Sovacool, 2013, p. 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 three 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 Percent 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 Sulfur Dioxide Emissions	Metric Tons of SO_2 per Person
Regulation and 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

(Table created by author)

The first dimension presented by Sovacool, *availability*, is covered completely within AESPI as well. “Security of supply” is represented via indicator one, “total primary energy per capita”. For the purpose of this thesis, the author has chosen to follow the AESPI equation, as for the comparison between different countries, comparing the per capita supply is better suited than strictly the total supply. The “production” component is satisfied with indicators eight, nine and ten of AESPI. While Sovacool’s component is simpler, by being combined into a single metric, all three primary energy fuels, coal, gas and oil see different uses and require different processing. For this reason, the author has chosen the AESPI indicators. The third component “dependency”, looking at domestic production to consumption ratio, equals indicator 20, “net energy import dependency”, which looks at energy import share within the primary energy supply. In order to calculate this value, the total net imports (imports minus exports) of natural gas, solid fuels and oil, as well as oil products, are calculated as a share of the total primary energy supply (EEA, 2013). The component “diversification” is covered completely in indicator 19, which also presents the diversification via the share of renewable energy.

Within the second dimension, *affordability*, both components five, “stability”, and eight, “affordability”, involve the price of energy. AESPI has overall avoided any indicator that concerns itself with pricing, except for indicator 24, which shows the income share spent on electricity. Component six is covered by indicator 23 in AESPI, but “equity”, “affordability” and “stability” are only partially included. Component eight “affordability” in Sovacool’s work equals in its purpose indicator 24, as both are meant to represent the affordability of energy but look at different commodities. “Affordability” will be included as “fuel pricing” in the final framework as a separate indicator from electricity pricing. Component five, “stability”, is not mentioned in AESPI and will therefore be included in this paper’s constructed framework. As Sovacool’s work focused on the last 20 years as a period of comparison, the author will adhere to this timeframe where applicable.

Component seven, “equity”, present in Sovacool’s index has no similar indicator within AESPI and will be included but renamed “solid fuel usage” for clarity purposes.

The third dimension, *technology development and efficiency,* features component nine, “innovation and research”, which considers government expenditures on research and development. As stated, the goal of AESPI is to provide a simple tool to compare past, present, and estimate future energy security, as well as support policy decisions. It does not include any governmental (policy) metrics. Therefore, such metrics will not be included within this framework and component nine will be disregarded. Component ten and eleven, “energy efficiency” and “safety and reliability”, are covered by AESPI’s indicators five, six and seven, “final energy intensity”, “loss in transmission”, and “loss in transformation”. The last component in this dimension, *resilience,* has no equivalent indicator and will thus be included in this paper’s final framework.

The next dimension, *environmental sustainability,* features two components, “land use” and “water”, which are not addressed in AESPI and will hence be added. A substitute for component 15, “climate change”, is the indicator 21, “CO_2 emission per capita”, as both are using the same metric. Component 16, “pollution”, has no comparable indicator present in AESPI and will therefore be included in the final framework. It concerns itself solely with sulfur dioxide emissions, most well known for being the leading cause of acid rain.

The final dimension, *regulation and governance,* provides two components, “governance” and “competition”, which are measuring government expenditures and government performance. As stated before, the author has chosen to follow AESPI’s model and will exclude these components. The components “trade and connectivity” and “information” define the net energy exports as well as the completion of all data points in Sovacool’s matrix respectively. Both are not included as indicators in AESPI and will be included in the final matrix.

3.2. Building the Final Framework: Definitions

Since the components and indicators from both AESPI and Sovacool's matrix have been chosen, all indicators need to be defined and need appropriate metrics by which to measure them. All indicators and components, which were equal in their purpose have been combined into a single indicator, as illustrated in the previous chapter. The final framework is presented under table 3 and features 35 indicators in total.

Spanning throughout this thesis, energy is represented in kilograms of oil equivalent or tons of oil equivalent (kgoe/toe). Eurostat defines the value as "a normalized unit of energy. By convention it is equivalent to the approximate amount of energy that can be extracted from one kilogram of crude oil. It is a standardized unit, assigned a net calorific value of 41.868 kilojoules/kg (or 41.868 gigajoules/ton) and may be used to compare the energy from different sources" (Eurostat, 2013). In cases where conversion is needed, the author will follow this formula.

Commonly used in various calculations is "total primary energy supply" (TPES). Sovacool's definition states that "total primary energy supply comprises the production of coal, crude oil, natural gas, nuclear fission, hydroelectric, and other renewable resources plus imports less exports, less international marine bunkers and corrected for net changes in energy stocks" (2013, p. 230). This closely resembles the OECD description, "primary energy supply is defined as energy production plus energy imports, minus energy exports, minus international bunkers, then plus or minus stock changes" (OECD, 2018b). The major difference here is the exclusion of the word *marine* in describing the kind of bunkers. The reason is provided by the IEA, which adds international aviation bunkers to international marine bunkers in their definition (IEA, 2019a). The OECD definition includes both marine and aviation bunkers and the author will adhere to this definition within this paper.

Calculating the primary energy equivalent is done by either of two models. These models significantly differ in the treatment of electricity generated by solar, hydro, wind, and other renewables. The first model, the partial substitution method, converts the electricity generated to the amount of energy necessary to generate an equivalent amount of electricity from a thermal energy plant and accounting for lower efficiency in such thermal plants. The IEA has stopped using this method, as these calculations are not relevant for countries with higher amounts of solar, hydro, wind, and other renewable electricity generating sources. The second method is called the physical energy content method. The physical energy content of the primary energy source is used as the primary energy equivalent. This is exemplified by thermal power plants, where it follows that the primary energy produced is heat. When looking at nuclear power, however, the primary energy form is notably also heat generated by the reactors. The IEA then calculates with an average efficiency rating of 33% to determine actual electricity generation. In the case of hydropower, electricity is already the primary form of energy generated and therefore the primary energy equivalent, with an assumed efficiency of almost 100% (IEA, 2019b). In the case of Japan and South Korea, the energy balances for renewables, including hydropower, display far higher energy values, as actual electricity produced, showing that these values are based upon the partial substitution model (KEEI, 2017; METI, 2016a).

The term final energy consumption is defined by Eurostat 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” (Eurostat, 2012). The European Environment Agency (EEA) covers Final Electricity Consumption as “electricity supplied to the final consumer's door for all energy uses, it does not include own use by electricity producers or transmission and distribution losses. It is calculated as the sum of final electricity consumption from all sectors. These are disaggregated to cover industry, transport, households, services (including agriculture and other sectors)” (EEA, 2010). The United Nations Economic Commission for Europe (UNECE) further elaborates,

> FINAL ENERGY CONSUMPTION IS CALCULATED AS THE SUM OF FINAL ENERGY CONSUMPTION FROM DIFFERENT ECONOMIC SECTORS AND HOUSEHOLDS. FINAL ENERGY CONSUMPTION INCLUDES THE CONSUMPTION OF TRANSFORMED ENERGY (ELECTRIC POWER, PUBLIC HEATING, PETROLEUM PRODUCTS, COKE, ETC.) AND PRIMARY FUELS SUCH AS NATURAL GAS AND RENEWABLE ENERGY SOURCES (SOLAR ENERGY, BIOMASS, ETC.). FINAL ENERGY CONSUMPTION IN INDUSTRY INCLUDES CONSUMPTION IN ALL INDUSTRIAL SECTORS EXCEPT THE “ENERGY SECTOR”. FINAL ENERGY CONSUMPTION IN TRANSPORT INCLUDES CONSUMPTION IN ALL TYPES OF TRANSPORTATION (RAIL, ROAD, PUBLIC TRANSPORT IN CITIES, PIPELINE AND AIR TRANSPORT AND INLAND AND MARITIME NAVIGATION). FINAL ENERGY CONSUMPTION IN HOUSEHOLDS INCLUDES QUANTITIES CONSUMED BY HOUSEHOLDS, EXCLUDING THE CONSUMPTION OF MOTOR FUELS FOR PERSONAL TRANSPORT. (2014)

The definition of electricity consumption is described by the CIA World Factbook as comparing total electricity generated annually including imports and less exports in kilowatt-hours. Discrepancies between the amount produced or imported to the amount consumed are presumed to be losses in transmission or distribution (Central Intelligence Agency, 2018). The U.S. Energy Information Administration specifies that total electricity consumption includes both retail sales to consumers and direct use electricity, whereby direct use electricity is both generated and used by the consumer. The industrial sector accounts for almost all of direct use electricity (USEIA, 2018b)

Energy intensity, briefly defined earlier, is the measurement of a nation's energy efficiency in regard to its economy. It is calculated as energy units per unit of GDP. A higher energy intensity indicates that more energy needs to be expended per unit of GDP, while inversely, a lower energy intensity means a lower cost of converting energy into GDP. While the prevalence of energy efficiency of appliances, buildings, vehicles and the patterns of transportation and pervasiveness of public transportation all play important parts in increasing efficiency, factors not generally considered to be within the energy realm contribute to increasing and decreasing energy intensity. These include, geographical distances within the country, occurrence of natural disasters, extreme weather conditions, stochastic economic shocks, wars, and others. This also means that activities that are less energy efficient, such as long drives to the workplace, but disproportionally increase GDP output, are in effect decreasing energy intensity (Bhatia, 2014, pp. 16–17).

Many indicators present data on a per capita basis, which requires the total population value of a country for calculation. The United Nations Statistics Division defines the *de jure* population as all usual residents and the *de facto* population as all persons present in the country at the time of the census (UN, 2008, p. 122). For the purpose of this paper, the *de jure* population will be used unless otherwise specified in case of missing data.

Another metric present in various indicators is the Gross Domestic Product (GDP). The OECD defines it 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) (2018A)

Within this paper, the author will rely on *purchasing power parity* (PPP) values. "Purchasing power parities (PPPs) are the rates of currency conversion that equalise the purchasing power of different currencies by eliminating the differences in price levels between countries. In their simplest form, PPPs show the ratio of prices in national currencies of the same good or service in different countries" (OECD, 2019b).

Indicator 20 deals with transmission power losses, which are inherent in any electrical grid. Generally, power losses are categorized in technical and non-technical losses. Technical losses refer to heat generated in power lines and transformers. Some of these losses are fixed and known, as transformers and conductors need to be energized. Other technical losses are variable based on power lines and cables transmitting. Non-technical losses refer to energy which has been delivered but was not recorded by a meter. This can include public utilities, such as public lighting, phone booths and traffic lights, which are often estimated instead of metered. Electricity theft also falls under this category (Council of European Energy Regulators, 2017, pp. 10–11).

As multiple indicators require analysis of renewable energy, it is necessary to define which energy sources fall under that umbrella. Twidell and Weir (2006) define renewable energy as "energy obtained from natural and persistent flows of energy occurring in the immediate environment" (p. 7). This flow exists regardless of the existence of devices to intercept and harness it.

Further elaboration by Ellabban et al. specify the origin of these flows of energy:

> RENEWABLE ENERGIES ARE ENERGY SOURCES THAT ARE CONTINUALLY REPLENISHED BY NATURE AND DERIVED DIRECTLY FROM THE SUN (SUCH AS THERMAL, PHOTO-CHEMICAL, AND PHOTO-ELECTRIC), INDIRECTLY FROM THE SUN (SUCH AS WIND, HYDROPOWER, AND PHOTOSYNTHETIC ENERGY STORED IN BIOMASS), OR FROM OTHER NATURAL MOVEMENTS AND MECHANISMS OF THE ENVIRONMENT (SUCH AS GEOTHERMAL AND TIDAL ENERGY)" (2014, P. 749).

Biomass is the general term for all organic material from plants, crops and trees, which stores the sun's energy through photosynthesis. Biomass energy derives from the conversion of biomass into heat, electricity, fuels, or other types of energy. Geothermal energy extracts energy from the earth, in small scale through heat pumps, in larger scales by geothermal power plants. The trapped heat energy in the earth's interior is either stored in rock, trapped steam or liquid water (Ellabban et al., 2014, pp. 750–751).

Hydropower is power produced by flowing water. Turbines turn the captured energy into electricity. The most prevalent form is found in dams. Hydropower plants are classified into three categories, according to operational type; Run-of-River (RoR), storage (reservoir), and pumped storage plants. A RoR plant draws power from a river's natural flow of water, with drawbacks being that electricity generation is highly dependent on precipitation and runoff, including variance related to weather and seasonal changes. Reservoir plants reduce the variance in energy generation by relying on a water storage downstream. Pump systems do not produce electricity but store water by pumping it into a higher reservoir during off-peak hours and then reverse the flow during peak hours. The pumping process is a net energy loss, but the large scale energy storage option makes it worthwhile (ibid., p. 752). Renewable marine energy has six potential forms. It spans from waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion to salinity gradients. Almost all ocean energy technologies are still undergoing research and development or are in their prototype phase, with tidal barrages being the exception (ibid.).

Solar energy is split into three distinct categories between photovoltaic (PV), concentrating solar power, and solar thermal heating and cooling. Photovoltaic systems directly convert solar energy into electricity via an array of semiconductor devices. Combined with inverters, batteries and other system components, this forms a PV system. These systems are classified in two categories, off-grid or grid-connected. Off-grid systems offer quick access to electricity in un-electrified areas of developing countries and are among the most cost-efficient. Grid-connected systems tie directly to the general electric grid. Centralized PV systems then simply supply bulk power to the network, while distributed PV systems provide power to individual customers. Concentrating solar power systems "produce electricity by concentrating direct-beam solar irradiance to heat a liquid, solid or gas that is then used in a downstream process for electricity generation" (ibid., p. 754).

Solar thermal heating and cooling works through the collection of the sun's thermal energy to offer hot water, heating, and cooling using heat exchangers. Wind power can be used via harvesting wind energy by using turbines to create electricity, windmills for mechanical power, wind pumps for drainage or water, or sails to propel ships. Wind turbines exist both on land and as offshore wind turbines in the sea. Reasons to build off-shore wind turbine farms include higher quality wind resources, larger wind turbines, larger power plants and the reduction of land-based transmission infrastructure (ibid., p. 755).

Waste to energy processing is not generally considered to be a form of renewable energy. However, as waste is continuously being produced and thermal forms of energy recovery can reduce waste volume by up to 90% while generating electricity or heat, the author has chosen to include this data point (Moya, Aldás, López, & Kaparaju, 2017, p. 293).

The metric non-carbon energy is based upon the Asia Pacific Energy Research Centre's energy security indicators. While not distinctly specified, their *Energy Security Indicator III* for a non-carbon intensive fuel portfolio includes hydro and nuclear energy as separate sources from other renewables (APERC, 2007, p. 52). As the original AESPI framework's indicator was constructed with these calculations in mind, the author will follow this definition.

To assess indicators *Climate Change 1* and *Climate Change 2*, carbon emission factors are necessary to calculate carbon-dioxide levels. The German Environment Agency writes, "to calculate carbon dioxide emissions, one needs both the relevant activity data and suitable emission factors, with the latter depending on the applicable fuel quality and input quantities" (Jurich, 2016, p. 4) and offers emission factors tailored to Germany for all major fuel types. The EEA and European

Monitoring and Evaluation Programme (EMEP) proposes emission factors with the 'EMEP/EEA Air Pollutant emission Inventory Guidebook 2016' (EEA & EMEP, 2016). The U.K. Department for Environment, Food and Rural Affairs (DEFRA) and the Department for Business, Energy and Industrial Strategy (BEIS) offer averages for various fuel types (BEIS & DEFRA, 2018). Since the British data is an overall average per fuel type and not specifically tailored to UK fuel types, the author will choose these factors for further calculations unless otherwise noted.

On the topic of water, the World Health Organization and the United Nations Children's Fund classify improved water sources as either piped, as in households with tap water, or non-piped, such as boreholes, protected wells and springs, rainwater and packaged water (United Nations Children's Fund [UNICEF] & World Health Organisation [WHO], 2017, p. 12).

According to the Food and Agriculture Organization of the UN, the term forest cover includes "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" (Food and Agriculture Organization [FAO], 2015, p. 3). Agricultural use also excludes systems where crops are grown under tree cover and any form of fruit tree plantations.

Within the efficiency and technology dimension, the commercial, the agricultural, the industrial and the transportation sector are mentioned. The commercial sector is defined by the U.S. Energy Information Administration's glossary as "an energy consuming sector that consists of service-providing facilities and equipment of businesses." (USEIA, 2018c). Included are private and public institutions and organizations as well as local, state, and federal governments. The Cambridge Dictionary states it is "the part of a country's economy that includes all businesses except those involved in manufacturing and transport" (Cambridge Dictionary, 2018). Griffith et al. (2007, p. 4) explicitly exclude industrial, residential, or agricultural activities in their classification of the commercial sector. In this thesis, the commercial sector will include all private and public economic activities and exclude agricultural, industrial, manufacturing, transport, or residential activities.

The transportation sector generally encompasses “all vehicles whose primary purpose is transporting people and/or goods.” (USEIA, 2018c). Excluded in this categorization are vehicles whose main purpose is not transportation but localized work (e.g. cranes, bulldozers, farming vehicles, etc.). Atabani et al. state that,

> ENERGY USE IN THE TRANSPORTATION SECTOR INCLUDES THE ENERGY CONSUMED IN MOVING PEOPLE AND GOODS BY ROAD, RAIL, AIR, MARINE, WATER AND PIPELINE. THE ROAD TRANSPORT INCLUDES LIGHT-DUTY VEHICLES SUCH AS AUTOMOBILES, SPORT UTILITY VEHICLES, MINIVANS, SMALL TRUCKS, AND MOTORBIKES AS WELL AS MEDIUM AND HEAVY-DUTY VEHICLES, SUCH AS LARGE TRUCKS USED FOR MOVING FREIGHT AND BUSES USED FOR PASSENGER TRAVEL (2011, P. 4587)

The FAO (2018) describes the agricultural sector and its sub-sectors as including gathering, production and post-harvest processes of crop farming, livestock management, agro-forestry, and fishing and aquaculture systems. The Eurostat (2008) Reference and Management of Nomenclatures page also categorizes agriculture to include crop and animal production, hunting and related activities, forestry, as well as fishing and aquaculture.

While many definitions of the industrial sector include agriculture, forestry, fishing and hunting in the term (Abdelaziz, Saidur, & Mekhilef, 2011; BusinessDictionary, 2018; Office of Energy Efficiency, 2008; USEIA, 2018c; Zhang, 2003), the current framework strives to separate these metrics into its own sector. Thus, it is necessary to separate these elements from the industrial sector. The author will use manufacturing, mining and construction activities as the baseline for the industrial sector.

Table 3 Final Combined Framework

Dimension	#	Indicator	Metric	Unit	Additional Notes
Availablility	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
Availablility	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 (Annualized)	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	Sulfur 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	

(Table created by author)

4. Analyzing the Country Cases

4.1. Japan

4.1.1. Overview

Japan is the world's fifth largest energy consumer, using around 456 million tons of oil equivalent in 2017 (BP, 2018a, p. 8). Access to coal, oil and gas reserves is severely limited and Japan is therefore highly reliant on imported coal, oil, and gas resources. Currently fossil fuels account for almost 90% of primary energy (METI, 2018a, p. 1). Already in the 1920s the domestic oil production was not sufficient to meet growing demands and renewed forays in the 1960s led to unsatisfactory results. Onshore projects produced low yields of around 8000 barrels per day, but incurred sizable costs to the Japanese government, which heavily subsidized these projects (Hughes, 2014, pp. 129–132; Thorarinsson, 2018, p. 12). Today, the yearly domestic production equals to around 0,3% of total demand. To cope with this deficit, Japan has adopted a strategy of importing crude oil and refining it domestically, as well as nurturing an overseas upstream oil industry (Petroleum Association of Japan, 2015, p. 8; Thorarinsson, 2018, pp. 13–15).

The first modern coal mine was established in Nagasaki as the Takashima coal mine in 1869. It was the first coal mine to be mechanized by steam engines and was subsequently purchased by Mitsubishi. Based on the success of the Takashima mine, Mitsubishi went on to purchase Hashima island three kilometers southwest of Takashima, in 1890, which was in operation until 1974. The Miike coal mine was the second coal mine in Japan to be industrialized after Takashima (National Congress of Industrial Heritage, 2015). It was nationalized along with Takashima and other important mines in 1872 but later sold to the Mitsui Zaibatsu and remained in operation until 1997, even after the largest mine accident in Japan occurred in 1963, during which 458 miners were killed (Kyodo News, 2013; Norman, 2000, p. 121). The domestic coal industry has overall been in decline since the early 1950s when energy demand shifted from coal to oil. While the postwar period saw around 450,000 people employed and a peak production of 55 million tons in 1961, this number drastically dropped to around three million tons in 2000. With around three times the cost to imported coal, domestic production ceased in 2002 when the last mine closed (Hirao, 2002). Some limited form of coal mining has restarted in Hokkaido in recent years. Being the third largest importer of coal, current imports come primarily from Australia and provide a baseload source for power generation in Japan. It also features the highest efficiency rate of coal technology worldwide (USEIA, 2017, p. 16).

Liquefied Natural Gas (LNG), with imports estimated around 84 million tons, is a major part of the energy mix and makes Japan the largest importer of LNG worldwide. Most of these imports are from the Asia-Pacific region, the main exporters being Australia and Malaysia (International Trade Administration [ITA], 2018a). Today LNG is the largest contributor to electricity generation in Japan, accounting for around 42% (METI, 2018a, p. 8).

There are currently 37 nuclear power plants in Japan. The four Fukushima plants have been shut down and eight reactors are scheduled to shut down permanently until 2036 at the latest. Before the great Tohoku earthquake of 2011, nuclear energy played an important part in the Japanese energy mix. Up to that point, around 30% of the total electricity generation was provided by nuclear energy. After the accident and following shut-down at the Fukushima Daiichi nuclear power plant, the government also required other nuclear facilities to commit stress tests and receive renewed governmental approval. In May 2012, no reactors were providing electricity, with the first reactors restarting in July of that year (USEIA, 2017, p. 17). By 2014, nuclear power accounted for less than one percent of electricity generation (Komiyama & Fujii, 2017, p. 595). Earlier plans to increase Japanese nuclear output to 90 GWe (Gigawatt electric) until 2050 have been halted. The 2014 METI *Fourth Basic Energy Plan* indicated that nuclear energy will continue to be an important base-load power source, as other options like geothermal and hydroelectric are limited. As coal emissions hinder Japan's environmental targets, LNG was designated as an intermediate solution (WNA, 2018b). The 2018 *Fifth Basic Energy Plan* reaffirms the support of nuclear power, aiming for an increase of nuclear power to 20% of total electricity generation by 2030. By the end of 2018, 9 reactors have been restarted (ibid.). Current laws do not allow for nuclear power plants older than 60 years, including a 20 year extension after passing safety tests, effectively banning all nuclear power plants by 2050. Since no new plants are being constructed amid rising costs, this would be the end for nuclear power in Japan (Sawa, 2018).

Renewable energy made up around 15,6% of total power generation in 2017. The largest share is large hydropower generation, followed by photovoltaic systems (Institute for Sustainable Energy Policies, 2018). While PV power generation steadily increased more than eightforld since 2010, the increase of renewable energy sources was flat in the case of hydropower and geothermal energy. This difference of PV to other forms of renewable energy is often attributed to the Feed-In-Tariffs granted by the Japanese Government (Japan for Sustainability, 2017). These tariffs have gradually been lowered over the last years and installation of PV and other renewables has slowed accordingly (ITA, 2018b). Japan features vast untapped geothermal energy reserves, ranking third globally. Land use issues, permitting, public opinion, and proximity to natural parks are limiting potential construction (ITA, 2016, p. 3).

4.1.2. Indicator 1: Supply

As previously mentioned, the *Supply* indicator comprises the production of coal, crude oil, natural gas, nuclear fission, hydroelectric, and other renewable resources, including imports, excluding exports and considering stock changes and international bunkers. According to METI data for the year 2016, coal supply amounted to 193.082.900 tons, with 1.254.200 tons being domestically produced, 193.085.100 tons imported, and 2.200 tons exported (METI, 2016a). Coal products and derivatives add an additional 2.301.700 tons of imports and subtract 1.258.200 tons of exports with an additional 809.000 tons of coal products being deducted in form of stockpile changes, which amounts to a net addition of 1.062.600 tons. As both coal and coal products feature the same calorific value in the report, they will be added together in order to simplify and convert the value into tons of oil equivalent (METI, 2016a). Overall, this amounts to 194.145.500 tons. With coal featuring an average energy density of 25,8 Gigajoule (GJ) per metric ton, the result is 5.008.953.900 GJ (American Physical Society [APS], 2018; UNDESA Statistics Division, 2016, p. 24). As one ton of oil equivalent is defined as being equivalent to 41,868 GJ, dividing the previously calculated total by the given value leads to a sum of 119.636.808,54 toe.

As for crude oil and oil products, official numbers state that 190.805.100 kiloliters (kl) of crude oil have been imported, 519.400 kl domestically produced and a positive stockpile change of 1.125.200 kl has been noted. No crude oil has been exported. This adds up to 192.449.700 kl overall. Regarding oil products, 46.559.000 kl have been imported and 33.519.000 kl exported. Additional stockpile changes added 522.100 kl. This amounts to 13.562.100 kl remaining for the domestic primary energy supply. As in the case of coal, both crude oil and oil products feature the same calorific value in the official data and will therefore be added together, amounting to a total of 206.011.800 kl of crude oil and oil products (METI, 2016a). One kl equals in amount to 6,28 barrels of oil, which in turn converts the previously established amount to 1.293.754.104 barrels. One barrel equals 6,11 GJ of energy, which equals 0,14 toe (APS, 2018; IEA, 2018d). After conversion, this amounts to 181.125.574,56 toe.

Concerning natural gas, Japan has imported 84.748.500 tons of LNG and domestically produced 2.092.100 tons of LNG in 2016. Stockpile changes amounted to a net positive of 12.200 tons. This results in overall 86.852.800 tons of LNG (METI, 2016a). According to the International Gas Union's Natural Gas Conversion Guide, one ton of LNG equals 55,38 MBTU (British Thermal Units in millions) (International Gas Union [IGU], 2012). One ton of oil equivalent features a heat value of 39.68 MBTU. The resulting 4.809.908.064 MBTU equal 121.207.644 toe (IEA, 2018d).

The nuclear power generation amounted to 148.965 Terajoule (TJ), and resulting from the direct production of electricity, no imports, exports or stockpile changes need to be taken into account (METI, 2016a). This equals to 3.558.803 toe_in energy (IEA, 2018d).

Renewable sources excluding hydroelectric energy produced 763.018,3 TJ domestically and 40.774,1 TJ was imported. With exports amounting to 32 TJ, this overall adds up to 803.760,4 TJ (METI, 2016a). After conversion, this equals 19.197.487,3 toe (IEA, 2018d). Hydroelectric energy generation reached 650.844,56 TJ. As with nuclear power generation, no imports, exports or stock changes need to be considered. Converting this value leads to 15.545.141,9 toe (IEA, 2018d).

Additionally, the Japanese METI tracks a separate point under 未活用エネルギー (*Mikatsuyou enerugi*), which is translated by the ministry as *effective recovery of* *wasted energy* (METI, 2016a). Kainou (2012, p. 220). describes this term as energy that is recovered during waste processing, most commonly through incineration In 2016, 584.567,9 TJ of energy were produced via waste processing. Converted, this equals 13.962.164,4 toe (IEA, 2018d).

Finally, to calculate the total primary energy supply, all values from the various energy sources now need to be added together, which amounts to 474.233.623,7 toe. To fulfill the first indicator of this paper's framework, we divide this by the total population of Japan to get the *per capita* value. According to the Japanese Statistics Bureau, the total population measured 126.933.000 people in 2016 (Statistics Bureau - Ministry of Internal Affairs and Communications [SBMIC], 2018, p. 10). Dividing the total primary energy supply by the total population then yields the desired value of 3,73609 toe/capita or 3.736,09 kgoe/capita.

4.1.3. Indicator 2: Final Energy Consumption

To measure the final energy consumption, as per the definition provided in chapter 3.2., the total energy consumed by various sectors needs to be considered. The data provided by the METI differentiates between three industrial sectors, the commercial, the residential, transportation, and non-energy sector (METI, 2016a). Within the industrial sector the data is split up into agriculture, fishery, mining and construction as one industrial sector, manufacturing as another, and the commercial sector as the third. Total energy consumption of the agricultural, fishery, mining and construction sector totaled 373.890 TJ in 2016 equaling 8.930.209,23 toe (IEA, 2018d; METI, 2016a). The second sector, manufacturing, features nine sub-sectors: food, beverages, tobacco, and feed; textile mill products; pulp, paper and paper products; chemical and allied products, oil and coal products; ceramic, stone and clay products; iron and steel; non-ferrous metals; machinery; manufacturing industry. Overall these industry sectors account for 5.771.170 TJ of energy consumption. After conversion, this amounts to 137.842.027 toe. The commercial sector overall used 2.135.209 TJ or 50.998.590,8 toe (IEA, 2018d; METI, 2016a).

The residential sector spent 1.917.087 TJ in 2016. This equals 45.788.836,3 toe. Transportation sector data differentiates between passenger transportation and freight. Passenger transportation accounted for 1.850.157 TJ, while freight accounted for 1.273.386 TJ. Added together, these values amount to 3.123.543 TJ which converts to 74.604.542,8 toe (IEA, 2018d). The final sector, non-energy encompasses uses of primary energy such as material production from crude oil (Research Institute of Innovative Technology for the Earth, 2018). Total energy transformation equaled 1.614.188 TJ, which converts to 38.554.218 toe (IEA, 2018d; METI, 2016a).

Adding these values, the final energy consumption reaches 356.718.424,13 toe. Divided by the total population this amounts to 2,81028 toe/capita or 2.810,28 kgoe/capita.

4.1.4. Indicator 3: Electricity per Capita

According to the METI data, a total of 7.769.226 TJ was expended to produce electricity for end-consumers and 1.287.950 TJ was used in self-generated (direct-use) electricity in 2016 (METI, 2016a). Before accounting for losses, this amounts to a total electricity generation of 1055,53 terawatt hours (TWh).

On the consumer side, the agriculture, fishery, mining and construction industries account for 10,12 TWh. Manufacturing industries, including self-generation, overall used 335,24 TWh of electricity. The commercial industry sector totaled 317,66 TWh. Residential electricity consumption accounted for 269,27 TWh. Within the transportation sector, passenger transport measured 16,73 TWh and freight 0,77 TWh (METI, 2016a). Overall this equals 949,79 TWh. The discrepancy between the amount produced and the amount consumed will, as per the definition in chapter 3.2., be assumed to be losses in transmission or distribution.

The total electricity consumed converts to 81.667.239,9 toe (IEA, 2018d). Divided by the total population, the value for this indicator results in 0,64338 toe per capita or 643,38 kgoe per capita.

4.1.5. Indicator 4: Resilience

To assess the total reserves, this indicator takes both proven reserves and stockpiles of coal, oil, gas and uranium into account. This chapter will first discuss stockpiles, then reserves, before adding these values to calculate the indicator. The final value (reserves in years) is determined by dividing through the total FEC. Coal stockpiles in Japan increased to 197 million tons at the end of 2015, the largest year-end stockpile within the last 25 years. These stockpiles are generally stored at power plants (Koji, 2016). After conversion, the coal stockpile equals 137.864.240 toe.

Petroleum stockpiling differs between private and national stockpiling. Private stockpiling, which was started in 1972, maintains a supply level of around 90 days of consumption. This equals 32.880.000 kl of crude oil and petroleum products overall. National stockpiling maintains around 47.820.000 kl which supplies around 117 days of current consumption levels. Most of this stock is in crude oil and only minimal reserves are in petroleum products. National stockpiles of crude oil are stored in national petroleum stockpile bases and leased private tanks. Oil products are stored in private tanks. Private stockpiling measures exclusively use private tanks. Additionally, a two-day supply is being jointly held with oil-producing nations. This amounts to around 800.000 kl (Japan Oil, Gas and Metals National Corporation [JOGMEC], 2016, p. 2). Adding these values, the overall stockpile totals 81.500.000 kl, which after conversion totals 74.692.371,26 toe.

Gas stockpiling in Japan relies on liquefied petroleum (LP) gas. LNG is only being stored in domestic facilities reprocessing it, where it is not stored as a stockpile (Urabe, Kawamura, Sakanoue, Uno, & Matsuzaki, 2016, p. 199). These private LNG tanks hold a voluntary stock equivalent to 20 days of consumption (Vivoda, 2014, p. 74). This supply would equal around 4.758.000 tons of LNG, which converts to 5.805.000 toe (Qatar Petroleum, 2018).

In March 2017, the LP gas stockpiles amounted to 1.347.000 tons in national stockpile and 1.508.000 tons in private stockpile, which equals around 50 and 55 days of supply (JOGMEC, 2017). Overall this stockpile totals 2.855.000 tons of LP gas, which equals 5.264.620 kl. As one kiloliter measures around 25 GJ of energy, the stockpile amounts to 3.193.879 toe (Hofstrand, 2008).

As for the uranium stockpile, the Japanese Nuclear Regulation Authority puts the stockpile in 2014 at 22.061 tons of enriched uranium, 15.793 tons of depleted uranium, and 1.349 tons of natural uranium (Nuclear Regulation Authority [NRA], 2015). IAEA data puts the amount of enriched uranium at 23.280 tons in 2016 (IEA, 2018). To calculate the energy value of this stockpile, the author assumes that all fuel used is enriched uranium, as all except the first nuclear reactor in Japan are light-water reactors (LWR) and solely use enriched uranium. Additionally, the first reactor, Tokai I, was closed in 1998 (WNA, 2018b). While depleted uranium can be reprocessed and used for energy generation purposes, it is not generally done and will therefore be disregarded (WNA, 2018d). For the remaining natural uranium, it is assumed it is going to be enriched. Japan features a uranium enrichment facility at Rokkasho (Japan Nuclear Fuel Limited, 2018). According to URENCO (2019), the remaining 1.349 tons of natural uranium after enriching, would amount to around 155 tons of enriched uranium. Overall the total of enriched and therefore usable uranium amounts to 23.435 tons of material. As enriched uranium used in a LWR possesses an energy density of 3900 GJ/kg the total amount of energy available in this stockpile adds up to 2.069.418.171 toe (WNA, 2018a).

Concerning proven reserves, Japan does have coal reserves between 347 and 359 million tons (BP, 2018b; U.S. Environmental Protection Agency [USEPA] & Coalbed Methane Outreach Program [CMOP], 2015, p. 162). This equals around 242.837.000 toe. Oil reserves are estimated at 45 million barrels (ENI, 2018, p. 5; Xu & Bell, 2017). Since one barrel equals 6,11 GJ of energy, the total amounts to 6.567.067 toe. Natural gas reserves are estimated to total around 738 billion cubic feet (USEIA, 2017, p. 8; Xu & Bell, 2017). As the conversion factor for billion cubic feet into million toe is 0,025, these reserves equal 18.450.000 toe (Qatar Petroleum, 2018). Japan has limited recoverable uranium reserves. The IAEA/NEA (2016, p. 288) puts the recoverable amount of uranium at around 6600 tons. Natural uranium features a heat value of 500 GJ/kg, which in turn means that the total reserves amount to 3.300.000.000 GJ of energy or 78.819.145 toe (WNA, 2018a). Assuming this amount being enriched as well, the natural uranium would transform into 1000 tons of enriched uranium, which would instead add 93.149.899 toe to the overall result (URENCO, 2019).

In order to calculate the final value for the resilience indicator, all stockpile and reserve values need to be added and then divided by the FEC. The total amounts to 2.759.722.355,37 toe, which divided by the FEC results in a value of 7,75 years.

4.1.6. Indicator 5: Reserve Production (Oil)

Reserve production is based upon production levels and total reserves. In the case of crude oil, Japan’s production hovers around 11 thousand barrels a day or 4 million barrels a year (ENI, 2018, p. 10). With reserves being estimated at 45 million barrels, this results in 11,25 years of reserve production.

4.1.7. Indicator 6: Reserve Production (Natural Gas)

Japan's production of natural gas amounted to around 100 billion cubic feet in 2015, down from 140 billion eight years prior, with most gas fields to be found on the western coastline (USEIA, 2017, p. 9). With the estimated reserves already established at around 738 billion cubic feet, the resulting reserve production is 7,38 years.

4.1.8. Indicator 7: Reserve Production (Coal)

While Japan possesses proven coal reserves, the last coal mine closed in 2002. There have been limited attempts to reopen production after the Fukushima Nuclear Disaster. Hokkaido coal mines have produced around 1,2 million tons annually for Hokkaido Electric (Kuo, 2012; Topf, 2012). Currently, the Kushiro Coal Mine produces around 530 thousand tons per year (Kushiro Coal Mine Co. Ltd., 2019). The BP Statistical Review puts the total proven reserves of coal at 359 million tons (BP, 2018b). Using current levels, the reserve production would amount to 677,35 years. The BP statistical review disregards values of over 500 years. Considering this limited and localized production, the author will also deem Japanese coal production to be negligible and exclude the value for reserve production.

4.1.9. Indicator 8: Dependency

The net energy import dependency is based on both imports and exports in relation to TPES. Japanese coal imports in 2016 totaled 191.830.900 tons. In addition, 2.301.700 tons of coal products were imported. Coal exports amounted for 2.200 tons and exports of coal products were registered at 1.158.200 tons (METI, 2016a). Net coal and coal product imports therefore add up to 192.972.200 tons. After conversion this value equals 135.045.511,13 toe (APS, 2018).

Crude oil imports accounted for 190.805.100 kl and oil products reached 46.559.000 kl. No crude oil was exported in 2016 and oil product exports were measured at 33.519.000 kl (METI, 2016a). Overall this adds to 203.845.100 kl of oil and oil products. This amount converts to 1.280.147.228 barrels and 179.220.611,92 toe (APS, 2018).

Natural gas was imported to the amount of 84.748.500 tons and no exports took place (METI, 2016a). One ton of LNG equaling 55,38 MBTU leads to 4.693.371.930 MBTU and in turn to 118.280.542,59 toe (IEA, 2018d).

The amount of all imported energy totals 416.414.949,29 toe. Dividing this value by the TPES leads to a net energy import dependency of 87,8%.

Though not specified as imported energy, nuclear energy could be considered imported, as no natural uranium production is occurring in Japan. Counting these 3.558.803 toe of nuclear energy as imported would increase the import dependency to 88,55% (METI, 2016a).

4.1.10. Indicator 9: Diversification

The diversification indicator looks at the share of renewable energy as part of TPES. The total primary energy supply has already been calculated to be 474.233.623,7 toe. Renewable sources, excluding hydropower, amounted to 19.197.487,3 toe, hydroelectric power generation totaled 15.545.141,9 toe, and waste energy recovery was measured at 13.962.164,4 toe (METI, 2016a). Added together, renewable energy accounted for 48.704.793,6 toe. By dividing this value through TPES, the percentage of renewable energy within TPES is calculated at 10,27%.

4.1.11. Indicator 10: Exports

According to METI (2016a) data, 2.200 tons of coal and 1.158.200 tons of coal products were exported in 2016. While no crude oil was exported, 33.519.000 kl of oil products were exported. Additionally, the data shows 32 TJ of renewable energy being exported. The UN Comtrade database shows the various exports and categorizes them. The large majority of these exports fall under “petroleum oils and oils from bituminous minerals, not crude; preparations n.e.c, containing by weight 70% or more of petroleum oils or oils from bituminous minerals; these being the basic constituents of the preparations; waste oils” (United Nations Statistics Division [UNSD], 2019b). These make up 7.591.982.223 USD as of 2016. The next largest group encompasses “oils and other products of the distillation of high temperature coal tar; similar products in which the weight of the aromatic constituents exceeds that of the non-aromatic constituents” (ibid.). Exports in this category made up 1.375.003.882 USD overall.

Smaller categories concerning petroleum and coke products encompass “coke and semi-coke; of coal, lignite or peat, whether or not agglomerated; retort carbon” with 155.242.089 USD in volume, “petroleum jelly; paraffin wax, micro-crystalline petroleum wax, slack wax, ozokerite, lignite wax, peat wax, other mineral waxes, similar products obtained by synthesis, other processes; coloured or not" with 69.444.639 USD, "petroleum coke, petroleum bitumen; other residues of petroleum oils or oils obtained from bituminous minerals" with 37.574.949 USD, "pitch and pitch coke; obtained from coal tar or from other mineral tars" with 34.790.404 USD, "bituminous mixtures based on natural asphalt; on natural bitumen, on petroleum bitumen, on mineral tar or on mineral tar pitch (e.g. bituminous mastics, cut-backs)" with 9.108.774 USD, "coal; briquettes, ovoids and similar solid fuels manufactured from coal" with 1.021.724 USD, and "peat; (including peat litter), whether or not agglomerated" with 4.254 USD in volume (ibid.).

Overall the export volume totals 9.372.170.034 USD of various coal and oil products. The data shows no electricity being exported from Japan, so the 32TJ of renewable energy are unaccounted for.

4.1.12. Indicator 11: Primary Energy Intensity

To calculate this indicator, both the TPES and the GDP are required. The TPES has already been established at 474.233.623,7 toe or 474.233.623.700 kgoe. The World Bank puts the GDP value at 4.949.273.341.993,9 USD (World Bank [WB], 2019c). The OECD values Japan's GDP in 2016 at around 5.245.730.500.000 USD (OECD, 2019a). The Statistical Handbook of Japan and the International Monetary Fund also supports this number in consideration of purchase power parity (International Monetary Fund [IMF], 2019c; SBMIC, 2018, p. 27). The author will use the latter value for calculation purposes. Dividing these values leads to a 0,0904 kgoe/USD or 3,78 MJ/USD (IEA, 2018d).

4.1.13. Indicator 12: Final Energy Intensity

Similar to the previous chapter, both the FEC and GDP are necessary to calculate this indicator. The FEC has been determined at 356.718.424,13 toe. Using the same GDP value as in the previous indicator, the result of the division of these two values leads to a final energy intensity of 0,068 kgoe/USD or 2,84 MJ/USD (IEA, 2018d).

4.1.14. Indicator 13: Transportation Energy Intensity

The energy expenditure within the transportation sector was 74.604.542,8 toe according to METI data (2016a). The Japanese Statistical Yearbook shows that the transportation sector accounted for 26.963 billion Yen in 2016. Converted into 2016 USD PPP, this equals 264.343.137.254 USD (OECD, 2019b; SBMIC, 2019). Dividing these two values leads to an energy intensity of 0,28 kgoe/USD or 11,8 MJ/USD (IEA, 2018d).

4.1.15. Indicator 14: Commercial Energy Intensity

Commercial energy expenditure was 50.998.590,8 toe. The GDP data within the commercial sector is split into various sub-categories. Wholesale and retail make up 73.998,2 billion Yen, accommodation and food services make up 12.865 billion, information and communication services make up 26.829,7 billion, finance and insurance services make up 22.461,7 billion, scientific and technical activities make up 39.255,8 billion, public administration services make up 26.678,6 billion, education makes up 19.430,2 billion, health and social work activities make up 37.743,6 billion and other services add 22.937,4 billion Yen (SBMIC, 2019). The commercial sector overall accounts for 282.200,2 billion Yen, which converts to 2.749.283.452.676 USD in 2016 PPP (OECD, 2019b). Dividing the energy expenditure by the sector's GDP yields an energy intensity of 0,018 kgoe/USD or 0,753 MJ/USD (IEA, 2018d).

4.1.16. Indicator 15: Agriculture Energy Intensity

The agricultural sector accounted for 8.930.209,23 toe of the energy use in 2016. The economic activity within the sector measured 6.193,9 billion Yen (SBMIC, 2019). Converted, this amounts to 60.724.509.803 USD PPP (OECD, 2019b). Dividing the total energy use by the sectorial GDP, the result yields 0,14 kgoe/USD or 5,86 MJ/USD (IEA, 2018d).

4.1.17. Indicator 16: Industrial Energy Intensity

The total energy expenditure within the industrial sector measured 137.842.027 toe. The Japanese Statistical Yearbook splits economic activity within this sector into three sub-categories. Mining activity accounted for 291,2 billion Yen, manufacturing for 113.337,2 billion Yen and construction for 23.724,6 billion Yen (SBMIC, 2019). Overall, economic activity totaled 143.353 billion Yen, which after conversion equals 1.405.421.568.627 USD PPP (OECD, 2019b). The resulting energy intensity is 0,098 kgoe/USD or 4,1 MJ/USD (IEA, 2018d).

4.1.18. Indicator 17: Household Consumption

Average household energy consumption can be calculated by dividing total energy expenditure by the residential sector by the number of households in Japan. The residential sector accounted for 45.788.836,3 toe in energy consumption. The Statistical Handbook of Japan puts the number of households, one-person households, nuclear-family households, and other forms of households at 53.332.000 (SBMIC, 2018, p. 11). The resulting value is 858,56 kgoe per household.

4.1.19. Indicator 18: Household Energy

Having already established the average household energy consumption, the average members per household value is necessary to calculate the per capita value. While the number has continually decreased over the last decades, current estimates put the average at 2,33 members per household (SBMIC, 2018, p. 11). Dividing the average household energy consumption value of 858,56 kgoe by 2,33 members yields 368,48 kgoe per capita.

4.1.20. Indicator 19: Household Electricity

Total residential electricity consumption in 2016 amounted for 269.278.500.000 kWh (METI, 2016a). As previously stated, the number of households is estimated at 53.332.000, which leads to a household electricity consumption of 5.049 kWh per year. Divided by 2,33, the average number of members in a household, the resulting electricity consumption is 2.166 kWh per capita.

4.1.21. Indicator 20: Grid Efficiency 1 (Loss in Transmission)

Statistics on distribution losses for Japan vary depending on the source. The World Bank reports losses of 4,3% in 2013 (WB, 2019b). The Tokyo Electric Power Company shows transmission losses at 4,6% within its own network (Tokyo Electric Power Company [TEPCO], 2016). Chubu Electric Power claims distribution losses at 4,48% (Chubu Electric Power, 2019). The Federation of Electric Power Companies of Japan release an annual report on the energy situation in Japan. The overall transmission losses are reported at 5% (Federation of Electric Power Companies of Japan [FEPC], 2017, p. 23). As this data uses information from all major power companies in Japan, the author will use this value.

4.1.22. Indicator 21: Grid Efficiency 2 (Loss in Transformation)

To calculate the loss in transformation, mostly energy lost as heat during the transformation from its original state to electricity, the formula presented in the framework “(1-(FEC/TPES))×100” is used. Inserting the FEC of 356.718.424,13 toe and the TPES value of 474.233.623,7 toe, the result for transformation losses is 24,78%.

4.1.23. Indicator 22: Access

According to the World Bank SE4ALL Global Tracking Framework data in collaboration with the IEA and the Energy Sector Management Assistance Program, the Japanese population has full electricity access (WB, 2019a). Data offered by the Federation of Electric Power Companies of Japan also shows that the number of private customers exceeds the number of households (FEPC, 2018). The author will therefore use a value of 100% as the percentage of households with access to electricity.

4.1.24. Indicator 23: Solid Fuel Usage

The World Health Organisation, in its Global Health Observatory data repository, assesses Japan as a high income country with solid fuel usage below five percent (WHO, 2013). Modeling from Rehfuess et al. (2006, p. 373) also predicts that for countries with a gross national income of over 10.500 USD per capita show solid fuel use of under five percent within the population. The United Nations' Millennium Development Goals Indicators point to solid fuel usage below 5% (UNSD, 2012). The author will therefore consider solid fuel use in Japan as negligible.

4.1.25. Indicator 24: Electricity Pricing

For this indicator, the necessary data points are annual electricity consumption per capita, average electricity price, and GDP per capita. Yearly electricity consumption per capita was already calculated for indicator 19 at 2.166kWh and person. TEPCO also puts its rates between 19,52 and 30,02 Yen, depending on contract and usage (TEPCO, 2019). The IEA's energy prices and taxes report also puts the price of one megawatt hour in 2016 at 27.239 Yen, which equals 27,239 Yen per kilowatt hour (IEA, 2018a, p. 175). Taking purchase power parity into consideration, the author will use a rate of 0,26 USD per kWh for the purpose of calculating this indicator (OECD, 2019b).

Japan's GDP in 2016 was established at 5.245.730.500.000 USD and the current population at 126.933.000 people. This leads to a GDP per capita of 41.326,76 USD. Filling in this indicator's formula results in a value of 1,36%.

4.1.26. Indicator 25: Stability

Japanese retail electricity prices between 1996 and 2001 fell by 3,5% (IEA, 2016, p. 171). From 2001 to 2006 average electricity prices decreased by 5,5%. Between 2006 and 2011 prices increased by 2,45%. Between 2011 and 2016 the increase was 9,92% (IEA, 2018a, p. 176).

4.1.27. Indicator 26: Fuel Pricing

Regular unleaded petrol, without taking tax into account, was 55,1 Yen per liter in 2016. Including the excise tax of 56,5 Yen and consumption tax of 8,9 Yen per liter increases the total cost of one liter of petrol to 120,6 Yen (IEA, 2018a, p. 174). One hundred liters of petrol therefore cost 12.060 Yen. In 2016 USD PPP this equals 118,23 USD (OECD, 2019b).

4.1.28. Indicator 27: Land Use

The overall forest level has been constant in Japan since 1950 at around 25 million hectares (ha). The composition of these forests has changed to include more planted forests and less natural forests (Forestry Agency Japan [FAJ], 2009, p. 4). Primary forests made up 4.591.000 ha, modified natural forests 9.955.000 ha and protective plantations 10.321.000 ha in 2005.

Primary forests are “forests that regenerate naturally, where the natural set of ecological processes are undisturbed by humans” (Carle & Holmgren, 2003, p. 12). Modified natural forests are described as “forests of native species that regenerate naturally where the natural set of ecological processes has been modified or disturbed but where intensive stand management is not practiced” or “forests of native species, established either through assisted or natural regeneration, or a mix of these, under non-intensive management. Example: soil protection areas where enrichment planting has been made” (ibid.). Protective plantations are defined as “Forests of exotic species that have been planted or seeded by human intervention and that are not under intensive management.” (ibid.).

Of the total 25 million ha forest, 7,61 million ha are national forest under the Japanese Forestry Agency’s jurisdiction and 64.000 ha being under the control of other agencies. The remaining 17,4 million ha forest are either private or public forests, with public forests making up 2,9 million ha and private forests accounting for 14,4 million ha (FAJ, 2017, pp. 25–26).

Japan's land mass being 37,8 million ha in total with a forest area of 25,08 million ha results in a forest cover of 66,34% (FAJ, 2017, p. 25).

4.1.29. Indicator 28: Water

The amount of water used in Japan is around 83,5 billion cubic meters, of which 55,2 billion are used in agriculture, 12,1 billion are used for industry and 16,2 billion are used for domestic purposes (Ministry of Land, Infrastructure, Transport and Tourism [MLIT], 2008).

Access to clean water in Japan has reached 97,5% in 2013 (Japan International Cooperation Agency, 2018). The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene also puts the access to safely managed water at 97,19% in 2015 with an additional 1,75% access to basic water supplies, putting the overall access to improved water at 98,94% (WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 2017).

4.1.30. Indicator 29: Climate Change 1 (CO_2 per Capita)

According to the framework, in order to calculate the CO2 emissions, all fossil fuel expenditures need to be considered. The CO2 emission per fossil fuel type can be determined by using the corresponding carbon emission factors.

Starting with coal and coal products, power generation took up 101.443.300 tons of coal. Auto-power generation accounted for 7.405.300 tons and auto-steam generation consumed 9.118.200 tons. Own-use and loss added 487.300 tons to this equation. Power generating coal products amounted to 8.837.500 tons, auto-power generation to 2.508.300 tons and auto-steam to 2.728.200 tons. Own-use and loss made up 4.740.900 tons of coal products. The amount reaches 118.454.100 tons of coal and 18.814.900 tons of coal products for a combined subtotal of 137.269.000 tons. In addition, the various economic sectors also consumed 16.131.200 tons of coal and 36.644.800 tons of coal products. Including those values to the subtotal yields a result of 190.045.000 tons (METI, 2016a).

Crude oil and oil products made up 3.277.200 kl and 11.544.400 kl in power generation respectively. Crude oil auto-power generation amounted to 1.300 kl and auto steam generation to 2.300 kl. Own-use and loss accounted for 67.800 kl of crude oil. With oil products, 5.480.100 kl counted for auto-power generation, 8.715.900 kl for auto-steam generation, 54.000 kl for district heat supply and 6.815.500 kl for own-use and loss. Crude oil amounts to overall 3.348.600 kl and oil products to 32.609.900 kl. Oil products are also used within the various economic sectors. In 2016, this overall consumption adds an additional 168.480.300 kl (METI, 2016a). The total of oil and oil products amounts to 201.090.200 kl.

Power generation with LNG expended 56.830.900 tons. Auto-power generation used 734.000 tons and auto-steam generation 430.700 tons. Own-use and loss accounted for 134.400 tons. The consumption of LNG totaled 57.995.600 tons. LNG use within the economic sectors amounted to an additional 1.150.800 tons (METI, 2016a). The total consumption of LNG equals 59.146.400 tons. Japan also uses city gas mostly throughout major metropolitan areas. It is a mix of LNG, natural gas and petroleum products including LPG (Anzai, 2004, p. 1). In a similar vein to LNG, city gas was used for power generation to the extent of 4.202.800.000 cubic meters in 2016. Auto-power generation accounted for 2.692.500.000 cubic meters and auto-steam generation for 4.778.800.000 cubic meters. District heat supply added another 363.400.000 cubic meters, and own-use and loss an additional 1.504.700.000 cubic meters. The overall expenditure amounts to 13.542.200.000 cubic meters. City gas use in the various economic sectors accounted for 25.261.200.000 cubic meters (METI, 2016a). The total city gas consumption then amounts to 38.803.400.000 cubic meters.

The carbon emission factor for coal is 2.247,66 kgCO_2 per ton (BEIS & DEFRA, 2018). Therefore 190.045.000 tons of coal produce around 427.156.544,7 tons of CO_2. Crude oil has a carbon emission factor of 73,3 tons of CO_2 per TJ (Jurich, 2016, p. 46). The previous value of 3.348.600 kl equal 128.488,46 TJ. The resulting emissions are 9.418.204,18 tons of CO_2. Oil products were used to an extent of 201.090.200 kl. Fuel oil is given a carbon emission factor of 3,16633 kgCO_2 per liter (BEIS & DEFRA, 2018). This yields a value of 636.717.932,96 tons of CO_2. LNG produces 2741,56 kgCO_2 per ton (BEIS & DEFRA, 2018). Given the previous overall amount of 59.146.400 tons, the resulting carbon emissions amount to 162.153.404,38 tons of CO_2. Finally, city gas has a carbon emission factor of 2,21 kgCO_2 per cubic meter (Tokyo Gas Group [TGG], 2018, p. 258). With the city gas usage totaling 38.803.400.000 cubic meters the carbon emissions reach 85.755.514 tons of CO_2. Adding these values together, the overall carbon emissions amount to

1.321.201.600,22 tons of CO_2. Dividing through the total population yields a result of 10,4 tons of CO_2 per capita.

The 2016 data on Japan's national greenhouse gas emissions of the Japanese Ministry for the Environment stated that 418 million tons CO_2 was produced by the industrial sector, 215 million tons by the transport sector, 214 million tons by the commercial sector, 188 tons by the residential sector and 92,6 million tons by the energy industry, including oil refineries, power plants and similar facilities. Overall emissions in 2016 totaled 1.128 million tons of CO_2 (Ministry for the Environment [MENV], 2018, p. 4). The discrepancy between the calculated value and the official governmental value could stem from a more detailed split of the various fuel types. Differing petroleum products and the types of coal used vary in their carbon emission factors. The author will use the value calculated according to the framework's specifications.

4.1.31. Indicator 30: Climate Change 2 (CO_2 per GDP)

To calculate this indicator, the established carbon emissions from the previous chapter and the GDP are necessary. Emissions equaled 1.321.201.600.220 kg of CO_2 and the GDP value was found to be 5.245.730.500.000 USD. Dividing total emissions by GDP yields a result of 0,25 kg CO_2 per USD.

4.1.32. Indicator 31: Renewable Capacity

Based upon monthly data, the total electricity generation capacity in Japan amounted to 273.337.387 kW on average (METI, 2016b). Of that, renewables, including waste energy recovery but excluding hydropower, accounted for 8.526,34 megawatts (MW) in power generation capacity. Hydropower accounted for 49.521,19 MW (ibid.). Added together, the renewable capacity is 58.047,53 MW, which equals 21,23% of the overall capacity.

In contrast, according to the 2018 government white paper, the installed capacity of PV energy generation in 2016 reached 42.229.000 kW alone (METI, 2018b, p. 168). Both the REN21 global status report on renewables and the International Energy Agency's report on global photovoltaic markets write about an installed capacity of 42.000 MW in 2016 and 49.000 MW in 2017 (IEA PVPS, 2018, p. 10; REN21, 2017, p. 64). The UN data on net installed capacity of electric power plants confirms both data entries. It differentiates between total net installed capacity and public net installed capacity, as well as autoproducer operations. The total net installed capacity of solar also equals the white paper value of around 42.000 MW and the net installed public capacity corresponds to the METI data on monthly capacity. As the data generally provides higher values for the total net capacity in contrast to net public capacity, the author concludes that net public capacity relates to capacity that is used to produce electricity which is then directly sold to third parties, while total net capacity includes capacity that is then self-used (UNSD, 2019a). This is supported by the IEA, which also states that "main activity supply undertakings generate electricity and/or heat for sale to third parties, as their primary activity whereas autoproducer undertakings generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity" (2019a). The main activity total of the UN data corresponds to the total public capacity values, while the total including autoproducer capacity of 335.636 MW corresponds to the higher 42.000 MW solar capacity. Taking the autoproducer capacity into account, the renewable capacity percentage increases to 27,45% of total capacity.

4.1.33. Indicator 32: Non-Carbon Energy

The total primary supply of hydropower amounted to 650.844,56 TJ which equals 15.545.141,9 toe. Nuclear power overall totaled 148.965 TJ, which converts to 3.558.803 toe (IEA, 2018d). Using the partial substitution method and assuming a thermal efficiency of 40%, renewable energy includes solar PV generation which accounts for 50.952 GWh or 10.952.716 toe, wind energy accounting for 5.951 GWh or 1.279.234,7 toe, and geothermal energy accounting for 97.850 TJ or 2.337.107 toe (Fu et al., 2015; IEA, 2018b; Patel, 2017). The entire value of non-carbon energy therefore equals 33.673.002,62 toe. Dividing by TPES yields a result of 7,1% of non-carbon energy within the primary energy supply.

4.1.34. Indicator 33: Renewables

Final energy consumption of waste amounted to the generation of 18.546 GWh electricity and 89.952 TJ in other consumption. Biofuels, both liquid and solid, as well as biogas produced 15.019 GWh electricity and consumption within the economic sectors amounted to 156.646 TJ in 2016. Geothermal energy produced 2.509 GWh and consumption reached 7.535 TJ while solar thermal energy reached

10.387 TJ. In addition, PV electricity generation accounted for 50.952 GWh, wind energy for 5.951 GWh and hydroelectricity for 78.906 GWh (IEA, 2018b; METI, 2016a). After conversion to toe and using the partial substitution method in the case of renewable energy, the total amounts to 43.266.145,25 toe, which equals 12,12% of FEC (IEA, 2018d).

4.1.35. Indicator 34: Pollution

Sulfur dioxide emissions in Japan have continually decreased since 1970. Today's air concentration is around 0,002 parts per million (ppm) (MENV, 2018, p. 199). The total emission data does not differentiate between sulfur dioxide and other sulfur oxide air pollutants, but sulfur dioxide is the only one present in atmospheric conditions to impact human health (Balmes & Eisner, 2016, p. 1339). Latest data from 2014 for total SO_x emission shows a value of 406.735 tons (MENV, 2017). Divided by the total population, the result is 0,0032 tons or 3,2 kg of SO_x emission per capita per year.

4.1.36. Indicator 35: Quality of Information

All data entry points within the framework are fulfilled and the information is adequate. Therefore 100% of the data is complete.

4.2. South Korea

4.2.1. Overview

According to the BP Statistical Review of World Energy, South Korea ranks ninth among the world's energy consumers (BP, 2018a, p. 8). It's energy consumption in 2017 amounted to 295 million tons of oil equivalent. As natural resources are scarce, South Korea relies on imports to sustain its energy needs. Almost 98% of fossil fuels are imported and since no pipelines lead into the country, LNG and oil needs are solely being serviced by tanker shipments. It is now among the five top importers of LNG, coal, crude oil, and refined products (USEIA, 2018a, p. 1).

The Korea National Oil Corporation (KNOC) has been exploring oil and gas fields off the Korean shore since 1980. In 1998 and 2003, gas fields were discovered, which led to the opening of the first domestic production field in 2004. At that time production hovered around 50 million cubic feet natural gas and 1000 barrels of crude oil per day. In 2016, oil production was estimated to be around 165 barrels of oil per day (Korea National Oil Corporation [KNOC], 2018). South Korea features high end oil refineries, with three of the ten largest worldwide being situated within the country, and is one of the largest exporters of oil products in Asia (USEIA, 2018a, p. 3).

Coal mining in the pre-war era focused mainly on northern Korea, specifically the area around Pyongyang. In 1928, the local mining division under Japanese control achieved an output of over 140.000 tons of coal, the largest coal mining operation in Korea at the time (Andrews & Cheong, 1956, p. 1; Kimura, 2018, p. 31). Annual growth rate in the mining industry was around 6,6% from 1914-27 and increased to almost 20% leading up to 1936. People working in the mining sector increased accordingly from 34.000 in 1930 to 176.000 by 1940 (Mizoguchi, 1979, pp. 14, 16). In 1950, the Korea Coal Corporation was established, which acquired various mines and increased production steadily until 1988, at which point coal production exceeded 5,22 million tons annually (Korean Coal Corporation [KCC], 2017b). Total production in that year amounted to 24,29 million tons. The production share of private coal mines has continually been decreasing, leading to the Korean Coal Corporation being responsible for around 61% of all coal produced in South Korea (KCC, 2017a). Private coal mines are Gyeongdong Changdeok Mining and Taebaek

Mining (KCC, 2019). After the adoption of other fuel types for households in the late 1980s, mines have been closed and production has decreased steadily (Hwang, 2016). Overall, domestic coal production is highly insufficient to satisfy demand, which requires the vast majority of coal to be imported (KEEI, 2017, p. 6).

South Korea relies almost exclusively on LNG imports for its supply. Domestic production, centered around the Donghae-1 field, amounted for less than half a percentage point of all LNG consumed in 2017. Imports made up around 33 million tons in 2016 (KEEI, 2017, p. 6; KNOC, 2018). Consumption of LNG has more than doubled since 2000 and this increased demand has mostly stemmed from electricity needs. Between 2013 and 2015, LNG consumption fell, due to the restarting of nuclear power plants and a global drop in coal prices, but since 2016, demand for LNG has risen again as a way to quickly reduce fine dust emissions and as a respone to nuclear power plant shutdowns caused by an earthquake (USEIA, 2018a, p. 11).

Nuclear power in South Korea started with a research reactor unit in 1962 and the first commercial power plant in operation in 1978, called Kori 1. Further eight reactors were under construction during the 1980s. Overall, 25 reactors have been constructed to date, out of which two have been permanently shut down. In addition, five reactors are planned to shut down within the next decade and another five shortly after that (Korea Hydro & Nuclear Power, 2018; Ministry of Trade, Industry and Energy [MOTIE], 2017a, p. 35; World Nuclear Association, 2019b). The eighth and current *Basic Plan for Long Term Electricity Supply and Demand 2017-2031* saw to the halt of six nuclear power plants in the planning stage and no further extension on the lifespan of 14 power plants (Cornot-Gandolphe, 2018, pp. 3–4). Planned operating capacity is now arranged to peak in 2022, and the following reduction by 2030 stemming from shutdowns is estimated to be 10% from 2017 levels (MOTIE, 2017, p. 35).

In 2016, renewable energies accounted for around 5% of the total primary energy supply. Of that, more than 60% of renewable energy is produced from waste, almost 20% from biomass. Hydropower made up roughly 5% of all renewables and is limited in potential because of high seasonal variations (KEEI, 2017, pp. 6, 45; Materia, 2017, p. 6). In 2012, a 'Renewable Portfolio Standard' replaced the previous feed-in tariff system, which requires power companies with power capacities of over 500

MW to continually increase their share of renewable energy within their energy mix. The goal for 2022 is currently set at 10% (IEA, 2017a; Korea Energy Management Corporation, 2009). In 2017, the first enhanced geothermal system was constructed and put into operation close to the city of Pohang with a capacity of around 1,2 MW (Richter, 2017). In November of the same year, an earthquake struck the city and preliminary studies indicate a possible, but unconfirmed, link between the geothermal plant's operation and the earthquake, causing a temporary shutdown (Zastrow, 2018). Solar power is considered to be the most important renewable energy for South Korea, reaching almost 33% of total installed renewable capacity in 2016. Both solar and wind power are being backed by the current government, with goals to increase solar power sixfold and wind power thirteenfold by 2030 (Alsharif, Kim, & Kim, 2018, p. 7). Wind speeds in South Korea are generally pretty low, hovering around 4 meters per second or below on average. Coastal regions and islands, such as Jeju island, are better situated for wind farms since they can reach average wind speeds of 6,5 to 8 meters per second. Commercial wind farms are planned offshore at Hangyeong-myeong, Hanlim-eup and Deajong-eup (ibid., pp. 16–17).

4.2.2. Indicator 1: Supply

The Korea Energy Economics Institute (KEEI) offers data on production, imports, exports, international bunkers, stock changes, and statistical differences for coal, petroleum and its products, LNG, city gas, hydropower, nuclear power, electricity, heat, and renewables (KEEI, 2017, pp. 50-51). The data is presented both in actual mass and electrical energy values as well as in tons of oil equivalent. Domestic production of coal in 2016 amounted to 1.726.000 tons and imports to 127.892.000 tons. Stock changes led to a subtraction of 286.000 tons and statistical differences added 97.000 tons. Overall this amounts to 129.428.000 tons of coal or 81.872.000 toe (ibid.).

The data on petroleum includes no domestic production, with imports reaching 1.492.220.000 barrels of oil, exports measuring 487.716.000 barrels. Reductions in international bunkers account for 62.494.000 barrels and stock changes led to an increase by 2.625.000 barrels. Statistical differences account for a decrease of

20.462.000 barrels. Overall the total petroleum supply amounts to 924.173.000 barrels of oil, which equals 119.108.000 tons of oil equivalent (ibid.).

LNG features a small domestic production of 118.000 tons and imports accruing 33.453.000 tons. Stock changes amount to a net plus of 1.339.000 tons and statistical differences decrease the total by 5.000 tons. In total, the primary supply of LNG amounted to 34.906.000 tons or 45.518.000 toe (ibid.).

Hydropower in South Korea amounted to 6.634 GWh in 2016. No imports, exports, bunkers or stock changes need to be taken into account. The ton of oil equivalent value is given at 1.400.000 toe. Nuclear power generated 161.995 GWh in total. With no additional changes that need to be considered, the oil equivalent is presented at 34.181.000 toe. Renewable sources, including solar, PV, wind, biomass, waste, geothermal and tidal energy, accounted for 13.575.000 toe in total (ibid.).

Adding these values, the overall total primary energy supply for South Korea in 2016 is 294.654.000 toe. According to the Korean Statistical Information Service (KOSIS) database, the total population of South Korea was 51.269.554 in 2016 (Korean Statistical Information Service [KOSIS], 2018d). Dividing the TPES by the population, the result is 5,74715 toe or 5.747,15 kgoe/capita.

4.2.3. Indicator 2: Final Energy Consumption

Final energy consumption is measured by combining the energy consumption of all economic sectors. The KEEI splits these sectors into an industry, transportation, residential, commercial and public sector (KEEI, 2017, pp. 50-51).

The industry sector compromises the agriculture and fishery, mining, manufacturing, and construction sector. Agriculture and fishery accounted for 2.719.000 toe in 2016. The mining sector used 212.000 toe. The manufacturing sector features eleven subsectors: food & tobacco; textile & apparel; wood & wood products; pulp & publications; petro. chemical; non-metallic; iron & steel; non-ferrous; fabricated metal; other manufacturing; other energy. Overall, the manufacturing sector used 40.748.000 tons of coal, 514.457.000 barrels of petroleum, 386.000 tons of LNG, 7.222 million cubic meters of city gas, and 252.824 GWh of electricity. Totaling and converting these values, the amount equals 120.372.000 toe. The construction sector amounted to an additional 2.746.000 toe (ibid.). The industry sector overall accounted for 138.469.000 toe of the FEC.

The transportation sector is split into rail, land, water and air transport subsectors. Rail travel consumed 725.000 barrels of petroleum and 2.689 GWh electricity, which converted and combined equals 335.000 toe. Land transportation accounted for 247.715.000 barrels, 1.217 million cubic meters of city gas, 443.000 toe of renewable energy sources, and in total 34.369.000 toe. The water transportation subsector consumed 21.569.000 barrels of petroleum or 3.351.000 toe. Air travel adds another 33.569.000 barrels to the transportation sector, which equals 4.659.000 toe (ibid.). Overall the transportation sector accounts for 42.714.000 toe.

The residential sector in 2016 consumed 1.255.000 tons of coal, 28.068.000 barrels of petroleum, 9.249 million cubic meters of city gas, 66.173 GWh of electricity, 1.484.000 toe of heat energy and 231.000 toe of renewable energy (ibid.). After conversion, these values add up to 21.256.000 toe.

The commercial sector accounted for 17.934.000 barrels of petroleum, 3.494 million cubic meters of city gas, 127.435 GWh of electricity, 187.000 toe of heat energy and 167.000 toe of renewable energy consumption (ibid.). These values total 17.005.000 toe after conversion.

Lastly, the public sector utilized 10.253.000 barrels of petroleum, 84 million cubic meters of city gas, 30.767 GWh of electricity, 39.000 toe of heat energy and 2.032.000 toe of renewable energy (ibid). Converted, this amounts to 6.237.000 toe overall.

After adding the various sectors, the total FEC equals 225.681.000 toe. Divided by the total population of 51.269.554, the resulting value is 4,40158 toe/capita or 4.401,85 kgoe/capita.

4.2.4. Indicator 3: Electricity per Capita

In 2016, 80.039.000 tons of coal, 19.307.000 barrels of petroleum, 15.507.000 tons of LNG, and 2800 cubic meters of city gas were expended in the production of electricity. Additionally, hydropower and nuclear power plants produced 6.634 GWh and 161.995 GWh respectively. Heat and renewable energy to the amount of 1.126.000 toe and 2.639.000 toe, respectively, were transformed to generate electricity. This amounts to a total electricity generation of 540.441 GWh (KEEI, 2017, pp. 50–51).

Electricity consumed by end users amounted to 15.397 GWh by the agriculture and fishery sector, 1.755 GWh in the mining sector, and a total of 252.824 GWh in the manufacturing sector, combining all the various subsectors. This adds to 269.975 GWh for the whole industry sector. The transportation sector consumed 2.689 GWh, solely in the rail transport subsector. The residential sector accounted for 66.173 GWh, and the commercial sector for 127.435 GWh. Additionally, the public sector accounted for 30.767 GWh (ibid).

Overall, the total amounts to 497.039 GWh in 2016. The difference between the amount produced and consumed will be presumed to be losses. Converted, this value equals to around 42.745.000 toe. Dividing by the total population, the resulting value is 0,83373 toe/capita or 833,73 kgoe/capita.

4.2.5. Indicator 4: Resilience

Governmental coal stockpiles were reduced to around 900.000 tons in 2015 (MOTIE, 2016, p. 3, 2017b, p. 7). Additional private stockpiles by coal-producing companies add an additional 800.000 tons for a total of around 1.7 million tons (Im, 2016). With an average energy density of 25,8 GJ per ton, this amount converts to 43.860.000 GJ or 1.047.578,1 toe.

Petroleum stockpiling by the Korea National Oil Corporation features a capacity of 146 million barrels and current stockpile levels are at 96 million barrels (KNOC, 2019). Private stockpiles from companies such as SK Energy, GS Caltex, S-Oil, and Hyundai Oilbank, hold additional stocks for industrial operations (USEIA, 2018a, p. 10). Petroleum stockpiles from private sources are estimated at around 86 million barrels. In addition, international producers store some of their oil in governmental strategic petroleum reserves as part of an international joint stockpile project. These additional stockpiles are not counted towards the IEA stockholding requirements however (Doshi & Six, 2017, pp. 19–20). The total then amounts to 182 million barrels of oil and oil product stockpiles. As one barrel amounts to an average of 6,11 GJ, the total converts to 1.112.020.000 GJ. This amount equals 26.560.141,39 toe.

Natural gas storage capacities in the form of underground storage do not exist in South Korea and there are no governmental or mandatory stocks. There are LNG storage tanks at LNG terminals, which in 2012 amounted to 64 tanks at four terminals, with a total capacity of 9,3 million cubic meters of LNG (5,8 billion cubic feet of natural gas). The level of these stocks varies between 585 and 920 million cubic feet of natural gas, depending on demand (IEA, 2014, p. 300). Natural gas hovers around 1000 BTU per cubic foot (American Physical Society, 2018). Taking the average value of stock levels, 752,5 million cubic feet and converting the resulting 752,5 billion BTU, the result equals 18.950,08 toe (IEA, 2018d). LP gas is also held in stockpile. Storage in South Korea is being held by KNOC, SK Gas and E1. The total storage by KNOC amounts to 360.000 tons, SK Gas adds another 466.000 tons, and E1 possess a stockpile of around 392.000 tons (Park & Chung, 2014, p. 296). This amounts to an overall stock of 1.218.000 tons. LP gas features an energy density of around 25 GJ, which converts the total to 30.450.000 GJ or 727.285,75 toe (Hofstrand, 2008).

The self-reported South Korean uranium stocks as of 2015 included 2000 tons of natural uranium and 6000 tons of enriched uranium (IAEA/NEA, 2016, p. 106). South Korea has no uranium enrichment capabilities as per the Korea-U.S. Atomic Energy Agreement, which was enacted in 1973 and renewed in 2015 (WNA, 2019b). As all of Korea's reactors are light-water types, the energy value of the enriched uranium is around 3900 GJ per kilogram. In addition, natural uranium used within these systems has a potential of 500 GJ per kilogram (WNA, 2018a). With 2000 tons of natural uranium and 6000 tons of enriched uranium, the total energy value equals 23.400.000.000 GJ. This in turn converts to 558.899.398,1 toe.

Estimates put the proven reserves of coal in South Korea at 326 million tons (BP, 2018b). Earlier reports show reserves of 126 million tons of sub-bituminous and lignite coals, but numbers have consistently been stated higher since 2016 (BP, 2016, 2017; USEPA & CMOP, 2015, p. 250). Taking the average heat value of 25,8 GJ per ton and after conversion, the total reaches 77.644.024,07 toe.

Oil reserves at the Donghae-1 oil and gas field are estimated at 480.000 barrels of oil (KNOC, 2018). This amount converts to 70.048 toe. KNOC puts the gas reserves at the Donghae-1 field at 450.000 barrels of oil equivalent, but the total Korean gas reserves are estimated by the Oil and Gas journal to be around 250 billion cubic feet (Xu & Bell, 2017). The conversion factor for billion cubic feet to million tons of oil equivalent is 0,025 (Qatar Petroleum, 2018). This results in 6.250.000 toe.

Uranium reserves, which are excavatable, are estimated between 27.000 and 63.000 thousand tons (IAEA, 2019). Taking the average of 45.000 tons and the heat value of natural uranium at 500 GJ per kilogram, the total equals 22.500.000.000 GJ or 537.403.267,41 toe.

Adding all stockpile and reserve values, the total is 1.331.865.175,56 toe. Divided by the FEC of 225.681.000 toe, the resulting resiliency value is 5,9 years.

4.2.6. Indicator 5: Reserve Production (Oil)

2016 production levels in South Korea hovered at around 165 barrels per day. 2016 reserves are estimated at around 100.000 barrels of oil, which leads to a reserve of around 606 days or 1,6 years (KNOC, 2018).

4.2.7. Indicator 6: Reserve Production (Natural Gas)

Gas reserves are estimated at 250 billion cubic feet or 6.250.000 toe (Xu & Bell, 2017). 2016 gas production by KNOC was 640.000 barrels of oil equivalent or 87.312,41 toe. Reserve levels at the currently operated gas fields amount to 1.3 million boe of reserves or 177.353,34 toe (Organization of the Petroleum Exporting Countries [OPEC], 2019). Reserve production here would amount to 2,1 years. Accounting for total estimated gas reserves and these production levels, the reserve production equals 71,58 years.

4.2.8. Indicator 7: Reserve Production (Coal)

The BP Statistical Review puts coal reserves in South Korea at 326 million tons (BP, 2018b). Production by the Korea Coal Corporation was 1.008.000 tons in 2016. Furthermore, private coal production added 718,000 tons of coal. Dividing the total reserves by the total production of 1.726.000 tons, the resulting value is 191,76 years of reserve production.

4.2.9. Indicator 8: Dependency

Imports in 2016 amounted to 1.078,1 million barrels of crude oil, mostly from the Middle East, which equals 198.211.000 toe. LNG imports of around 33,5 million tons from Qatar, Australia, and Indonesia account for 43.623.000 toe after conversion. Additionally, coal imports amounted to 118,5 million tons bituminous, mainly from Australia, Russia, and Indonesia, as well as 9,4 million tons anthracite from China, Australia and Russia. The totaling amount of 127,9 million tons equals 81.311.000 toe. (KEEI, 2017, pp. 6, 23). Overall, imports total 323.145.000 toe.

Exports of petroleum products, which include LPGs, gasoline, kerosene, diesel, jet oil, etc., amount to 487.716.000 barrels or 67.481.000 toe (KEEI, 2017, p. 23, 2018, p. 100).

After subtracting these exports from total imports, the remaining value is 255.664.000 toe. With TPES being 294.654.000 toe, the Net Energy Import Dependency is 86,76%.

Including nuclear energy as an imported source, which adds an additional 34.181.000 toe, the dependency increases to 98,36% (KEEI, 2017, p. 53).

4.2.10. Indicator 9: Diversification

To calculate this metric, the share of renewable energy within TPES is required. Solar energy accounted for 28.500 toe in 2016. PV systems added 1.092.800 toe. Biomass energy generation accounted for 2.765.500 toe and waste recovery for another 8.742.700 toe. Other renewable energy sources, including wind, fuel cells, geothermal and tidal energy added 945.700 toe. Lastly, hydropower generation constituted a further 1.400.000 toe (KEEI, 2017, pp. 27, 45). Overall, the renewable energy totaled 14.975.200 toe.

TPES was established at 294.654.000 toe, which puts the share of renewable energy at 5,08%.

4.2.11. Indicator 10: Exports

KEEI data shows that petroleum product exports amounted to 487.716.000 barrels or 67.481.000 toe in 2016 (KEEI, 2017, p. 23, 2018, p. 100). According to the UN Comtrade database, South Korean energy exports can be categorized into 15 groups. The largest export falls under the category "petroleum oils and oils from bituminous minerals, not crude; preparations n.e.c, containing by weight 70% or more of petroleum oils or oils from bituminous minerals; these being the basic constituents of the preparations; waste oils" with an export value of 25.528.128.374 USD (UNSD, 2019b). The following group with a value of 763.728.787 USD is "oils and other products of the distillation of high temperature coal tar; similar products in which the weight of the aromatic constituents exceeds that of the non-aromatic constituents" (ibid.). The third largest export category falls under "Petroleum gases and other gaseous hydrocarbons" with a value of 338.025.428 USD (ibid.).

Smaller groups encompass “petroleum jelly; paraffin wax, micro-crystalline petroleum wax, slack wax, ozokerite, lignite wax, peat wax, other mineral waxes, similar products obtained by synthesis, other processes; coloured or not” at 23.083.389 USD, “pitch and pitch coke; obtained from coal tar or from other mineral tars” at 9.380.836 USD, “tar distilled from coal, from lignite, peat and other mineral tars, whether or not dehydrated or partially distilled; including reconstituted tars” at 9.373.231 USD, “bituminous mixtures based on natural asphalt; on natural bitumen, on petroleum bitumen, on mineral tar or on mineral tar pitch (e.g. bituminous mastics, cut-backs)” at 6.065.598 USD, and seven smaller categories at levels below 1 million USD each (ibid.).

Overall these exports amount to 26.679.036.921 USD of fossil fuel exports.

4.2.12. Indicator 11: Primary Energy Intensitys

Calculating the primary energy intensity, requires South Korea’s total GDP for 2016. The Korean Statistical Information Service puts the GDP at 1.641.786 billion Won or 1.414 trillion USD (KOSIS, 2019b). Adjusted for PPP, this value climbs to 1,903 trillion USD, which is also the value that the OECD uses (OECD, 2018a, 2019b). The author will use the latter value for calculation. Dividing the TPES of 294.654.000 toe by the GDP, the result is 0,1548 kgoe/USD or 6,48 MJ/USD.

4.2.13. Indicator 12: Final Energy Intensity

Using the GDP adjusted for purchase power parity of 2016 and the FEC of 225.681.000 toe, the result of dividing those values leads to the final energy intensity. This value is 0,11859 kgoe/USD or 4,96 MJ/USD.

4.2.14. Indicator 13: Transportation Energy Intensity

According to the Korean Statistical Information Service, the transportation and storage sector accounted for 59.230,7 billion Won (KOSIS, 2018c). While the storage sector could not been split from the transportation sector in the data, the author has chosen to still use the available data. Adjusted for 2016 PPP, this equals 68.668.482.986 USD. The transportation sector amounted consumed 42.714.000 toe in 2016 (KEEI, 2017, p. 34). Dividing these two values, the result is 0,622 kgoe/USD or 26,04 MJ/USD.

4.2.15. Indicator 14: Commercial Energy Intensity

The commercial sector, including the public sector accounted for 23.242.000 toe of energy consumption (KEEI, 2017, p. 51). The total economic product of the sector amounted to 823.228.1 billion Won (KOSIS, 2018c). This equals a PPP of 954.412.034.084 USD in 2016. After dividing these values, the energy intensity for the commercial sector is 0,0243 kgoe/USD or 1,01 MJ/USD.

4.2.16. Indicator 15: Agriculture Energy Intensity

The agriculture sector accounted for 31.647 billion Won in 2016 (KOSIS, 2018c). After considering the PPP, this value equals 36.692.173.913 USD. The energy used within the agricultural sector amounted to 2.719.000 toe (KEEI, 2017, p. 51). Dividing this sector's GDP by energy consumption, the resulting intensity is 0,074 kgoe/USD or 3,09 MJ/USD.

4.2.17. Indicator 16: Industrial Energy Intensity

The industrial sector encompasses mining, manufacturing and construction. Mining accounted for 2.802,1 billion Won, manufacturing for 439.700,3 billion Won and construction for 84.374,3 billion Won (KOSIS, 2018c). Overall, this amounts to 526.876,7 billion Won, which in 2016 USD PPP equals 610.836.125.442 USD. Energy expenditure amounted to 135.750.000 toe (KEEI, 2017, p. 51). After division, the resulting industrial energy intensity is 0,222 kgoe/USD or 9,3 MJ/USD.

4.2.18. Indicator 17: Household Consumption

The number of households in South Korea in 2016 was 19.837.665 (KOSIS, 2018d). The total energy expenditure in the residential sector in 2016 amounted to 21.256.000 toe (KEEI, 2017, p. 51). The resulting household consumption is 1071,49 kgoe per household.

4.2.19. Indicator 18: Household Energy

With a population of 51.269.554 and the number of households being 19.837.665, the average members per household is 2,58. To calculate the per capita value, the previously established household consumption of 1071,49 kgoe, is divided by the average members per household, which yields a result of 414,59 kgoe/capita.

4.2.20. Indicator 19: Household Electricity

Total electricity consumption in 2016 within the residential sector in South Korea amounted to 66.173 GWh or 66.173.000.000 kWh (KEEI, 2017, p. 51). With the number of households being 19.837.665 and the average number of members in these households being 2,58, dividing the total electricity consumption by these two values leads to a per capita consumption of 1.292,91 kWh per capita.

4.2.21. Indicator 20: Grid Efficiency 1 (Loss in Transmission)

World Bank data shows that transmission losses have been stable since 2003. The 2014 entry shows a loss in transmission of 3,347% (WB, 2019b). KEPCO's own data shows a distribution loss of 3,59% in 2016 (Korea Electric Power Corporation [KEPCO], 2017a, p. 25). The Ministry' of Trade, Industry and Energy's own electric power statistics information system shows the transmission loss at 3,593% (Electric Power Statistics Information System [EPSIS], 2019a). The author will use the latter value, as the data concerns itself with all electricity providers in South Korea.

4.2.22. Indicator 21: Grid Efficiency 2 (Loss in Transformation)

Calculating the loss in transformation requires the use of the framework's formula of $(1-(FEC/TPES))\times 100$. Inserting the values required, the FEC equals 225.681.000 toe and TPES was established at 294.654.000 toe. The result of this calculation and therefore the loss in transformation is 23,4%.

4.2.23. Indicator 22: Accesss

The World Bank SE4ALL Global Tracking Framework puts the electricity access in South Korea at 100% (WB, 2019a). The Electric Power Statistics Information System also shows more household customers than households by the Korean Statistical information Service (EPSIS, 2019a). The author will utilize the value of 100% for this metric.

4.2.24. Indicator 23: Solid Fuel Usage

The Global Health Observatory data by the World Health Organization classifies South Korea as a high income country and therefore claims a solid fuel usage below five percent (WHO, 2013). The model by Rehfuess et al. also applies to Korea, with a GDP exceeding 10,500 USD per capita, which predicts a solid fuel use below five percent (2006, p. 373). The traditional Korean coal briquette, known as yeontan, used for heating and cooking dropped in usage from 77,8% in 1988 to 32,8% just five years later. By 2001, the percentage of families using yeontan was 1,5% (Lankov, 2007). For the purpose of this thesis, the author will consider the solid fuel usage in South Korea as negligible.

4.2.25. Indicator 24: Electricity Pricing

Yearly electricity consumption per capita was already calculated at 1.292,91 kWh per capita per year. The Electric Power Statistics Information System puts the price of one kWh at 121,52 Won in 2016 (EPSIS, 2019b). The International Energy Agency also supports that value in its report but shows this value before tax. Including the excise tax and value added tax, the cost of one kWh rises to 138,16 Won (IEA, 2018a, p. 182). After considering PPP and converting to USD, the price of one kWh in 2016 was 0,16 USD (OECD, 2019b).

The GDP was found to be 1,903 trillion USD and the current population was established at 51.269.554. The GDP per capita PPP is therefore 37.059,03 USD. Filling in this indicator's formula with these values, the resulting electricity pricing value is 0,55%.

4.2.26. Indicator 25: Stability

Electricity prices from 1996 to 2001 increased by 16,6% (IEA, 2016, p. 178). Between the years 2001 and 2006, prices fell by 6,3%. Prices between 2006 and 2011 increased by 3%. Finally, retail electricity prices from 2011 to 2016 increased 1,9% (IEA, 2018a, p. 183).

4.2.27. Indicator 26: Fuel Pricing

Unleaded gasoline in 2016 was valued at a pre-tax price of 529,24 Won per liter. Excise tax added 745,86 Won and the value added tax an additional 127,51 Won. The total retail price was 1.402,64 Won per liter (IEA, 2018a, p. 181). One hundred liters of petrol therefore cost 140.264 Won or 162,61 USD after conversion and accounting for PPP (OECD, 2019b).

4.2.28. Indicator 27: Land Use

The forest cover in South Korea has drastically decreased between 1940 and 1950, but overall levels since then have been declining only slightly, decreasing from 6.415.419 ha in 1953 to 6.326.285 ha in 2016 (Korea Forest Service, 2018, pp. 40–41). In 2015, of the total forest cover, 1.617.658 ha are national forests, split between 1.471.527 ha under the Korea Forest Service and 146.131 under the supervision of other governmental authorities. Non-national forests account for 4.716.957 ha, of which 467.072 ha were public forests and 4.249.885 ha private forests (ibid., pp. 42–43).

The total land mass of Korea equals 10.036.372 ha and with total forest cover amounting to 6.326.285 ha in 2016, the forest cover equals 63,03% (Korea Forest Service, 2018, p. 20).

4.2.29. Indicator 28: Water

Total water consumption in South Korea in 2016 amounted to a 37,2 billion cubic meters. This usage is split between domestic use, industrial use, agricultural use, and maintenance use. Domestic use accounted for 7,6 billion cubic meters, industrial use for 2,3 billion cubic meters and agricultural use added another 15,2 billion cubic meters. In addition, maintenance use accounted for 12,1 billion cubic meters. Of the total consumption, 12,2 billion cubic meters is stream water, 4,1 billion cubic meters from underground water sources and 20,9 billion cubic meters from dams (KOSIS, 2018e).

Access to safely managed clean water in Korea in 2015 was 98,02% with an additional 1,57% of basic access according to the WHO/UNICEF JMP. Unimproved drinking water only accounts for 0,41%. This puts the total of improved water access at 99,59% (WHO/UNICEF Joint Monitoring Programme for Water Supply Sanitation and Hygiene, 2017b). The Korean Ministry of Environment also supports these numbers, with safely managed water access numbers of 98,6% in 2014 (Ministry of Environment, 2016, p. 13).

4.2.30. Indicator 29: Climate Change 1 (CO_2 per Capita)

All fossil fuel usage in 2016 and its corresponding carbon emission factors need to be considered in order to calculate this indicator. Coal products used to generate electricity were used to an amount of 80.039.000 tons. The manufacturing industry accounted for an additional 40.748.000 tons of coal usage. Residential coal consumption amounted to 1.255.000 tons. The overall amount of coal consumed is 122.042.000 tons of coal (KEEI, 2017, pp. 50–51).

Crude oil and petroleum products were used to an extent of 19.307.000 barrels in electricity generation, with an additional 1.251.000 barrels used for heating. The industry sector used 542.566.000 barrels and the transportation sector 303.578.000 barrels. Residential use accounted for 28.068.000 barrels, commercial for 17.934.000 barrels and public for 10.253.000 barrels. The overall use amounted to 922.957.000 barrels (ibid.).

LNG was used to generate electricity, with an amount of 15.507.000 tons. District heating amounted to 1.556.000 tons. The entire industry sector accounted for an additional 386.000 tons of LNG consumed. The total is 17.449.000 tons (ibid.).

City gas was used to generate electricity to an amount of 280.000.000 cubic meters, and for heating to an amount of 253.000.000 cubic meters. 7.226.000.000 cubic meters were expended within the industry sector and 1.217.000.000 cubic meters in the transportation sector. Residential consumption amounted to 9.249.000.000 cubic meters, commercial consumption to 3.494.000.000 cubic meters and public consumption added 84.000.000 cubic meters. The total city gas consumption amounts to 21.806.000.000 cubic meters of city gas (ibid.).

The carbon emission factor for coal was established at 2.247,66 kgCO_2 per ton (BEIS & DEFRA, 2018). Given the total coal consumed, the carbon emission amount to around 274.308.921,72 tons of CO_2. A barrel of oil equals around 159 liters, which means that the total amount of crude and petroleum products amount to 146.750.163.000 liters. The carbon emission factor for fuel oil is 3,16633 kgCO_2 per liter (ibid.). This leads to the total carbon emissions of 464.659.443,61 tons of CO_2. With a carbon emission factor of 2741,56 kgCO_2 per ton, the total LNG emissions amounted to 47.837.480,44 tons of CO_2 (ibid.). Finally, city gas, with an emission factor of 2,21 kgCO2 per cubic meters added an additional 48.191.260 tons of CO_2 (TGG, 2018, p. 258). Adding these carbon emissions, the total emissions in 2016 amount to 834.997.105,77 tons of CO_2 overall. Dividing this value by the total population of 51.269.554, the results is 16,28 tons of CO_2 per capita.

Carbon emissions in 2015 accounted for 692.923.900 tons according to the Korean Statistical Information Service, of which 641.016.500 tons were produced by all industries and 51.907.400 tons by households (KOSIS, 2018a). The variance between the calculated value and the official value is assumed to be differing carbon emission factors, depending on the exact type of fuel being used. For this thesis, the author will use the calculated value.

4.2.31. Indicator 30: Climate Change 2 (CO_2 per GDP)

Dividing the total emissions of 834.997.105,77 tons of CO_2 by the 2016 GDP of 1,903 trillion USD produces a result of 0,43kg CO_2 per USD.

4.2.32. Indicator 31: Renewable Capacity

Total electricity generation capacity in Korea 2016 was 105.865.557 kW or 105.865,55 MW (KEPCO, 2018, p. 28). Hydropower generation capacity amounted to 6.485,21 MW, including large and small hydropower as well as pumped storage. Solar power capacity amounted for 3.716,31 MW. Wind generation capacity accounted for 1.051 MW, ocean/tide capacity for 255,11 MW, biomass for 382,412 MW capacity, landfill gas generation capacity for 68,956 MW, waste burn generation capacity for 177,63 MW, product gas for 1.355,5 MW capacity, and fuel cells for 214,82 MW capacity (KEPCO, 2017b, pp. 30–43). Combining all these values, the total renewable capacity is 13.965,29 MW. Measured against the total amount of generation capacity, renewable capacity is at 13,19%.

4.2.33. Indicator 32: Non-Carbon Energy

Non-carbon-based energy includes hydropower, nuclear power and renewables. Hydropower accounted for 6.634 GWh or 1.400.000 toe. Nuclear power plants produced 161.995 GWh, which converts to 34.181.000 toe (KEEI, 2017, pp. 50–54). Renewable energy, excluding waste energy recovery and biomass, includes 28.500 toe in solar energy, 1.092.800 toe in PV generated electricity, and 945.700 toe overall in wind, fuel cells, geothermal, and tidal energy (KEEI, 2017, p. 45). Adding these values, the result is 37.648.000 toe. Measured against the TPES of 294.654.000 toe, the non-carbon energy percentage is 12,77%.

4.2.34. Indicator 33: Renewables

Hydropower produced 6.634 GWh of electricity, PV accounted for an additional 5.123 GWh, tide energy for 496 GWh and wind energy for 1.683 GWh. Energy generation through municipal waste incineration accounted for 460 GWh, industrial waste for 360 GWh, solid biofuels for 3.674 GWh, biogas for 519 GWh, and liquid biofuels for 1.358 GWh. Furthermore, heat energy produced 9.983 TJ by municipal waste, 10.072 TJ by industrial waste, 3.770 TJ by solid biofuels, and 453 TJ by biogases. Finally, consumption in the economic sectors accounted for 23.362 TJ of municipal waste, 94.252 TJ of industrial waste, 37.194 TJ of solid biofuels, 1.893 TJ of biogases, 489 TJ of liquid biofuels, 6.785 TJ of geothermal energy, and 1.193 TJ of solar thermal energy (IEA, 2018c).

Converting these values, and using the partial substitution method, the total electricity converts to 4.365.219,25 toe and the heat and consumption energy values convert to 4.524.839,97 toe (IEA, 2018d). Added together, the 8.890.059,22 toe constitute 3,93% of FEC.

4.2.35. Indicator 34: Pollution

Air quality has drastically improved in South Korea since 1990 (Kim & Lee, 2018, p. 2144). Current measurements put the SO_x levels at around 0.004 parts per million (KOSIS, 2019a). Total emissions in 2015 were recorded at 351.900 tons (KOSIS, 2018b). Divided by the total population of 51.269.554, the resulting value is 6,86 kg of SO_x per capita.

4.2.36. Indicator 35: Quality of Information

Data for all indicators was available, which puts the quality of information at 100%.

4.3. Taiwan

4.3.1. Overview

Taiwan ranks 22nd on the list of energy consumers worldwide, with an energy consumption of around 114 million tons of oil equivalent in 2016 (BP, 2018b). Similar to Japan and South Korea, the island features only limited natural resources and is therefore dependent on imports of fossil fuels. Even though Taiwan has also been a proponent of the “nine-dash line”, its claim to parts of the South China Sea and the natural resources within that area, Taiwan is now an advocate of the United Nations’ maritime laws. Through the establishment of the South China Sea Peace Initiative, Taiwan’s aims are to establish joint exploration and development of these resources. The same diplomatic strategy is employed in the disputes with Japan in the East China Sea (USEIA, 2016).

During the Japanese colonial rule, 251 oil wells were drilled in 21 areas of Taiwan. Of these, seven oil and gas fields were discovered, and the 150 resulting production wells produced a total of 190.000 kl of crude oil and 1 billion cubic meters of natural gas (Yang, 1985, p. 234). In 1946, the Chinese Petroleum Corporation (CPC) established an oil and gas exploration division for Taiwan. With increased technological capabilities, present wells were deepened and additional fields, like the Tiehchenshan field in 1961 were discovered. Between 1959 and 1969, four major oil and gas fields were found (Yang, 1985, p. 234). Offshore drilling exploration was started in 1973, but first trials were unsuccessful. More promising operations were inhibited by poor profitability (Ministry of Foreign Affairs, 1981). New efforts in 2012 have been made to explore the waters around Itu Aba island for potential oil resources (Cole, 2012). Proved oil reserves today are minimal though, as is domestic production. In addition, most of this production is refinery processing gains (USEIA, 2016). Refinery processing gains are described by the Environmental Council of States (ECOS) as,

> THE VOLUMETRIC AMOUNT BY WHICH TOTAL OUTPUT IS GREATER THAN INPUT. THIS DIFFERENCE IS DUE TO THE PROCESSING OF CRUDE OIL INTO PRODUCTS THAT, IN TOTAL, HAVE LOWER SPECIFIC GRAVITY THAN THE CRUDE OIL PROCESSED. THEREFORE, IN TERMS OF VOLUME, THE TOTAL OUTPUT OF PRODUCTS IS GREATER THAN INPUT (ECOS, 2019).

Large scale coal mining operations started at the end of the nineteenth century. Limited technology, the lack of capital, and missing expertise hindered early coal mining projects (Chen, 1998, p. 182). Coal shortages during and after the First World War caused European naval transport capacity to be reduced significantly. Japanese shipping companies profited highly from these circumstances while coal was being shipped to Japan from its colonies, including Taiwan. As coal demand in Southern Asia rose after the war, Japan could not satisfy demand with its domestic production, and Taiwan became a major coal exporter within the Indian ocean under the rule of Japanese authorities, stimulating the coal industry on the island (Chen, 1998, p. 183). After a short economic downturn, production increased from 1921 to 1926. Economic and political disputes in China caused a slump in exports after that period, which resulted in the closure of two-thirds of coal mines (ibid., p. 188). With the founding of the Taiwanese Coal Mining Association in 1933, coal production was supposed to increase competitiveness and control production. Both the heavy industries in Japan and the continued industrialization in Taiwan required increased production levels. With the begin of the Sino-Japanese war, estimated yearly output reached two million tons until production was halted after the destruction of mines during the Second World War (ibid., p. 189).

In the post-war period, Taiwan restarted its mining industry, leading to the construction of over 400 mines, which employed around 60.000 miners during the 1960s and 1970s period (S. Yu, 2002). Production levels reached around 5 million tons per year during this period, but fell in the upcoming decades to less than 0,1 million tons in 1997 (Wu, 2000, p. 150). In addition to the rising costs of coal production, three major mining explosions in 1984, which led to the death of 180 miners played another part in the decline. Consequently, imported coal was favored. The last coal mine closed in 2000, when the Lifong Coal Company stopped its production (S. Yu, 2002).

Taiwan is the fifth largest importer of LNG worldwide (IGU, 2017). Domestic production, reaching around 350-400 million cubic meters, is dwarfed by these imports (E. Hsu & Lin, 2015). The consumption of natural gas has rapidly increased since 1990 and experienced another boost in 2007 (Bureau of Energy/Ministry of Economic Affairs [BEMEA], 2018i; CEIC, 2019). Similar to other countries, most of the natural gas today is being used for power generation, while early natural gas utilization was mainly focused on the residential and industrial sector (USEIA, 2008, p. 5).

The first nuclear power plant began construction in 1972, which began operation in 1978 under the control of Taipower. This Chinshan 1 and 2 power plant was granted a forty-year operating license, which would have been prolonged by an additional 20 years after a safety evaluation by the Atomic Energy Council. A 2011 national energy policy has removed the possibility of such an extension, which led to the closure of the Chinshan power plant in 2018. Currently, two other nuclear power plants (Kuosheng 1 and 2; Maanshan 1 and 2), which were established between 1981 and 1985, are providing electricity for Taiwan. Licenses for these power plants are set to expire between 2021 and 2025 (WNA, 2018c). After the election in 2016, the incoming government had plans to phase out nuclear power completely while waiting for licenses to expire. The power plant Lungmen 1 and 2, which, at that point, was under construction, was ultimately deferred by Taipower under regulations of the previous government. A public referendum was conducted in 2018, determining the future of nuclear power in Taiwan, in which 59% of the population voted for the continued use of nuclear energy (WNA, 2018c).

Shortly after the Second World War in the pacific theater ended, hydropower became the main source of electricity in Taiwan in the following decades. In 1962, thermal power first surpassed hydropower generation, as Taiwan lacked further hydro-capacity (Chang, 2017, p. 61). Environmental concerns made large-reservoir projects unfeasible, which prompted the construction of low yield hydropower plants under 20MW (ITRI, 2009). Solar power is being heavily pursued and installed capacity has more than doubled between 2012 and 2015. Current plans aim for a total PV capacity of 2500 MW by 2025 (BEMEA, 2013; IEA PVPS, 2018, p. 3). There are currently 352 onshore wind turbines with a capacity of 696 MW on Taiwan. Current plans aim to increase this capacity to 1200 MW by 2025. In addition, offshore wind projects are making an effort to drastically increase the share of wind power. Planned offshore wind farms are anticipated to create a capacity of around 3000 MW by 2025 (ITRI, 2019).Currently, the Formosa demonstration wind park is the only offshore site producing electricity. At this time, it features 8MW capacity and after completion of the second phase, 120 MW are to be added in 2019 (Pan & Kao, 2017). Geothermal energy has been drilled for in 1976 by the CPC. The first geothermal power plant was started in 1981 but low efficiency led to its closure in 1993 (Central News Agency, 2017). In 2018, explorations have begun around Yilan county in order to explore geothermal potential (Tsai & Hsu, 2018).

4.3.2. Indicator 1: Supply

The Taiwanese Bureau of Energy under the Ministry of Economic Affairs publishes its annual energy balance sheet providing both original units and units in oil equivalent kiloliters. It includes coal and coal products, crude oil and petroleum products, natural gas, biomass and waste. Electricity generation is divided into nuclear, hydro, geothermal, solar PV and wind generation. In addition, solar thermal and heat data is provided. In addition to stock changes, both marine and aviation bunker stocks are presented (BEMEA, 2018h, 2018i). As per the ministry's own conversion table, 1.000 kiloliters of oil equivalent will be equaled with 900 tons of oil equivalent (BEMEA, 2017, p. 12).

In regard to coal and coal products, no domestic production was reported. Imports of coal amounted to 6.581.500 tons of bituminous coking coal and 46.235.700 tons of bituminous steam coal. Anthracite made up 284.300 tons of coal imports. Sub-bituminous coal accounted for 12.532.400 tons and coke added 200.500 tons to the overall imports. Exports were miniscule, with 1.200 tons of anthracite and 300 tons of coke being reported. Stock changes accounted for an extra 67.700 tons of bituminous coking coal, a reduction of 1.187.600 tons of steam coal, 1.500 tons reduction of anthracite, an extra 1.442.900 tons of sub-bituminous coal and a reduction of 7.100 tons of coke. Loss and statistical differences demonstrated a reduction of the coking coal value by 73.700 tons, an increase of 133.000 tons of steam coal, a reduction of 36.600 tons of anthracite, a reduction of 773.900 tons of sub-bituminous coal and an increase of 177.600 tons of coke. The final TPES values for each category amount to 6.513.700 tons of bituminous coking coal, 47.423.300 tons of bituminous steam coal, 284.500 tons of anthracite, 11.089.500 tons of sub-bituminous coal and 207.300 tons of coke (BEMEA, 2018h, p. 29). These values differ slightly from the expected values by adding all subtotals. The document does not give an explanation for this difference, but as these values are presented under the TPES header, they will be used within this thesis. In total, coal and coal products amounted to 65.518.300 tons in 2016. As per the oil equivalent table, the TPES is valued at 42.981.600 kloe. The conversion into tons of oil equivalent results in 38.683.440 toe (BEMEA, 2018i, p. 29).

Crude oil and petroleum products featured small domestic productions with 8.500.000 kl produced domestically and 77.800.000 kl produced in refinery feedstocks. 49.828.000 kl of crude oil were imported. Further imports include 3.126.300 kl of LPG, 16.547.800 kl of naphtha, 166.700 kl of motor gasoline, 263.600 kl of jet fuel, 1.772.700 kl of fuel oil, 374.100 kl of lubricants, 77.900 kl of asphalts, 1.615.400 kl of solvents, 45.400 kl of petroleum coke and 876.400 kl of other petroleum products. Exports amounted to 7.200 kl of LPG, 6.027.200 kl of motor gasoline, 1.141.100 kl of jet fuel, 10.634.900 kl of diesel, 1.331.100 kl of fuel oil, 638.700 kl of lubricants, 336.800 kl of asphalts, 52.200 kl of solvents, 508.800 kl of petroleum coke and 140.900 kl of other petroleum products. International marine bunkers added 109.900 kl of diesel and 1.253.700 kl of fuel oil. Aviation bunkers accounted for an additional 3.434.300 kl of aviation gasoline. Negative stock changes amounted to 156.900 kl of crude oil, 500 kl of refinery feedstock, 53.800 kl of LPG, 92.500 kl of diesel, 107.700 kl of fuel oil, 5.700 kl of lubricants, 37.100 kl of asphalts, 8.000 kl of solvents, and 200.000 kl of other petroleum products. Positive stock changes included 27.600 kl of naphtha, 193.300 kl of motor gasoline, 44.600 kl of jet fuel, 3.300 kl of kerosene, and 27.300 kl of petroleum coke. In addition, negative losses and statistical differences were recorded at 82.000 kl for crude oil, 200 kl for refinery feedstock, 600 kl for LPG, 126.700 kl for motor gasoline, 800 kl for kerosene, 158.900 kl for diesel, and 155.200 kl for fuel oil. Positive statistical differences include 64.300 kl of naphtha and 4.800 kl of jet fuel. Total final TPES values are provided as 49.993.300 kl of crude oil, 78.300 kl of refinery feedstock, 3.172.900 kl of LPG, 16.520.200 kl of naphtha, –6.056.900 kl of motor gasoline, –4.356.300 kl of jet fuel, –3.300 kl of kerosene, –10.652.300 kl of diesel, –707.400 kl of fuel oil, –259.000 kl of lubricants, –221.900 kl of asphalts, 1.571.200 kl of solvents, –490.800 kl of petroleum coke, and 935.500 kl of other petroleum products (BEMEA, 2018h, p. 29). Overall, crude oil and petroleum products supply make up 49.526.500 kl. Crude oil and petroleum products feature an oil equivalent value of

48.325.200 kloe, which after conversion results in 43.492.680 toe (BEMEA, 2018i, p. 29).

Natural gas was domestically produced to an extent of 321.500.000 cubic meters. LNG imports measured 19.744.300.000 cubic meters. While not explicitly stated, this value represents the total amount of natural gas, after transformed back from its liquefied form. The reasoning for this assumption by the author is the fact that, transformed into tons, an import amount of 8.8 billion tons of LNG would exceed the LNG imports of Japan, known as the largest importer worldwide, by a hundredfold. As this is neither realistic nor supported by the converted value in kloe, the author has concluded that the values represent natural gas in its original form, converted back from LNG. Using the conversion table by the International Gas Union supports this assumption (IGU, 2012). Stock changes accounted for a loss of 48.300.000 cubic meters of natural gas and a loss of 17.200.000 cubic meters of LNG. Statistical differences and loss accounted for a gain of 800.000 cubic meters of natural gas and of 1.813.560 cubic meters of LNG (BEMEA, 2018h, p. 29). Total TPES for natural gas measured 369.800.000 cubic meters of natural gas and 33.594.550 cubic meters of LNG. Natural gas TPES in kloe equaled 20.090.200, which converts to 18.081.180 toe (BEMEA, 2018i, p. 29).

Biomass and waste energy accounted for 1.739.000 kloe or 1.565.100 toe. No statistical differences or losses need to be taken into account. Imports only measured 100 kloe of the overall value (BEMEA, 2018i, p. 29).

Nuclear energy produced 31.661,4 GWh of electricity in 2016. The converted value to kloe follows the partial substitution method and is given at 9.169.100 kloe or 8.252.190 toe after conversion. This is counted as imported energy by the Taiwanese Bureau of Energy. It can only be assumed this is due to the fact that all fissile material needs to be imported. Hydropower produced 6.562 GWh or 627.300 kloe, solar PV accounted for 1.132,2 GWh or 108.200 kloe, and wind energy produced 1.457,1 GWh or 139.300 kloe. After conversion, hydropower accounted for 564.570 toe, solar PV for 97.380 toe, and wind for 125.370 toe. Solar thermal energy added 112.100 kloe, which converts to 100.890 toe (BEMEA, 2018h, p. 29, 2018i, p. 29).

Overall, TPES amounts to 110.962.800 toe. Official statistics by the Department of Household Registration Affairs calculated a population of 23.539.816 inhabitants in 2016 (2019). Dividing TPES by the total population leads to a value of 4,71383 toe/capita or 4.713,83 kgoe/capita.

4.3.3. Indicator 2: Final Energy Consumption

The Bureau of Energy differentiates between five economic sectors in their energy use; the industrial sector, the transportation sector, the agricultural sector, the service sector, and the residential sector. Additionally, non-energy use is treated as a separate sector (BEMEA, 2018h, p. 30). The industrial sector consumed 10.228.500 tons of bituminous steam coal, 277.200 tons of anthracite, 648.100 tons of coke, 1.738.500.000 cubic meters of coke oven gas, 3.224.400.000 cubic meters of blast furnace gas and 331.700.000 cubic meters of oxygen steel furnace gas. The energy value of this consumption was 8.792.000 kloe or 7.912.800 toe. Of crude oil and petroleum products, the industrial sector consumed 3.900.000 cubic meters of refinery gas, 381.200 kl of LPG, 6.200 kl of motor gasoline, 1.200 kl of jet fuel, 113.800 kl of diesel oil, 1.549.000 kl of fuel oil, 63.000 tons of petroleum coke and 13.500 kl of other petroleum products. The total energy value of these petroleum products equals 2.119.300 kloe or 1.907.370 toe. Natural gas was consumed to an extent of 525.100.000 cubic meters of natural gas and 3.378.580 cubic meters of LNG, which in total values 1.859.200 kloe or 1.673.280 toe. Biomass and waste add another 520.100 kloe or 468.090 toe. In addition, the industrial sector consumed 136.890,1 GWh of electricity, which is valued at 13.086.700 kloe or 11.778.030 toe. Heat energy consumption in this sector amounted to 274.800 kloe or 247.320 toe (BEMEA, 2018i, p. 30, 2018h, p. 30). The total consumption within the industrial sector adds up to 23.986.890 toe.

The agricultural sector did not consume any coal or coal products, natural gas, or biomass and waste. It accounted for 600 kl of LPG and 300 kl of motor gasoline. 372.500 kl of diesel oil were consumed, as were 30.100 kl of fuel oil. The energy value of this consumption adds to 380.400 kloe or 342.360 toe. Natural gas consumption accounted for 6.460 cubic meters of LNG which equals 2.900 kloe or 2.610 toe in energy value. Electricity consumption amounted to 2.922,7 GWh, which is converted to 279.400 kloe or 241.460 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). The total consumption in the agricultural sector amounts to 596.430 toe.

The transportation sector consumed no coal or coal products, natural gas or biomass and waste. Of crude oil and petroleum products, 59.500 kl of LPG, 10.444.200 kl of motor gasoline, 119.800 kl of jet fuel, 4.788.600 kl of diesel oil, and 97.400 kl of fuel oil were consumed. The energy value of these products amounts to 13.775.400 kloe or 12.397.860 toe. Electricity consumption amounts to 1.361,4 GWh or 130.200 kloe, which equals 117.180 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). The total consumption adds up to 12.515.040 toe.

The service or commercial sector did not consume any coal or coal products and no biomass or waste. The petroleum products consumed amounted to 115.000 kl of LPG, 38.300 kl of motor gasoline, 168.700 kl of jet fuel, 6.700 kl of kerosene, 392.200 kl of diesel oil, and 318.700 kl of fuel oil. This consumption totals 980.200 kloe or 882.180 toe. Natural gas consumption added 386.000.000 cubic meters and LNG accounted for 224.230 cubic meters. Converted to its energy value, this equals 359.900 kloe or 323.910 toe. Electricity consumption in the service sector amounted to 47.960 GWh, which corresponds to 4.585.000 kloe or 4.126.500 toe. Solar thermal energy was consumed to the extent of 3.400 kloe or 3.060 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). After adding these values, the service sector totals a consumption of 5.335.650 toe.

The residential sector consumed no coal or coal products and no biomass or waste. LPG was the only petroleum product consumed, amounting to 1.712.800 kl. This equals 1.262.700 kloe or 1.212.192 toe. 755.000.000 cubic meters of natural gas and 94.860 cubic meters of LNG were consumed in 2016 within this sector, which equals 550.000 kloe or 498.000 toe. Electricity consumption amounted to 47.332,4 GWh which converts to 4.525.000 kloe or 4.072.500 toe. Solar thermal energy added another 108.800 kloe or 97.920 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). Total residential consumption measures 5.880.612 toe.

Non-energy use made up 43.900 tons of anthracite and 344.200 tons of coke. The energy value equals 302.400 kloe or 272.160 toe. Crude oil and petroleum products in the non-energy use sector amounted to 2.662.700 kl of LPG, 22.597.300 kl of naphtha, 587.000 kl of lubricants, 397.100 kl of asphalts, 1.663.200 kl of solvents, 27.900 tons of petroleum coke, and 910.800 kl of other petroleum products. These petroleum products equal 25.085.300 kloe in energetic value, which converts to 22.576.770 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). The total non-energy use amounts to 22.848.930 toe.

The total final energy consumption adds up to 71.163.552 toe. Divided by the total population, the resulting value is 3,02311 toe/capita or 3.023,11 kgoe/capita.

4.3.4. Indicator 3: Electricity per Capita

In terms of power generation, 32.711.400 tons of bituminous steam coal, 11.863.400 tons of sub-bituminous coal, 704.500.000 cubic meters of coke oven gas, 7.494.800.000 cubic meters of blast furnace gas, and 727.800.000 cubic meters of oxygen steel furnace gas have been expended. In addition, 119.500.000 cubic meters of refinery gas, 132.300 kl of diesel oil, 2.498.800 kl of fuel oil, 827.200 tons of petroleum coke, and 22.700 kloe of other petroleum products were used. 2.200.000 cubic meters of natural gas and 27.548.160 cubic meters of LNG were consumed to produce electricity. Biomass and waste energy accounted for 1.218.700 kloe. Nuclear energy added 31.661,4 GWh, hydropower 9.855,7 GWh, solar PV 1.132,2 GWh, and wind added 1.457,1 GWh. Converted to oil equivalent, coal and coal products accounted for 23.733.500 kloe, crude oil and petroleum products for 3.683.700 kloe, natural gas for 16.206.700 kloe, nuclear power for 9.169.100 kloe, hydropower for 942.200 kloe, solar PV for 108.200 kloe, and wind energy for 139.300 kloe. Added together this amounts to a total expenditure to produce electricity of 53.982.700 kloe or 48.584.430 toe (BEMEA, 2018h, p. 30, 2018i, p. 30).

Total transformational output amounts to 264.130,9 GWh, which is converted to 25.250.900 kloe or 22.725.810 toe. Own-use amounted to 18.953,5 GWh or 1.812.000 kloe, which converts to 1.630.800 toe. The Industrial sector accounts for 136.890,1 GWh, the agricultural sector for 2.922,7 GWh, the transportation sector for 1.361,4 GWh, the service sector for 47.960 GWh, and the residential sector for 47.332,4 GWh. The total electricity consumed, excluding own-use, amounts to 236.466,6 GWh or 22.606.200 kloe, which equals 20.345.580 toe (BEMEA, 2018h, p. 30, 2018i, p. 30).

Divided by the total population, the resulting value is 0,8643 toe/capita or 864,3 kgoe/capita of electricity consumption.

4.3.5. Indicator 4: Resilience

Taiwan has two coal terminals in Taichung and Hsinta, which are required to hold a coal stockpile of 30 days electricity generation (Kwon & Hong, 2015, p. 15). Vice chairman of the Chinese National Federation of Industries, Mark Lin, confirms this number in an interview with the Taipei Times (C. Hsu, 2017). With around 44.574.800 tons of coal used to produce electricity for 2016, a 30 day stockpile would equal around 3.600.000 tons of coal (BEMEA, 2018h, p. 30). This amount of coal equals 2.250.000 toe, considering the average energy density of coal at 25.8 GJ per ton.

According to the Petroleum Administration Act, article 24 forces oil refinery operators and importers to maintain an oil security stockpile of at least sixty days supply, measured by the consumption of the previous year. LPG stockpiles are expected to offer twenty-five days of supply. The minimum amount is 50.000 kl for oil refineries and 10.000 kl for oil importers. Additionally, the government must maintain its own stockpile worth 30 days of consumption (Ministry of Economic Affairs, 2014). Crude oil consumption was around 50.000.000 kl in 2015. LPG consumption measured 4.067.900 kl in the same period (BEMEA, 2018h, p. 30). A sixty-day supply of crude oil therefore equals 8.200.000 kl. The LPG supply is expected to measure around 222.000 kl. With two companies importing and refining oil in Taiwan, CPC and the Formosa Petrochemical Corporation, oil supplies should measure 16.400.000 kl of crude oil and 444.000 kl of LPG (BEMEA, 2018f). 16.400.000 kl of oil equal 102.992.000 barrels, which in turn converts to 14.418.880 toe. With one kiloliter of LPG measuring 25 GJ, the total energy value is 17.500.000 GJ or 265.118 toe (Hofstrand, 2008).

LNG stockpiles measure around 10 days' worth in Taiwan (C. Hsu, 2017). LNG consumption in 2016 amounted to 18.624.400.000 cubic meters of natural gas. As one cubic meter of natural gas equals $7{,}692 \times 10^{-4}$ tons of LNG, converting the previous value yields a result of 14.325.888,48 tons of LNG (IGU, 2012, p. 22). 10 days' worth therefore makes up 392.490 tons of LNG. One ton of LNG equals 55,38 MBTU, which converts the total value to 21.736.101 MBTU (Hofstrand, 2008). This equals 547.740 toe (IEA, 2018d).

In the 1980s, 35 tons of uranium hexafluoride were bought and planned to be enriched within Taiwan, but this proposal was later abandoned. This led to the selling of these stocks (Huang & Lin, 2017). No further data on potentially existing uranium stocks could be found by the author.

Coal reserves in Taiwan are estimated at around 100 million tons, mostly consisting of bituminous coal and anthracite (*World Coal Reserves Lack Credibility*, 1997, p. 271). With an average energy value of 25,8 GJ, the total equals 2.580.000.000 GJ or 61.622.241 toe.

Oil reserves are hovering around 2.380.000 barrels (Xu & Bell, 2017). One barrel features an energy value of 6,11 GJ, which in turn means that reserves equal 14.541.800 GJ or 347.324 toe.

Gas reserves are estimated at 220 billion cubic feet (Xu & Bell, 2017). With a conversion factor of 0,025 of billion cubic feet to million tons of oil equivalent, the resulting value is 5.500.000 toe (Qatar Petroleum, 2018).

Taiwan does not have naturally occurring uranium deposits (Russian Federation Foreign Intelligence Service, 1995).

The total stockpiles and reserves add up to a total of 84.951.303 toe. Divided by the FEC, the resulting value is 1,19 years.

4.3.6. Indicator 5: Reserve Production (Oil)

Domestic production was miniscule with around 8500 kl in 2016, which equals approximately 54.000 barrels (BEMEA, 2018a, p. 2). Considering the reserves of 2.380.000 barrels (Xu & Bell, 2017). At 2016 production levels, reserves would last 44 years.

4.3.7. Indicator 6: Reserve Production (Natural Gas)

With estimated natural gas reserves of 220 billion cubic feet, which equals 6.226.000.000 cubic meters and a domestic production of 321.500.000 cubic meters, the resulting reserve production is 19,36 years (IGU, 2012; Xu & Bell, 2017).

4.3.8. Indicator 7: Reserve Production (Coal)

Coal reserves are estimated at around 100 million tons (*World Coal Reserves Lack Credibility*, 1997, p. 271). Coal production has been halted completely in Taiwan since 2000 (BEMEA, 2018j; S. Yu, 2002). Hence, no reserve production can be calculated.

4.3.9. Indicator 8: Dependency

Imports of coal products in 2016 amounted to 6.581.500 tons of bituminous coking coal, 46.235.700 tons of bituminous steam coal, 284.300 tons of anthracite, 12.532.400 tons of sub-bituminous coal, and 200.500 tons of coke. The energy value of these imports amounted to 43.036.900 kloe or 38.733.210 toe (BEMEA, 2018h, p. 29).

Oil and petroleum product imports encompass 49.828.000 kl of crude oil, 3.126.300 kl of LPG, 16.547.800 kl of naphtha, 166.700 kl of motor gasoline, 263.600 kl of jet fuel, 1.772.700 kl of fuel oil, 374.100 kl of lubricants, 77.900 kl of asphalts, 1.615.400 kl of solvents, 45.400 kl of petroleum coke and 876.400 kl of other petroleum products. Overall, these imports value 71.637.300 kloe or 64.473.570 toe (BEMEA, 2018h, p. 29).

LNG imports add up to a converted amount of 19.744.300.000 cubic meters of natural gas, which equals 14.957.800 kloe or 13.462.020 toe (BEMEA, 2018h, p. 29).

A small amount of biomass and waste was imported in 2016, amounting to about 100 kloe or 90 toe.

Exports of coal products included 1.200 tons of anthracite and 300 tons of coke, for a combined energy value of 1.200 kloe or 1.080 toe (BEMEA, 2018h, p. 29).

Crude oil and petroleum product exports measured 7.200 kl of LPG, 6.027.200 kl of motor gasoline, 1.141.100 kl of jet fuel, 10.634.900 kl of diesel, 1.331.100 kl of fuel oil, 638.700 kl of lubricants, 336.800 kl of asphalts, 52.200 kl of solvents, 508.800 kl of petroleum coke and 140.900 kl of other petroleum products. The combined energy value of these exports is 19.297.100 kloe or 17.367.390 toe (BEMEA, 2018h, p. 29).

Calculating imports minus exports, the resulting value is 99.300.420 toe. With TPES being 110.962.800 toe, the resulting import dependency is 89,48%.

Including nuclear power in this calculation, which Taiwan considers imported, featuring an energy value of 9.169.100 kloe or 8.252.190 toe, the import dependency increases to 96,92%.

4.3.10. Indicator 9: Diversification

In 2016, hydropower accounted for 6.562 GWh or 627.300 kloe, which equals 564.570 toe. Solar PV electricity generation was responsible for 1.132,2 GWh or 108.200 kloe. This equals 97.380 toe. Wind energy added 1.457,1 GWh or 139.300 kloe to renewable energy, which represents 125.370 toe. Finally, solar thermal energy accounted for 112.100 kloe or 100.890 toe. Biomass and waste energy measured 1.739.000 kloe which equals 1.565.100 toe (BEMEA, 2018h, p. 29, 2018i, p. 29). Adding these values, renewable energy amounts to 2.453.310 toe. Measured against TPES, the value represents 2,21%.

4.3.11. Indicator 10: Exports

Since Taiwan is not a member of the United Nations, no UN Comtrade data is available. The Department of Statistics within the Ministry of Economic Affairs (2019) offers its own web service presenting export data. While the classification of the various products is not as nuanced, data from 2016 shows that mineral product exports made up 9.192.000.000 USD.

4.3.12. Indicator 11: Primary Energy Intensity

To calculate primary energy intensity, Taiwan's GDP for 2016 is required. The IMF puts the 2016 GDP PPP at 1.134.190.000.000 USD (IMF, 2019b). The Directorate General of Budget, Accounting and Statistics of Taiwan, Executive Yuan puts the GDP at 171.763 billion New Taiwan Dollars (NTD), which considering the implied PPP conversion rate by the IMF of 15,129, results in a value of 1.135.322.899.814 USD (Directorate General of Budget Accounting and Statistics Executive Yuan [DGBAS], 2019; IMF, 2019a). The author will go with the latter value throughout this thesis.

Using the TPES of 110.962.800 toe or 110.962.800.000 kgoe and dividing by the GDP, the resulting primary energy intensity is 0,0977 kgoe/USD or 4,09 MJ/USD (IEA, 2018d).

4.3.13. Indicator 12: Final Energy Intensity

As with the primary energy supply, the 2016 GDP of Taiwan is required to calculate this indicator. FEC has been established at 71.163.552 toe or 71.163.552.000 kgoe. Dividing this value by the GDP of 1.135.322.899.814 USD leads to a final energy intensity value of 0,062 kgoe/USD or 2,6 MJ/USD (IEA, 2018d).

4.3.14. Indicator 13: Transportation Energy Intensity

Taiwan includes both transportation and storage within the same economic sector. Calculations within this indicator may therefore be inaccurate in representing the transportation sector itself. The author has chosen to use this data, as it is the closest approximation, nevertheless. Transportation and storage made up 2,92% of total GDP, which equals 33.151.428.674 USD (DGBAS, 2017b).

The transportation sector consumed, 59.500 kl of LPG, 10.444.200 kl of motor gasoline, 119.800 kl of jet fuel, 4.788.600 kl of diesel oil, and 97.400 kl of fuel oil. Electricity consumption amounts to 1.361,4 GWh. (BEMEA, 2018h, p. 30, 2018i, p. 30). The total consumption adds up to 12.515.040 toe.

Dividing total consumption by economic activity, the resulting energy intensity is 0,37 kgoe/USD or 15,4MJ/USD (IEA, 2018d).

4.3.15. Indicator 14: Commercial Energy Intensity

The commercial sector in 2016 accounted for 62,68% of Taiwan's GDP. The sector is split up into four sub-sectors. These include the wholesale and retail trade, transportation and storage, financial and insurance activities, and the public administration and defense, including social security. Wholesale and retail trade account for 16,12% of GDP. Transportation and storage account the aforementioned 2,92%. Financial and insurance activities make up 6,53% of GDP and the final sector, public administration and defense including social security, makes up 6,18%. The remaining percentage points are general services. To refrain from double counting the transportation sector, the GDP output is subtracted from the commercial sector's total. This results in a value of 678.468.964.929 USD (DGBAS, 2017b).

This sector expended 115.000 kl of LPG, 38.300 kl of motor gasoline, 168.700 kl of jet fuel, 6.700 kl of kerosene, 392.200 kl of diesel oil, and 318.700 kl of fuel oil. Natural gas consumption was 386.000.000 cubic meters and LNG usage was a converted 131.900.000 cubic meters. Electricity amounted to 47.960 GWh. Solar thermal energy was consumed to the extent of 3.400 kloe or 3.060 toe (BEMEA, 2018h, p. 30, 2018i, p. 30). The commercial sector's total consumption adds up to 5.335.650 toe.

Dividing the total energy consumption by the economic activity, the resulting energy intensity is 0,0078 kgoe/USD or 0,32 MJ/USD (IEA, 2018d).

4.3.16. Indicator 15: Agriculture Energy Intensity

The share of the agricultural sector in 2016 was 1,79% of total GDP. In real terms, this amounts to 20.322.279.906 USD (DGBAS, 2017b).

The sector consumed 600 kl of LPG, 300 kl of motor gasoline, 372.500 kl of diesel oil, and 30.100 kl of fuel oil. Natural gas amounted to 3.800.000 of converted cubic meters of LNG. Electricity consumption measured 2.922,7 GWh (BEMEA, 2018h, p. 30, 2018i, p. 30). The total consumption in the agricultural sector amounts to 596.430 toe.

After dividing the total consumed energy by the output of the agricultural sector, the energy intensity results in 0,0293 kgoe/USD or 1.22 MJ/USD (IEA, 2018d).

4.3.17. Indicator 16: Industrial Energy Intensity

The Taiwanese industrial sector in 2016 accounted for 35,54% of GDP. It features three sub-sectors, which include manufacturing, electricity and gas supply, and construction. Manufacturing accounts for 30,68% of the industrial sector. Electricity and gas supply account for 1,73% and construction measures 2,39%. The remaining percentage points are not further defined within the industrial sector (DGBAS, 2017b).

Taking the total GDP into account this sector's output measures 403.493.758.593 USD.

Consumption of energy in 2016 included 10.228.500 tons of bituminous steam coal, 277.200 tons of anthracite, 648.100 tons of coke, 1.738.500.000 cubic meters of coke oven gas, 3.224.400.000 cubic meters of blast furnace gas and 331.700.000 cubic meters of oxygen steel furnace gas. Further consumption encompassed 3.900.000 cubic meters of refinery gas, 381.200 kl of LPG, 6.200 kl of motor gasoline, 1.200 kl of jet fuel, 113.800 kl of diesel oil, 1.549.000 kl of fuel oil, 63.000 tons of petroleum coke, 13.500 kl of other petroleum products, 525.100.000 cubic meters of natural gas, and 1.987.400.000 converted cubic meters of LNG. Additionally, biomass and waste added 520.100 kloe. Electricity consumption amounted to 136.890,1 GWh of electricity. Heat energy consumption in this sector was 274.800 kloe (BEMEA, 2018i, p. 30, 2018h, p. 30). The total consumption within the industrial sector adds up to 23.986.890 toe.

Using the total energy expenditure and dividing it by the economic output of the industrial sector, the energy intensity results in 0,059 kgoe/USD or 2,47 MJ/USD (IEA, 2018d).

4.3.18. Indicator 17: Household Consumption

Calculating household consumption requires the total number of households in Taiwan, as well as the energy consumed in the residential sector overall. Energy consumption included 1.712.800 kl of LPG, 755.000.000 cubic meters of natural gas, and 54.800.000 converted cubic meters of LNG. Electricity consumption amounted to 47.332,4 GWh. Solar thermal energy added another 108.800 kloe (BEMEA, 2018h, p. 30, 2018i, p. 30). Therefore, total consumption was 5.880.612 toe.

The number of households in Taiwan in 2016 was 8.561.383 according to the Department of Household Registration Affairs (Department of Household Registration Affairs [DHRA], 2019). Dividing consumption by the number of households yields a value of 686,87 kgoe/household.

4.3.19. Indicator 18: Household Energy

In order to calculate household energy, the average number of household members needs to be considered. Similar to Japan and South Korea, the number of household members has decreased within the last decades. In 2016, the average number of members in a household was 2,75 (DHRA, 2019). Dividing the average household consumption of 686,87 kgoe, the average residential per capita consumption is 249,77 kgoe/capita.

4.3.20. Indicator 19: Household Electricity

Residential electricity consumption counted 47.332,4 GWh or 47.332.400 MWh in 2016 (BEMEA, 2018h, p. 29). The previously established number of households counted 8.561.383 and the average number of household members is 2,75 (DHRA, 2019). Dividing these values, the household electricity consumption is 2,01 MWh or 2.010 kWh/capita.

4.3.21. Indicator 20: Grid Efficiency 1 (Loss in Transmission)

The Bureau of Energy states that transmission losses in 2016 totaled 8.684,6 GWh. The total domestic electricity consumption amounted to 255.420,1 GWh, including own-use (BEMEA, 2018k). This leads to a loss in transmission of 3,4%.

4.3.22. Indicator 21: Grid Efficiency 2 (Loss in Transformation)

According to the framework's own formula, loss in transformation is calculated by (1-(FEC/TPES))×100. With an FEC of 71.163.552 toe and TPES of 110.962.800 toe, the calculation yields a loss in transformation result of 35,86%.

4.3.23. Indicator 22: Access

According to the World Energy Council, the latest data entry for Taiwan in 2015 puts the population's access to electricity at 99% (World Energy Council, 2019).

4.3.24. Indicator 23: Solid Fuel Usage

While the Global Health Observatory by the World Health Organization does not feature data specifically on Taiwan, the model by Rehfuess et al. will be applied in this case as well. Considering the 2016 GDP of 1.135.322.899.814 USD and a population of 23.539.816, the GDP per capita PPP is 48.299 USD. Used as a predictor, solid fuel use is expected to be below five percent (Rehfuess et al., 2006, p. 373).

4.3.25. Indicator 24: Electricity Pricing

Official government data on electricity pricing over the years, based on information by the Taiwan Power Company, show that the 2016 prices for lighting was 2,7915 NTD per kWh and regular electric power was 2,5405 NTD per kWh (BEMEA, 2018b). The average price was 2,6159 NTD per kWh. Using the regular currency conversion rate, this would equal 0,85 USD, but considering the PPP the value shrinks to 0,1431 USD per kWh.

As established in the previous indicator, the GDP per capita in 2016 was 48.299 USD. With electricity consumption per capita of 2.010 kWh, the total cost per year would amount to 287,75 USD. Divided by the GDP per capita, the result is 0,59%.

4.3.26. Indicator 25: Stability

As no data on 1996 exists, 1997 has been used instead. Using data by the Bureau of Energy and adjusting the prices by PPP per respective year, electricity prices in the period from 1997 to 2001 rose by 5,71%. Between 2001 and 2006, the electricity price increase was 17,3%. From 2006 to 2011, average prices increased by 44,17%, from 0,1193 USD per kWh to 0,172 USD per kWh. Prices fell by 16,8% between 2011 and 2016 (BEMEA, 2018b; IMF, 2019a).

4.3.27. Indicator 26: Fuel Pricing

The wholesale price for unleaded gasoline 95, including a business tax of 5%, amounted to 26,14 NTD in 2016. Excise tax on one liter of this fuel type is 6,86 NTD since 2001. The total retail price for one liter was 33 NTD or, accounting for PPP in 2016, 2,18 USD. Therefore, the price for one hundred liters of fuel is 218,12 USD (BEMEA, 2018g, 2018c; IMF, 2019a).

4.3.28. Indicator 27: Land Use

Taiwan's climate borders between subtropical and tropical. Its forests feature tropical, subtropical, temperate and boreal climates. The main types of forests in Taiwan fall under eight categories. Spruce-fir type forests, which are found in higher elevations above 2.500 meters. Hemlock type forests, which represent the most important conifer. Cypress type forests with red and yellow cypresses. Pine type, which are the most common conifer forests. Other groups include, other conifer types, conifer-hardwood mixed types, hardwood types and bamboo forests (Forestry Bureau/Council of Agriculture [FBCOA], 2017).

Natural forests in Taiwan compromise 1.131.800 ha, which represents 77,69% of all forests. Deciduous forests make up the majority of these forests with 597.700 ha, followed by 318.700 ha of mixed forests and 215.400 ha of coniferous forest. Artificial forests make up 295.500 ha, or 20,28%. These are overwhelmingly coniferous forests, which cover 171.800 ha. Artificial mixed forests account for 49.000 ha. The remaining 2,03% are bamboo forests, which make up 29,900 ha in Taiwan (FBCOA, 2016a).

Taiwan's total land size is 3.591.500 ha. Considering the total forest size of 2.102.400 ha, this represents a forest cover of 58.53% (FBCOA, 2016b).

4.3.29. Indicator 28: Water

The Taiwan Water Corporation is the sole body providing water in the country. In 2016, the total capacity of the water supply system measured 11.419.323 cubic meters of water a day. The capacity of the water-purification stations amounted to 13.779.752 cubic meters per day (Taiwan Water Corporation [TWC], 2017, p. 16). In the annual report on water usage, agricultural use of water amounted to 70,92% of total water consumption with 11.733,62 million cubic meters. Domestic consumption amounted to 3.181,41 million cubic meters, which represents 19,24%

of overall consumption. Industrial water usage accounted for 9,85%, which equals 1.629 million cubic meters. Total water consumption was 16.546,03 million cubic meters (Water Resource Agency, 2017, p. 17).

The Taiwan Water Corporation serves 97,2% of its designated population, but only 92,5% of the actual population (TWC, 2017, p. 16). The author can only speculate that this difference stems from Taiwan's multiple remote islands, which are not served by the Taiwan Water Corporation (Taipei Times, 2013). According to a survey by Stantec, the total access to drinking water is around 94% (2017). The author could find no further information on improved water access and will therefore use the latter value for this indicator.

4.3.30. Indicator 29: Climate Change 1 (CO_2 per Capita)

To calculate this indicator, all fossil fuel consumption and its respective carbon emission factors need to be considered.

With regard to coal and coal products, 32.711.400 tons of bituminous steam coal was expended for electricity generation, while 10.228.500 tons were used within the industrial sector. 321.200 tons of anthracite were used in the industrial sector and for non-energy use. 11.863.400 tons of sub-bituminous coal were used in electricity generation. Additionally, 992.300 tons of coke were used in the industrial sector and for non-energy use. Coke oven gas, blast furnace gas and oxygen steel furnace gas were consumed in electricity generation and within the industrial sector to an extent of 3.049,7 million cubic meters, 21.996,2 million cubic meters and 1.428,3 million cubic meters respectively (BEMEA, 2018h, p. 30). The total amount of coal and coal products used was 56.116.800 tons. The gases add up to a combined 26.474,2 million cubic meters.

Regarding oil and oil products, 132,300 kl of diesel oil and 2.498.800 kl of fuel oil were used to generate electricity. Additionally, 119,5 million cubic meters of refinery gas, 827.200 kl of petroleum coke and 22.700 kl of other petroleum products were used. As for consumption, 2.231,9 million cubic meters of petroleum gas were consumed, mostly for own-use. Of other petroleum products, 21.077.900 kl were consumed, of which non-energy use is already subtracted (BEMEA, 2018h, p. 30). The total amounts to 24.558.900 kl of oil and oil products and 2.351,4 million cubic meters of refinery gas.

Natural gas to produce electricity accounted for 16.207 million cubic meters overall, after converting LNG back to natural gas. 4.087,3 million cubic meters were used within the various economic sectors (BEMEA, 2018h, p. 30). The total consumption amounts to 20.294,3 million cubic meters.

The carbon emission factor for coal was 2.247,66 kgCO_2 per ton (BEIS & DEFRA, 2018). With 56.116.800 tons consumed, the total carbon emissions amount to 126.131.486,68 tons of CO_2. The various coal gases, which amount to 26.474,2 million cubic meters, feature an average emission factor of 256,8 tons of CO_2 per TJ (Jurich, 2016, p. 47). These gases show an energy value of 3.618.300 kloe or 136.341,88 TJ (BEMEA, 2018i, p. 30; IEA, 2018d). The total carbon emission of these gases amounts to 35.012.594,78 tons of CO_2.

Fuel oil features an average carbon emission factor of 3,16633 kgCO_2 per liter (BEIS & DEFRA, 2018). The consumption in 2016 amounted to 24.558.900 kl, which results in carbon emissions of 77.761.581,83 tons of CO_2. Refinery gas produces 61,2 tons of CO_2 per TJ (Jurich, 2016, p. 46). The total consumption equals 2.349.800 kloe or 88.543,28 TJ (BEMEA, 2018i; IEA, 2018d). This leads to a total emission of 5.418.848,73 tons of CO_2.

Considering the carbon emission value of natural gas at 2,04275 kgCO_2 per cubic meter and total consumption of 20.294,3 million cubic meters, the total carbon emissions of natural gas in Taiwan in 2016 amounts to 41.456.181,32 tons of CO_2 (BEIS & DEFRA, 2018).

Adding these values, overall total emissions amount to 285.780.693,34 tons of CO_2. Latest data from 2015 via the Statistical Yearbook of the Republic of China shows that carbon emissions amounted to 271.013.000 tons (DGBAS, 2017a, p. 49). The author will use the calculated value going forward in this thesis. Divided by the total population of 23.539.816, the per capita value is 12,14 tons of CO_2.

4.3.31. Indicator 30: Climate Change 2 (CO_2 per GDP)

Dividing the total emissions of 285.780.693,34 tons of CO_2 by the 2016 GDP of 1.135.322.899.814 USD, the resulting value is 0,25 kgCO_2 per USD.

4.3.32. Indicator 31: Renewable Capacity

Total installed capacity in Taiwan in 2016 was 49.960,5 MW. Hydropower generation totals 4.691,4 MW. Solar PV capacity was 1.245 MW, while wind power capacity amounted to 682,1 MW. Biomass and Waste account for an additional 726,6 MW (BEMEA, 2018d). The total installed renewable capacity amounts to 7.345,1 MW. Measured against the total capacity, this amounts to 14,7%.

4.3.32. Indicator 32: Non-Carbon Energy

This indicator includes electricity generation via nuclear power and renewable energy, including hydropower but excluding biomass and waste. Overall electricity production of non-carbon energy totaled 44.106,5 GWh. Electricity production via hydropower amounted to 9.855,7 GWh in 2016. Main source of this production was the Taiwan Power Company, with 9.689,5 GWh. Independent Power Producers (IPP) accounted for only 166,2 GWh. As 3,293,7 GWh of this electricity was used for pump-storage activities, the TPES value for hydropower is reduced to 6.562 GWh. Nuclear power produced 31.611,4 GWh in total, of which all power plants belong to the Taiwan Power Company. Renewable production, excluding biomass and waste accounted for 2.586,4 GWh in 2016. 669 GWh were produced by facilities belonging to the Taiwan Power Company and 839,9 GWh by IPPs. The remaining 1.080,5 GWh are accounted for by autoproducers (BEMEA, 2018e).

Converted to tons of oil equivalent, hydropower equals 564.570 toe, nuclear power equals 8.252.190 toe, and solar PV and wind combined add 222.750 toe. Solar thermal energy accounted for 100.890 toe. Adding these values, the total of non-carbon energy is 9.140.400 toe (BEMEA, 2018i, p. 30). Measured against the TPES of 110.962.800 toe, non-carbon energy represents 8,23%.

4.3.33. Indicator 33: Renewables

Electricity production via hydropower amounted to 9.855,7 GWh and renewables accounted for 6.204,1 GWh (BEMEA, 2018e). Converted to tons of oil equivalent, hydropower equals 847.980 toe, and solar PV, wind, and biomass and waste combined added 1.319.580 toe. Solar thermal energy and heat accounted for 348.210 toe. Biomass and waste consumption in the industrial sector add 468.090 toe (BEMEA, 2018i, p. 30). This amounts to an overall amount of 2.983.860 toe. With the FEC being 71.163.552 toe, the ratio of renewable energy equals 4,19%.

4.3.34. Indicator 34: Pollution

Sulfur dioxide concentrations have steadily improved from 2004 onwards, decreasing from 4,08 ppm to 2,97 ppm in 2016 (Department of Environmental

Monitoring and Information Management, 2019). A 2018 fact sheet by the Department of Air Quality and Protection and Noise Control (2019) based on 2010 data puts the total sulfur oxide emissions at 103.000 tons. Divided by the total population of 23.539.816, the resulting value is 0,004375 tons or 4,37 kgSO_x per capita.

4.3.35. Indicator 35: Quality of Information

As all indicators could be supplied with sufficient data, the quality of information is 100%.

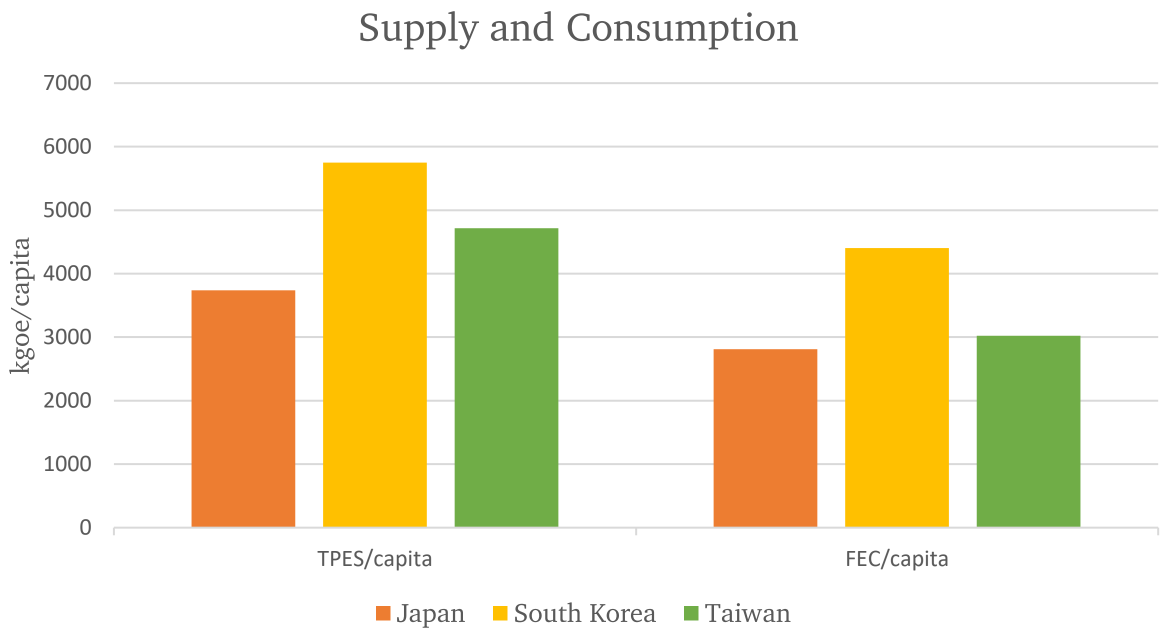
5. Results, Comparison and Critique

5.1. Results and Comparison

The first of the five dimensions analyzed in this thesis, *availability*, consists of the first ten indicators. These indicators provide a way to compare energy supply and demand data, including imports, exports, and information on self-sufficiency. On the supply side, significant differences were observed between the three chosen countries for the year 2016. While South Korea's total primary energy supply was around 60% of Japan's total, the per capita energy supply is 53,8% higher than Japan's and 21,9% higher than Taiwan's. Japan's total TPES was 474.233.623,7 toe, South Korea's measured 294.654.000 toe, and Taiwan showed a value of 110.962.800 toe. The per capita values calculated measured 3.736,09 kgoe per capita in the case of Japan, 5.747,15 kgoe in South Korea, and 4.713,86 kgoe in Taiwan.

The final energy consumption per capita of South Korea is 56,6% higher than Japan's. Compared to Taiwan, Korea's FEC per capita is 45,6% higher. Total consumption value was 356.718.424,13 toe in Japan, 225.681.000 toe in South Korea, and 71.163.552 toe in Taiwan. Per capita values measured 2.810,28 kgoe in the case of Japan, 4.401,85 kgoe for South Korea, and 3.023,11 kgoe for Taiwan.

Figure 1 Supply and Consumption



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The overall electricity consumption measured per capita was 29,6% higher in South Korea than in Japan. The highest per capita consumption was measured at 864,3 kgoe in Taiwan. This is 34,3% higher than in Japan, which was calculated at 643,38 kgoe, and 3,4% higher than in South Korea, at 833,73 kgoe. Considering the storage of fuels, Japanese storage in 2016 amounted to 7,75 years in comparison to South Korea's 5,9 years and Taiwan's 1,19 years. This equals a 31% longer duration than South Korea and a 551% longer duration than Taiwan. The largest contributor to these differences in length is the amount of stored uranium and the ability to enrich it. Japan stored around 23.000 tons of enriched uranium, while South Korea had around 6.000 in 2016. Taiwan was not found to have any storage of enriched uranium at all. Petroleum stockpiles are important for all three countries, measuring from 30 to 90 days' worth of consumption. While all three countries feature low fossil fuel production, Taiwan especially features a miniscule production of crude oil, at around half the level of South Korea and no mining of coal, as well as depleted natural reserves. Natural gas is the largest domestic fossil fuel production, but still only satisfies around 1,5% of demand.

Crude oil reserve production is lowest for South Korea, with a calculated reserve of 1,6 years, disregarding slowing production or the discovery of new oil fields. Japan's reserve production would theoretically last about 11 years, but many of the potential fields feature no current operation or may not be economically feasible. Possible reserve production for Taiwan would last a theoretical 44 years, but this number is inflated through the current low production. In direct comparison, Japan's proven reserves are almost twenty times the amount of Taiwan's.

At 2016 levels, natural gas production in Japan is estimated to last 7,38 years with proven reserves of 250 billion cubic feet. In South Korea, the current gas fields have reserves of around 2,1 years at 2016 production, but total proven gas reserves could support this production for 71,58 years. Construction of new oil and gas platforms would most likely feature different production levels, however. Taiwan's proven reserves are similar in scope to Japan's at 220 billion cubic feet. Production levels are significantly lower in comparison, which leads to a reserve production time of 16,36 years.

Concerning coal, both Japan and Taiwan have no reserve production value. In the case of Japan, around 360 million tons of coal are supposed to be still available. The 2016 production levels are miniscule, however, and would in effect show a reserve production of over 677 years. The author has chosen to disregard this value. In Taiwan, coal production has been completely halted. While there are still around 100 million tons of coal reserves left, a reserve production value cannot be provided. For South Korea, the proven coal reserves amount to 326 million tons. At current production levels, the Korean reserves would last 191,76 years.

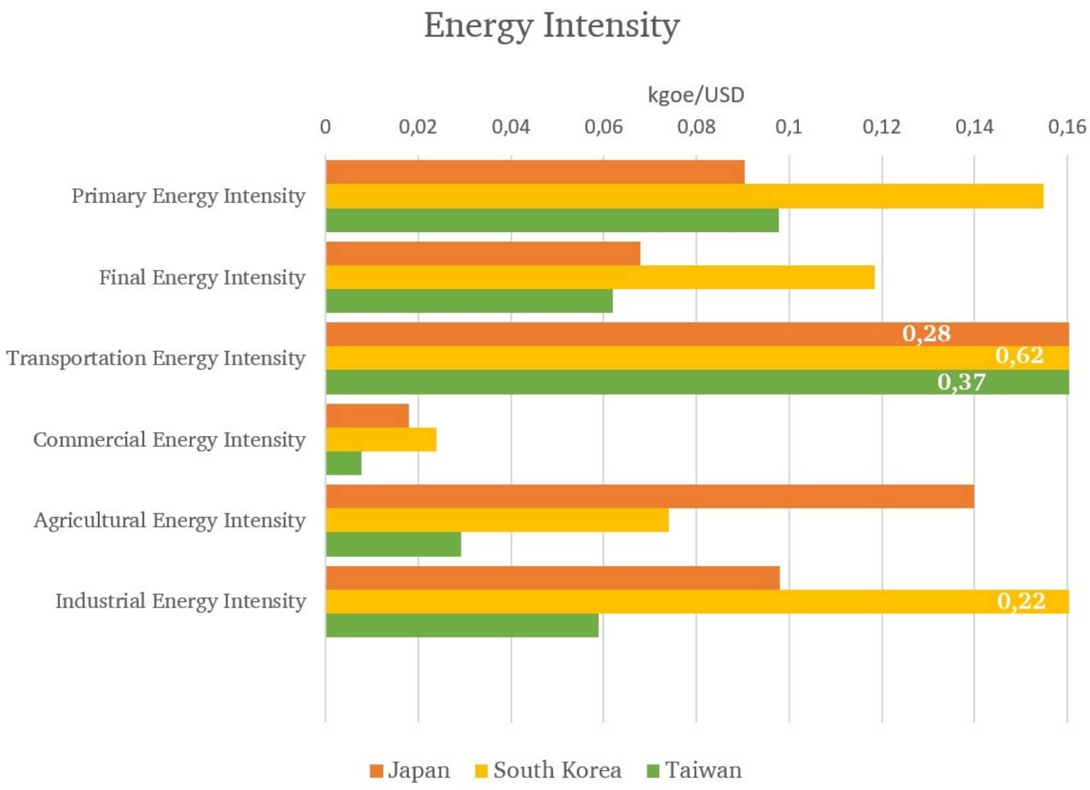
Import dependency between the three countries are vaguely similar at 87,8% for Japan, 86,76% for South Korea, and 89,48% for Taiwan. Larger differences are apparent when including nuclear energy as part of imported energy, which only Taiwan does in its official statistics. Import dependency rises significantly for South Korea and Taiwan, to 98,36% and 96,92% respectively. Since Japan has used nuclear power generation significantly less after the Fukushima nuclear accident, dependency only rises slightly to 88,55%.

Japan leads in the diversification indicator, as renewable energies, including waste energy, provide more than 10% of TPES. South Korea features a level of 5,08%, approximately half of Japan's. Hydropower in Korea only accounted for around 9% of all renewable energies, solar, wind, and other new renewable energies accounted for 13,7%, while the rest consists of waste and biomass energies. Taiwan features the lowest level of diversification at 2,21%. It is hindered by a low hydropower generation with little possibilities to improve it. Off-shore wind power generation is preferred over on-shore generation and strongly pursued, but still in its infancy. The largest share of renewable energy in Taiwan was also produced by waste energy and biomass.

The export value of South Korean processed fossil fuels and derivates in USD is thrice the value of the same category of products of Japan and Taiwan. Exports in real numbers amounted to 9.372.170.037 USD for Japan and 9.192.000.000 USD for Taiwan. South Korea's exports reached approximately 26.679.036.921 USD PPP in 2016. While not affecting energy security concerns at first sight, a larger export value of fossil fuel and derivates has both positive and negative effects in supply constrained situations. A sudden loss in supply would lead to a loss of export revenue, hurting the economy in addition to the damage a supply constraint would already incur. On the other hand, if circumstances require, parts of the energy supply which are usually refined and exported can be repurposed for the domestic energy supply to increase resilience.

The second dimension within the framework, *efficiency*, features eleven indicators which aim to show how much economic value is generated in relation to energy expended. If less energy is needed to provide the same economic output, efficiency is increased. Energy intensity is a value to show such a difference in efficiency. In addition, this dimension includes household consumption comparisons and electrical grid information, in form of both transmission and transformation losses.

Figure 2 Energy Intensity



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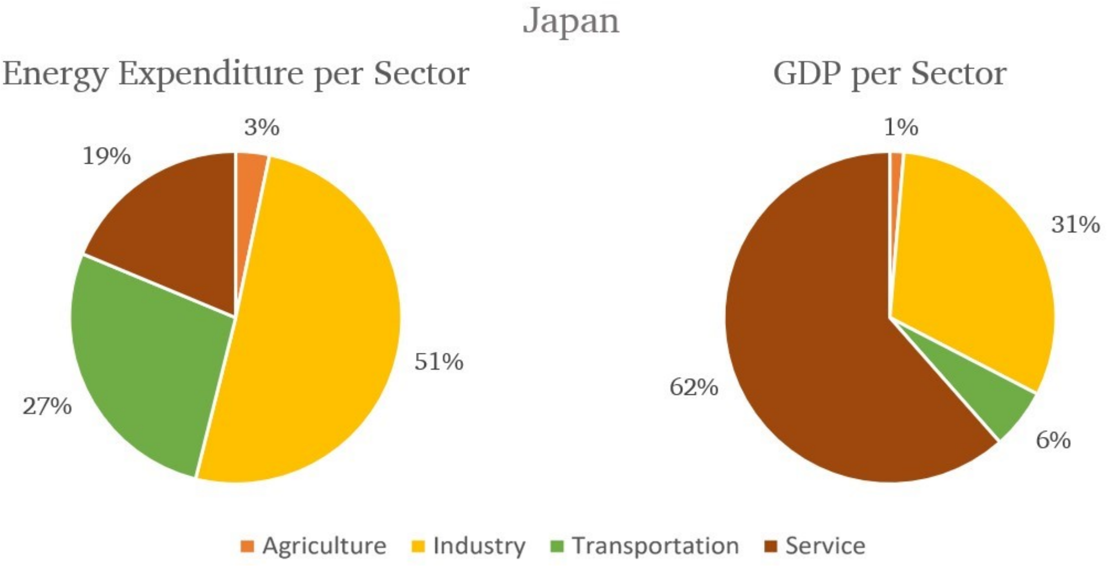
The primary energy intensity for Japan was 42,7% lower compared to South Korea and 7,5% lower compared to Taiwan, which makes Japan the overall most

Figure 3 Energy Expenditure and GDP per Economic Sector in Japan



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energy efficient country. Actual values were 0,0904 kgoe per USD in the case of Japan, 0,1548 kgoe per USD for South Korea, and 0,0977 kgoe per USD for Taiwan. When looking at the final energy intensity, the lowest value is calculated for Taiwan at 0,062 kgoe per USD. Compared to Japan, this value is 9% lower and compared to South Korea it is 47,6% lower. This lower final energy intensity shows that Taiwan uses the energy most efficiently after transformation and after accounting for losses.

Through the energy intensity in various sectors, strengths and weaknesses of each country can be observed. All three economies feature a strong commercial sector, while energy use in other sectors vary greatly. Within the transportation sector, the energy intensity was 121% higher in South Korea than in Japan, at 0,62 kgoe per USD compared to 0,28 kgoe per USD. Looking at Taiwan, the transportation sector was 67,5% more energy intensive than Japan's.

The commercial sector's energy intensity was found to be the highest in South Korea, at 0,024 kgoe per USD, followed by Japan at 0,018 kgoe per USD. Taiwan shows a significantly lower energy intensity in the commercial sector at 0,0078 kgoe per USD. This makes it 67% lower than South Korea and 56% lower than Japan.

In the agricultural sector, Taiwan also shows the lowest energy intensity at 0,0293 kgoe per USD. This is 60% lower than South Korea's intensity of 0,074 kgoe per USD and 80% lower than Japan's 0,14 kgoe per USD.

In the industrial sector, Taiwan leads among the three countries with an energy intensity of 0,059 kgoe per USD. It is 40% lower than Japan's 0,098 kgoe per USD and 73,4% lower than South Korea's 0,222 kgoe per USD.

Household energy consumption was measured using the overall numbers of households and the total residential energy consumption. Household consumption was 24% higher in Korea, compared to Japan in 2016. Taiwan showed the lowest household consumption at 686,87 kgoe, which was 20% lower than in Japan and 35,9% lower than in South Korea. Considering the average number of people per household, this difference increases to a 32% lower per person consumption compared to Japan and a 40% lower per person consumption compared to South Korea.

In contrast to household energy consumption overall, electricity consumption per capita in Japanese and Taiwanese households is around two thirds higher than in their South Korean counterparts. Japanese households consumed 2.166 kWh in 2016. Taiwanese households were similar in their consumption at 2.010 kWh. Korean households showed the lowest consumption at 1.292,91 kWh.

Electrical energy loss in transmission in Japan is 39% higher than in South Korea and 47% higher than Taiwan. South Korea's rate is 3,4% compared to 3,6% in Taiwan. Losses in transformation are similar in both Japan and South Korea at

Figure 4 Energy Expenditure and GDP per Economic Sector in South Korea

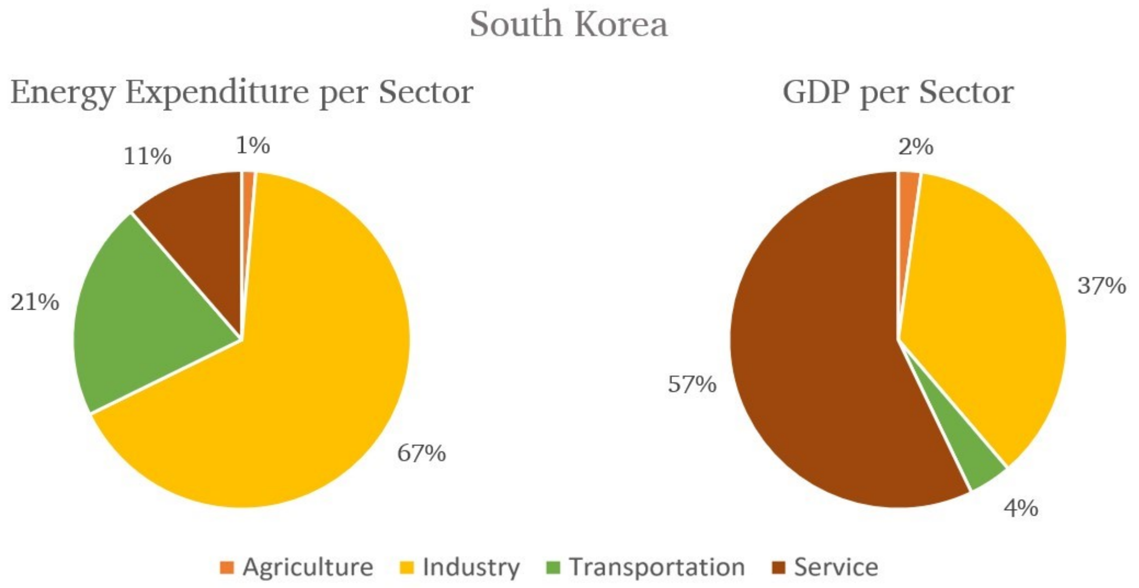

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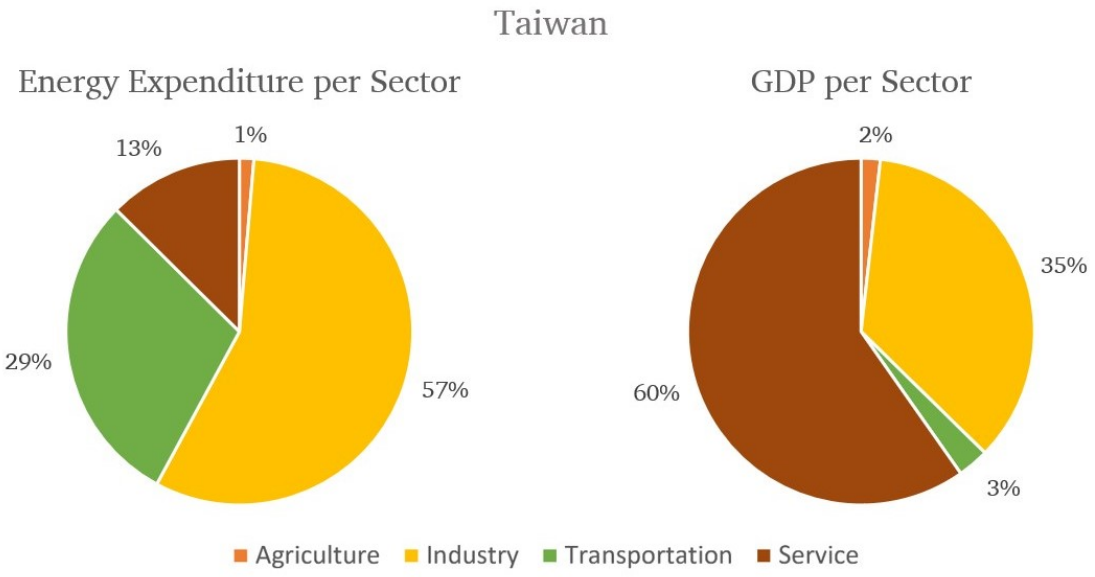
Figure 5 Energy Expenditure and GDP per Economic Sector in Taiwan



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24,78% and 23,4% respectively. Taiwan shows a significant difference, around 50% higher than both of the other two countries measured. Its transformation losses make up 35,86%.

The third dimension, *affordability*, includes five indicators which show access to and pricing of electricity, price stability of electricity, fuel pricing for consumers, and the rate of solid fuels used in households.

Access to electricity is 100% in both Japan and South Korea. Taiwan's official numbers put the access at 99% of the population.

Solid fuel usage data was modeled to be under 5% for countries with a sufficiently high GDP per capita, which all three countries provide. Electricity pricing shows a large variance between both countries, as Japanese consumers need to expend 147% more for their electricity demands in comparison to their South Korean counterparts by GDP per capita. Measured against Taiwan, the difference is similar at 130%. In total, Japanese consumers spend 1,36% of the 2016 GDP per capita on electricity, while South Koreans and Taiwanese spend 0,55% and 0,59% respectively.

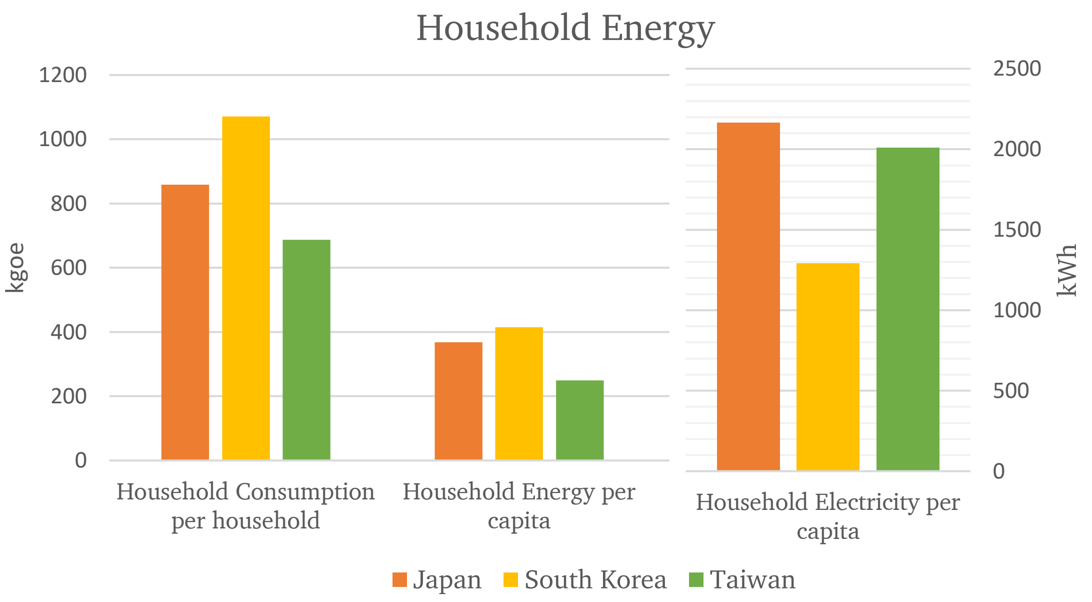
Electricity price stability in Japan measured a 0,84% increase averaged over a period of 20 years. South Korea's electricity prices increased by 3,8% averaged over the same period. In Taiwan, electricity prices rose by 12,6% over the same timeframe.

All three countries feature major spikes in pricing in specific time periods. Japan's electricity price increase correlates with the great Tohoku earthquake and the subsequent shutdown of all nuclear power plants. Between 2011 and 2016, Japanese electricity prices increased by 9,92%. In the period of 1996-2001, South Korean energy prices increased by 16,6%, while recent years saw only small increases of 1,9%. In Taiwan, prices rose most sharply between 2006 and 2011 with an increase of 44,17%.

Compared to Japan, fuel prices for 100 liters of standard gasoline were 37% higher in South Korea and 84% higher in Taiwan. Japanese consumers paid around 118,23 USD, while South Koreans paid around 162,61 USD and Taiwanese 218,12 USD in 2016. The largest difference between Japan and South Korea is the excise tax which is lower in Japan, as base prices and VAT are mostly similar. While in Taiwan the excise tax is comparatively low at around 20%, the base price of gasoline is around triple of that in both Japan and South Korea.

The *environmental* dimension features eight indicators, which provide information on land and water usage, pollution, carbon emissions, and renewable energies. Emissions are measured on a per capita basis but also per economic value added. Renewables are measured on their electrical generation capacity, total electrical generation and carbon emissions.

Figure 6 Household Energy



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Both Japan and South Korea have similar forestation levels with Japan reaching 66,34% and South Korea at 63,03%. Taiwan's level is 58,53%. In all three countries, the forestation rate was stable over the last decades.

Access to improved water was 98,94% in Japan and 98,6% in South Korea. Taiwan shows a marked decrease at around 94%.

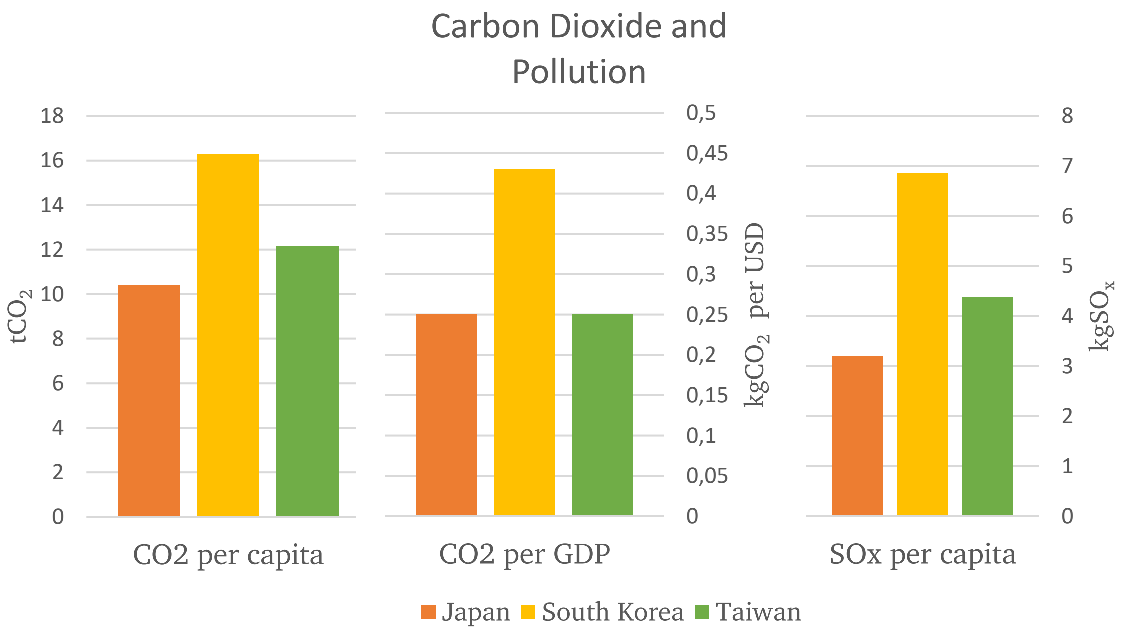
Carbon dioxide emissions, in comparison to Japan, are 16,7% higher in Taiwan and 56% higher in South Korea on a per capita basis. The actual values were 10,4 tons of CO_2 for Japan, 16,28 tons of CO_2 for South Korea and 12,14 tons of CO_2 for Taiwan, measured on a per capita basis in 2016.

Measured by GDP, South Korea produces 72% more emissions per USD than Japan and Taiwan. Japan and Taiwan both have the same calculated value of 0,25 kg of CO_2 per USD. The value for South Korea was 0,43 kg of CO_2 per USD.

Sulfur Oxide emissions are lowest in Japan with 3,2 kg per capita. Taiwan's levels are 36% higher at 4,37 kg and South Korea tops the comparison, more than doubling Japan's result, with a value of 6,86 kg per capita in 2016.

The total renewable energy generation capacity in Japan measured twice the amount compared to Korea's and Taiwan's capacity. The capacity in Japan reached 27,45% of total installed capacity. South Korea and Taiwan, in contrast, showed a

Figure 7 Carbon Dioxide and Pollution



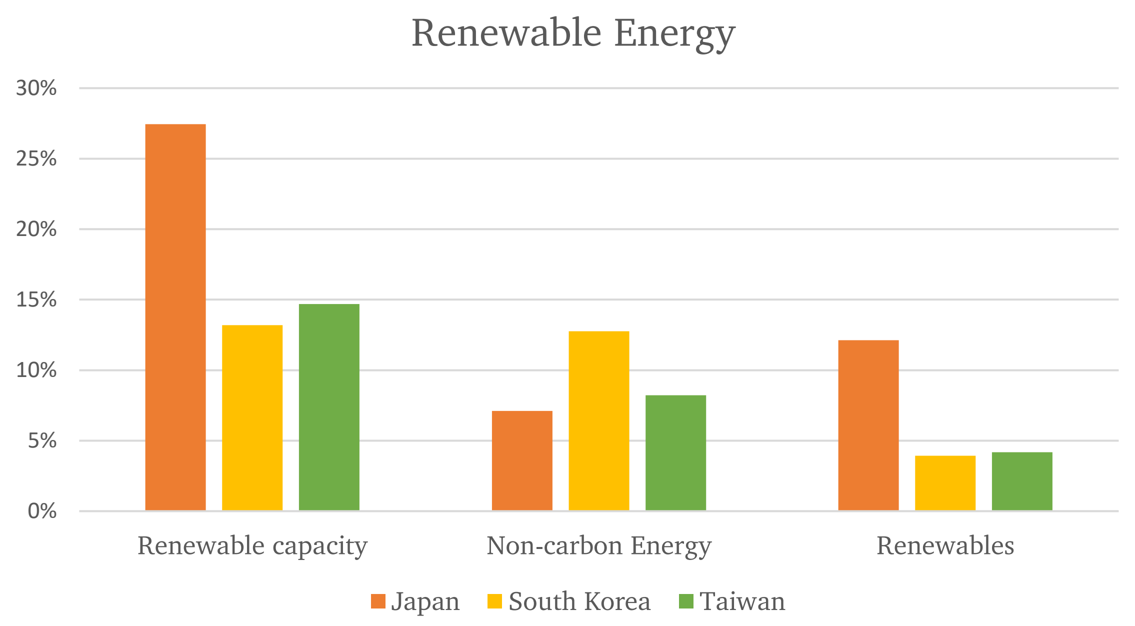
(Figure created by author)

renewable energy generation capacity of 13,19% and 14,7% respectively. A major part in this difference is the larger hydropower generation in Japan, which is proportionally more than three times larger than South Korea's and doubling Taiwan's. The largest difference is the amount of solar PV capacity, which Japan led in 2016 at 42.000 MW compared to South Koreas 3.716 MW and Taiwan's 1.245 MW. Considering the total installed capacity of 273.337 MW in Japan, 105.865 MW in South Korea and 49.960 MW in Taiwan, Japan had significantly more installed PV capacity in proportion.

Measuring non-carbon energy, or carbon emission free electricity generation, South Korea leads among the three analyzed countries, showing a 79% higher non-carbon electricity generation compared to Japan and 55% higher compared to Taiwan. The largest difference between South Korea and Japan is the lack of nuclear energy after 2011, which amounts to a large share of the non-carbon energy. In Taiwan, the lack of large hydropower plants and the slow increase of other renewables lead to a similar level as in Japan. Non-carbon energy accounts for 7,1% of all electricity generated in Japan. For South Korea the value is 12,77%, while Taiwan sits in the middle at 8,23%.

Considering all renewable electricity generation, Japan produced the largest share among the three observed countries, at 12,12% of total generation in 2016.

Figure 8 Renewable Energy



(Figure created by author)

This is around 245% higher compared to South Korea and 189% higher than Taiwan. Similarly to the capacity indicator, South Korea's level of 3,93% and Taiwan's level of 4,19% can be explained with lacking hydro and solar PV power generation compared to Japan.

The final dimension, *information*, only has a single indicator which concerns itself with the previous indicators' available data. As data for all indicators in every country could be provided for the framework, the information level is 100% in all three cases.

The final data for all indicators is presented in table 4.

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%

(Table created by author)

5.2. Limitations and Critique

Some indicators of this framework produce data which offers little insight into the energy security of the chosen countries or fails to bring forth meaningful differences. Some of these limitations likely stem from the fact that the frameworks upon which the author's framework is based, were designed with emerging economies in mind. Other limitations are based on issues of information requirements and necessary formulas.

Indicator 4, *resilience*, calculates the total time, a country could be sustained without any further imports, based upon stockpiles and natural reserves. The result from this indicator offers little value in any real-world scenario, however. In the case of Japan, an extensive stockpile of uranium pushes the number upwards, even though nuclear power plants are not able to simply increase their production with more fuel. Furthermore, does electricity alone not satisfy domestic demand for energy. Fossil fuels are still a necessity for everyday transportation and production of various products. Splitting this indicator into fossil fuel resilience and electricity generation resilience would prove more useful, as electricity generation from renewable energy sources could be taken into account, which is currently not the case. To calculate this indicator, final energy consumption is being used instead of total primary energy supply, which poses another issue, since transformation losses are not considered.

Similarly, the indicators 5-7, reserve production values, offer little actual insight into a country's reserves. In the case of South Korea, coal mining reserves show a value of around 191 years, which to some observers could signal a healthy natural reserve. This ignores current production levels and feasibility, which play a major part in coal production. A split into both current reserve production, based on the reserves of the mines in operation and total natural reserves would offer more insight into the reserve resource levels of the country.

For indicator 22, *access*, little value is gained when applied to developed countries, as the differences will mostly be miniscule. Rather, the amount of electricity providing companies, or the rate of electrification could be points to consider.

In accordance with the model of Rehfuess et al. (2006), using solid fuel access as a metric in developed countries seldom yields discernable results. Instead measuring overall fossil fuel usage in the residential sector could provide data on the prevalence of gas or oil-fired heating or cooking compared to electrical solutions as an example.

Another issue the author takes is with indicator 24, *electricity pricing*. According to Martchamadol and Kumar's framework, the calculation shows the share of income spent on electricity (Martchamadol & Kumar, 2013, p. 669). It is the author's view that using the GDP per capita is an inadequate measure of this value. Rather than using the GDP per capita as a form of average income, the author believes that the median income would prove a better base value for comparisons of income spending.

Looking only at a specific year, indicator 27, *land use*, the values give insight into only the current forest cover, but don't provide enough context to make use of such a number. Geographical differences alone could lead to drastic variances between two countries. Using forestation rates would provide information on the growth or decline of forest cover within a country, which would be a better fit for the *environmental sustainability* dimension in the author's view.

Access to improved water, indicator 28, suffers from the comparable issues as indicator 22. Researching data for developed nations will in many cases produce similar results and offer little information on energy security. As indicator 28 also falls under the *environmental sustainability* dimension, an analysis of water usage could provide a better point of comparison. Similar to the energy intensity indicators, water usage could be researched at a per capita basis overall, as well as consumption per sector and in relation to GDP per economical sector.

6. Conclusion

The central aim of this thesis is to establish the differences in energy security between the three countries Japan, South Korea, and Taiwan. In order to achieve this, firstly, the term energy security had to be defined. With many varying definitions presented, a common theme throughout the works of energy security analysis are the topics of energy supply, energy use, technology, environment, and society. Within these topics, availability, affordability and accessibility provide the three aspects required to achieve energy security, with a fourth aspect, acceptability, introduced in response to growing environmental and societal concerns.

To analyze the energy security of Japan, South Korea, and Taiwan, a suitable framework was established based upon the work of Martchamadol and Kumar's *Aggregated Energy Security Performance Indicator (AESPI)* (2013) and Sovacool's *Assessing Energy Security performance in the Asia Pacific, 1990-2010* (2013). AESPI is built upon 25 indicators, categorized into 3 dimensions; economical, environmental, and societal. It was designed to be used as an overview tool of a country's energy security status, with the intention that it is similar in application to the human development index or the gross domestic product. Sovacool's work in comparison features 5 dimensions, and 20 components, but with certain overlap between these frameworks. These dimensions include availability, affordability, technology development and efficiency, environmental sustainability, and regulation and governance. This overlap between the indicators, components, and dimensions allowed the author to create a combined framework of 35 indicators in total.

The following chapter then provides the required definitions for the 35 indicators established within author's framework. These include both numerical definitions of energetic values and formulas required for various calculations throughout the thesis but also definitions of energy related and economic terms.

The three chosen nations are then analyzed on a per country basis, using the combined framework. First, a general overview over each country's current energy situation with information on each fossil fuel type as well as nuclear and renewable energy is given. Then, each indicator is assessed individually and calculated according to the author's framework. Data was used from the year 2016 whenever possible and substituted with the closest year available, when data could not be found.

The results of applying this framework show that overall, Japan has the smallest energy supply and the lowest consumption of all three countries on a per capita basis, while South Korea sits at opposite end. On energy efficiency terms, Japan also has the lowest primary energy intensity, showing that measured on total energy supply, it is the most energy efficient country. Looking at the final energy intensity, however, after the supply has been transformed, Taiwan leads among the three observed countries, slightly ahead of Japan. This discrepancy between primary and final energy intensity would lead to the assumption that, while Taiwan has a less efficient energy transformation process, the various economic sectors are more efficient than Japan's. Looking at the indicator for loss in transformation confirms this assumption. South Korea has both the highest primary energy intensity and highest final energy intensity.

Looking at the economic sectors individually, the most substantial difference is evident in the agricultural sector, where Taiwan's energy intensity is 60% lower than South Korea's and 80% lower than Japan's. In the other sectors, Taiwan also shows the lowest energy intensity with the transportation sector being the exception. Japan is slightly more efficient in that sector. South Korea shows an industrial energy intensity doubling the value of Japan and tripling Taiwan's results. This leads to the question if South Korea's heavy industries drive this difference.

Household use of energy shows the lowest use of electricity per capita in South Korea, while having the highest household energy consumption. This would imply that other forms of energy, like fuel oils or gas for heating and cooking, are consumed instead.

Reserves in all three countries are either miniscule or economically unfeasible to explore, as is the case with coal. Resilience ratings show that Japan and South Korea could sustain their economies even without any additional imports for several years, while Taiwan edges just over the one-year mark. In the case of both Japan and South Korea, these numbers are highly inflated by fissile material used for their nuclear power plants. Import dependency is high in all three cases, similarly hovering between 87–90% of the total energy supply. When nuclear material is considered imported energy, this value even rises to 98% for South Korea and 96% for Taiwan.

Other areas, like access to water and electricity, show well connected systems and almost complete saturation. Electricity pricing is highest in Japan, related in part to an increase after the Tohoku earthquake, while the inverse is true for fuel pricing, where Taiwan showed the highest price for gasoline, while Japan was at the bottom.

The observations lead to two conclusions concerning the three analyzed countries. Firstly, as there are strong variations between the energy intensity and therefore energy efficiency in some economic sectors, while the overall sectorial GDP output is similar, the reasons for this contrast need to be analyzed. If South Korea and Japan can successfully reduce their energy intensity to the levels of Taiwan in the commercial, industrial, and agricultural sector, the energy savings could be considerable. This would be a possible area for further research. The increased efficiency directly improves energy security in a given country, without the need to change the makeup of supply and power generation facilities. As the commercial sector is already the most energy efficient, a further decrease of the size of the industrial sector would also yield a lower energy intensity overall.

The second conclusion to be drawn from analyzing the framework and its results is the necessity for a vast expansion of renewable energy. As the only form of domestic energy that does not require any exploration, it is the fastest way to drive down dependency on imports and simultaneously reduce carbon emissions and overall pollution. Japan already has the largest installed capacity of renewable energy sources at 27% and the highest electricity production via renewables at 12%. Carbon emissions per capita are the lowest among the measured countries and so are sulfur oxide levels. While nuclear energy emits no greenhouse gases and shares this property with renewable energy sources, none of the three countries can produce natural uranium currently and only Japan has the necessary enrichment facilities. If the existing measures, set by the respective countries for the next decades, suffice, could be the focus of further research.

Any long-term disruption to the fossil fuel supply of any of these countries would prove disastrous for both economy and society. Current tensions in the Middle East and in the South China Sea could result in such a scenario. In the interim, it is unrealistic to expect overnight changes to the energy composition. What can be done, is to minimize the impact of such events. It is therefore in the best interest of these countries to diversify their imports by securing multiple shipping lanes and strategic connections across the region. Contracts, partnerships, and multilateral agreements, as practiced with nuclear fuel assurances, offer another avenue to buffer disruptions. A steady and well-maintained stockpile of fossil fuels is an obvious choice for emergencies, but the necessity of these states remains to diversify their own energy supply and invest greatly into new energies. Japan has so far bet heavily on solar PV generation, while Taiwan appears to be focusing on offshore wind energy. South Korea has also started to increasingly expand its solar power generation and wind power in coastal regions in recent years. With natural reserves unavailable, there are few other options for Japan, South Korea and Taiwan to increase their energy independence.

Energy remains the building block of all modern civilizations, and many countries have rightfully equaled energy security with national security. As the oil shocks have demonstrated, independent actions can quickly escalate a seemingly unrelated crisis into a worldwide threat. Today, the topic of climate change has pushed renewable energies into the public spotlight, but the topic of energy security could be the one to tip the scales and force drastic change by governments to keep their countries safe.

7. Appendix

Appendix 1 IEA Matrix – Global Energy Security (OECD/IEA, 2009, p. 49)

Dimension	Areas for Improvement
Increasing transparency, predictability and stability of global energy markets	• Competition in energy markets • Independence of gas and electricity networks • Data transparency and free flow of information • Greater international dialogue • Independent regulation • Emergency response measures • Good governance of public revenues and action to reduce corruption
Improving the investment climate in the energy sector	• Facilitating investment in supply and demand infrastructure and measures • Development of competitive power markets • Removing barriers to cross-national investment in the energy sector and market integration • Adequately maintaining and developing the energy labour force
Enhancing energy efficiency and energy saving	• Development of integrated energy policy • Strengthened policies in the building sector • Enhanced energy efficiency data collection • Enhanced uptake of more energy-efficient appliances • Moving to best practice in lighting • Improving transport sector efficiency
Diversifying energy mix	• Diversifying energy supply • Removing barriers to cross-national investment in the energy sector and market integration • Developing domestic cleaner coal resources (including CCS) • Reducing natural gas flaring • Developing nuclear resources • Addressing long-term nuclear waste disposal • Developing other alternative resources
Securing critical energy infrastructure	• Inventory of security priorities • Ensuring security of transportation routes
Reducing energy poverty	• Progress towards funding the Millennium Development Goals • Other initiatives aimed at reducing energy poverty
Addressing climate change and sustainable development	• Progress towards achieving Kyoto targets (if applicable) • Other policies to reduce carbon dioxide emissions • Policies to implement a market signal for greenhouse gas emissions

(Table created by author)

Appendix 2 International Index of Energy Security Risk Framework (Global Energy Institute, 2016, pp. 56–58)

Category	Metrics	Weighting (Overall in %)
Global Fuels	• Security of World Oil Reserves • Security of World Oil Production • Security of World Natural Gas Reserves • Security of World Natural Gas Production • Security of World Coal Reserves • Security of World Coal Production	14
Fuel Imports	• Petroleum Import Exposure • Natural Gas Import Exposure • Coal Import Exposure • Total Energy Import Exposure • Fossil Fuel Import Expenditures per GDP	17
Energy Expenditures	• Energy Expenditure Intensity • Energy Expenditure per Capita • Retail Electricity Prices • Crude Oil Prices	20
Price & Market Volatility	• Crude Oil Price Volatility • Energy Expenditure Volatility • World Oil Refinery Utilization • GDP per Capita	15
Energy Use Intensity	• Energy Consumption per Capita • Energy Intensity • Petroleum Intensity	14
Electric Power Sector	• Electricity Diversity • Non-CO_2 Emitting Share of Electricity Generation	7
Transportation Sector	• Transportation Energy per Capita • Transportation Energy Intensity	7
Environmental	• CO_2 Emissions Trend • Energy-Related CO_2 Emission per Capita • Energy-Related CO_2 Emissions Intensity	6

(Table created by author)

Appendix 3 Abstract

English

Since the topics of energy consumption and alternative energies have become prominent issues, so too has energy security stepped back into the spotlight of public discourse. This thesis aims to analyze the energy security situation of three East Asian countries, Japan, South Korea, and Taiwan. As all three countries feature similar predicaments, being reliant on imports over waterways, having little to no natural reserves, and being high-tech and service-based economies, the author attempts to determine similarities and differences from an energy security perspective.

In order to assess these countries, a framework was created with 35 distinct indicators relating to energy security was created. Each country is then analyzed individually by presenting and calculating each indicator systematically.

The results are then presented in a table and various graphs to simply 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.

Deutsch

Alternative Energien und der heutige Energieverbrauch sind aktuell populäre Themen, was dazu beigetragen hat, dass auch das Thema Energiesicherheit wieder in den Vordergrund gerückt ist. Diese Arbeit möchte die Lage der Energiesicherheit in drei Ostasiatischen Ländern, Japan, Südkorea und Taiwan analysieren. Alle drei Länder haben ähnliche Ausgangslagen, da Importe über den Wasserweg geschehen müssen, die natürlichen Rohstoffreserven praktisch ausgeschöpft sind und alle drei high-tech Wirtschaftsmächte mit einem starken Dienstleistungssektor sind. Der Autor versucht Ähnlichkeiten, aber auch Unterschiede, festzustellen, welche das Thema Energiesicherheit betreffen.

Dazu wurde ein Framework geschaffen, welches 35 verschiedene Indikatoren aufweist. Jedes der drei Länder wird einzeln untersucht und die Indikatoren werden aufgearbeitet. Die Resultate werden in einer Tabelle und in unterschiedlichen Grafiken aufgezeigt, um einen einfachen Vergleich der Länder zu ermöglichen. Die Resultate zeigen, dass sich die größten Unterschiede im Bereich Energieeffizienz und in der Diversifizierung der Energieversorgung finden. Die abschließenden Anmerkungen behandeln sowohl Erkenntnisse, die durch diese Arbeit gewonnen wurden, als auch mögliche Bereiche für zukünftige Forschung.

8. References

Abdelaziz, E. A., Saidur, R., & Mekhilef, S. (2011). A review on energy saving strategies in industrial sector. *Renewable and Sustainable Energy Reviews*, Vol. *15*(1), 150–168.

Alsharif, M. H., Kim, J., & Kim, J. H. (2018). Opportunities and challenges of solar and wind energy in South Korea: A review. *Sustainability*, Vol. *10*(6).

American Physical Society. (2018). *Energy Units*. Retrieved March 1, 2019, from https://www.aps.org/policy/reports/popa-reports/energy/units.cfm

Andrews, D. A., & Cheong, C. H. (1956). Coalfields of the Republic of Korea. *Geological Survey Bulletin*, (1041-A).

Ang, B. W., Choong, W. L., & Ng, T. S. (2015a). A framework for evaluating Singapore's energy security. *Applied Energy*, Vol. *148*, 314–325.

Ang, B. W., Choong, W. L., & Ng, T. S. (2015b). Energy security: Definitions, dimensions and indexes. *Renewable and Sustainable Energy Reviews*, Vol. *42*, 1077–1093.

Anzai, K. (2004). *City Gas Industry's Agenda in Japan*.

Asia Pacific Energy Research Centre. (2007). *A Quest for Energy Security in The 21st Century Resources and Constraints*. Retrieved March 1, 2019, from www.ieej.or.jp/aperc

Atabani, A. E., Badruddin, I. A., Mekhilef, S., & Silitonga, A. S. (2011). A review on global fuel economy standards, labels and technologies in the transportation sector. *Renewable and Sustainable Energy Reviews*, Vol. *15*(9), 4586–4610.

Azad, S. (2015). *Koreans in the Persian Gulf: Policies and International Relations*. New York: Routledge.

Balmes, J. R., & Eisner, M. D. (2016). Indoor and Outdoor Air Pollution. In R. C. Mason, J. F. Murray, J. A. Nadel, & M. Gotway (Eds.), *Murray & Nadel's Textbook of Respiratory Medicine* (6th ed.). Elsevier Health Sciences.

Bhatia, S. C. (2014). *Advanced Renewable Energy Systems* (Vol. 1). New Delhi: Woodhead Publishing.

BP. (2016). *BP Statistical Review of World Energy June 2016*. Retrieved March 1, 2019, from http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

BP. (2017). *BP Statistical Review of World Energy June 2017*.

BP. (2018a). *BP Statistical Review of World Energy*.

BP. (2018b). *BP Statistical Review of World Energy - All Data, 1965 - 2017*.

Brown, M. A., Wang, Y., Sovacool, B. K., Louis, A., & Agostino, D. (2014). Energy Research & Social Science Forty years of energy security trends : A comparative assessment of 22 industrialized countries. *Energy Research & Social Science*, Vol. *4*, 64–77.

Bureau of Energy/Ministry of Economic Affairs. (2013). *Policy for Promoting Renewable Energy & Current Status in Taiwan*. Retrieved March 1, 2019, from https://www.mofa.gov.tw/Upload/RelFile/2508/111035/2e9e6ebe-d594-4d46-822b-1110f07f8482.pdf

Bureau of Energy/Ministry of Economic Affairs. (2017). *106 年能源平衡表編製說明 (2017 Energy Balance Sheet Explanation)*.

Bureau of Energy/Ministry of Economic Affairs. (2018a). *原油供給及煉製平衡表 Crude Oil Supply and Refinery Balance Sheet*. xxx https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1434

Bureau of Energy/Ministry of Economic Affairs. (2018b). *歷年電價一覽表 Changes in Electricity Prices*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1531

Bureau of Energy/Ministry of Economic Affairs. (2018c). *歷次調整油氣之貨物稅率表 Changes in Excise Tax of Petroleum Products and Gas*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1527

Bureau of Energy/Ministry of Economic Affairs. (2018d). *發電裝置容量統計表民 Installed Capacity*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1463

Bureau of Energy/Ministry of Economic Affairs. (2018e). *發電量統計表 Power Generation*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1466

Bureau of Energy/Ministry of Economic Affairs. (2018f). *石油煉製業主要煉製設備及處理能量表 Refining Capacity*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1520

Bureau of Energy/Ministry of Economic Affairs. (2018g). *石油產品價目表 Prices of Petroleum Products*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1523

Bureau of Energy/Ministry of Economic Affairs. (2018h). *能源供需平衡表(原始單位) Energy Balance Sheet (Original Unit)*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1407

Bureau of Energy/Ministry of Economic Affairs. (2018i). *能源供需平衡表(油當量單位) Energy Balance Sheet (Oil Equivalent)*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1410

Bureau of Energy/Ministry of Economic Affairs. (2018j). *臺灣地區煤礦生產能量概況表 Productive Scale of Coal Mines in Taiwan Area*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1468

Bureau of Energy/Ministry of Economic Affairs. (2018k). *電力消費統計表 Electricity Consumption*. Retrieved March 1, 2019, from https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1535

BusinessDictionary. (2018). Industrial Sector. *Business Dictionary.* Retrieved March 1, 2019, from http://www.businessdictionary.com/definition/industrial-sector.html

Cambridge Dictionary. (2018). Commercial Sector in Business English. *Cambridge Dictionary.* Retrieved March 1, 2019, from https://dictionary.cambridge.org/dictionary/english/commercial-sector

Carle, J., & Holmgren, P. (2003). *Definitions Related to Planted Forests*.

CEIC. (2019). *Taiwan Natural Gas: Consumption.* Retrieved April 2, 2019, from https://www.ceicdata.com/en/indicator/taiwan/natural-gas-consumption

Central Intelligence Agency. (2018). *The World Factbook*. Retrieved March 1, 2019, from https://www.cia.gov/library/publications/the-world-factbook/rankorder/2233rank.html

Central News Agency. (2017). Mt. Datun near Taipei may be a source of geothermal green energy. *Taiwan News.* Retrieved April 4, 2019, from https://www.taiwannews.com.tw/en/news/3322505

Chang, H.-W. (2017). *Wounded Land and Wounded Peoples*. University of Washington.

Chen, T. (1998). The Development of the Coal Mining Industry in Taiwan during the Japanese Colonial Occupation 1895-1945. In S. M. Miller, A. J. H. Latham, & D. O. Flynn (Eds.), *Studies in the Economic History of the Pacific Rim* (pp. 181–196). London, New York: Routledge.

Cheng, J. Y. S. (2009). The 1979 Oil Shock and the "Flying Geese Model" in East Asia. *The 1979 "Oil Shock:" Legacy, Lessons, and Lasting Reverberations*.

Cherp, A., & Jewell, J. (2014). The concept of energy security: Beyond the four As. *Energy Policy*, Vol. *75*, 415–421.

Chubu Electric Power. (2019). Increasing Thermal Efficiency of Thermal Power Plants and Reducing Power Transmission and Distribution Loss. Retrieved March 1, 2019, from http://www.chuden.co.jp/english/initiatives/eini_environment/eenv_measures/emea_thermalefficiency/index.html

Cole, M. J. (2012). Taiwan to start oil exploration in S China Sea. *The Taipei Times.* Retrieved March 30, 2019, from http://www.taipeitimes.com/News/front/archives/2012/12/28/2003551168

Cornot-Gandolphe, S. (2018). South Korea's New Electricity Plan: Cosmetic Changes or a Breakthrough for the Climate. *Édito Énergie*, (February), 1–8. Retrieved March 1, 2019, from https://www.ifri.org/sites/default/files/atoms/files/cornotgandolphe_south_korea_electricity_2018.pdf

Council of European Energy Regulators. (2017). *CEER Report on Power Losses*. Retrieved March 1, 2019, from https://www.ceer.eu/documents/104400/-/-/09ecee88-e877-3305-6767-e75404637087

Deese, D. A. (1979). Energy : Economics , Politics , and Security. *International Security*, Vol. *4*(3), 140–153.

Department for Business Energy and Industrial Strategy, & Department for Environment Food and Rural Affairs. (2018). *UK Government GHG Conversion Factors for Company Reporting*.

Department of Air Quality Protection and Noise Control. (2019). *Major Sources of Air Pollutants*. Retrieved March 2, 2019 from https://www.epa.gov.tw/DisplayFile.aspx?FileID=E77DAD70962CDE82&P=ffe1309b-e1a6-4179-abfa-815929a990a3

Department of Environmental Monitoring and Information Management. (2019). *Concentration of Air Pollutants*. Retrieved March 2, 2019, from https://www.epa.gov.tw/DisplayFile.aspx?FileID=890C875095CE3F14&P=58b01ba0-393e-42fa-ad0b-78ca49979ffc

Department of Household Registration Affairs. (2019). *土地面積、村里鄰、戶數暨現住人口 Number of Villages, Neighborhoods, Households and Resident Population*. Retrieved March 1, 2019, from https://www1.stat.gov.tw/ct.asp?xItem=15408&CtNode=4692&mp=3

Department of Statistics/Ministry of Economic Affairs. (2019). *Export Orders* Survey. Retrieved April 6, 2019, from https://dmz26.moea.gov.tw/GMWeb/investigate/InvestigateBA.aspx?lang=E

Dettmer, J. (2019). US Officials Issue Sanctions Warnings to Europe Over Russian Gas. Retrieved March 3, 2019, from https://www.voanews.com/a/us-officials-issue-sanctions-warnings-to-europe-over-russian-gas/4815954.html

Directorate General of Budget Accounting and Statistics Executive Yuan. (2017a). *Statistical Yearbook of the Republic of China*. Retrieved March 1, 2019, from https://eng.stat.gov.tw/lp.asp?ctNode=2815&CtUnit=1072&BaseDSD=36

Directorate General of Budget Accounting and Statistics Executive Yuan. (2017b). *各業生產毛額結構 Composition of Gross Domestic Product by Kind of Activity*. Retrieved March 1, 2019, from https://eng.stat.gov.tw/public/data/dgbas03/bs4/Statistical%20Tables/webdata2008yoy(030).xls

Directorate General of Budget Accounting and Statistics Executive Yuan. (2019). *Expenditures on GDP*. Retrieved March 1, 2019, from https://eng.stat.gov.tw/ct.asp?xItem=37408&CtNode=5347&mp=5

Doshi, T., & Six, S. (2017). Joint Oil Stockpiling between Middle East Exporters and Northeast Asian Importers : A Winning Formula? *King Abdullah Petroleum Studies and Research Center*, (KS-2017--DP06), 1–56.

Doukas, H., Papadopoulou, A., Savvakis, N., Tsoutsos, T., & Psarras, J. (2012). Assessing energy sustainability of rural communities using Principal Component Analysis. *Renewable and Sustainable Energy Reviews*, Vol. *16*(4), 1949–1957.

Eckert, V. (2019). Renewables overtake coal as Germany's main energy source. Retrieved March 3, 2019, from https://www.reuters.com/article/us-germany-power-renewables/renewables-overtake-coal-as-germanys-main-energy-source-idUSKCN1OX0U2

Electric Power Statistics Information System. (2019a). *Key Electric Power Index*. Retrieved March 6, 2019, from http://epsis.kpx.or.kr/epsisnew/selectEkesKepChart.do?menuId=010400&locale=eng

Electric Power Statistics Information System. (2019b). *Sale Cost by Contract Classification*. Retrieved March 3, 2019, from http://epsis.kpx.or.kr/epsisnew/selectEksaScfChart.do?menuId=060700&locale=eng

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, Vol. *39*, 748–764.

ENI. (2018). *World Oil Review 2018* (Vol. 1).

European Environment Agency. (2010). *Final electricity consumption by sector*. Retrieved March 1, 2019, from https://www.eea.europa.eu/data-and-maps/indicators/final-electricity-consumption-by-sector

European Environment Agency. (2013). *Net Energy Import Dependency*. Retrieved March 1, 2019, from https://www.eea.europa.eu/data-and-maps/indicators/net-energy-import-dependency/net-energy-import-dependency-assessment-2

Eurostat. (2008). *Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008)*. Retrieved March 1, 2019, from http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=18493724&StrLayoutCode=&IntCurrentPage=1

Eurostat. (2012). *Glossary:Final Energy Consumption*. Retrieved March 1, 2019, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Final_energy_consumption

Eurostat. (2013). *Glossary: Kilograms of oil equivalent*. Retrieved March 1, 2019, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Kilograms_of_oil_equivalent_(kgoe)

European Environment Agency, & European Monitoring and Evaluation Programme. (2016). *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016*. Retrieved March 1, 2019, from http://efdb.apps.eea.europa.eu/?source=%7B%22query%22%3A%7B%22match_all%22%3A%7B%7D%7D%2C%22display_type%22%3A%22tabular%22%7D

Federation of Electric Power Companies of Japan. (2017). *Electricity Review Japan*. Retrieved March 1, 2019, from https://www.fepc.or.jp/english/library/electricity_eview_japan/__icsFiles/afieldfile/2018/01/11/2017ERJ_full_2.pdf

Federation of Electric Power Companies of Japan. (2018). *Electricity Statistics Information*. Retrieved March 1, 2019, from http://www5.fepc.or.jp/tok-bin-eng/kensaku.cgi

Food and Agriculture Organization. (2015). Forest Resources Assessment 2015: Terms and Definitions. *Forest Resources Assessment Working Paper 180*, 36. Retrieved March 1, 2019, from http://www.fao.org/docrep/017/ap862e/ap862e00.pdf

Food and Agriculture Organization. (2018). *Agricultural sub-sectors*. Retrieved March 1, 2019, from http://www.fao.org/rural-employment/agricultural-sub-sectors/en/

Forestry Agency Japan. (2009). *State of Japan’s Forests and Forest Management*. Retrieved March 1, 2019, from http://www.rinya.maff.go.jp/j/kaigai/pdf/countryreport-1.pdf

Forestry Agency Japan. (2017). *Annual Report on Forest and Forestry in Japan*. Retrieved March 1, 2019, from http://www.maff.go.jp/e/data/publish/attach/pdf/index-95.pdf

Forestry Bureau/Council of Agriculture. (2016a). The Area of Forest of the National Forestry Management. Retrieved April 5, 2019, from https://www.forest.gov.tw/EN/0001394

Forestry Bureau/Council of Agriculture. (2016b). *The Area of Land Availability*. Retrieved April 5, 2019, from https://www.forest.gov.tw/EN/0001391

Forestry Bureau/Council of Agriculture. (2017). *Forest Resource Management*. Retrieved April 5, 2019, from https://www.forest.gov.tw/EN/0002664

Fu, C., Anantharaman, R., Jordal, K., & Gundersen, T. (2015). Thermal efficiency of coal-fired power plants: From theoretical to practical assessments. *Energy Conversion and Management*, Vol. *105*, 530–544.

Global Energy Institute. (2016). *International Index of Energy Security Risk*. Retrieved March 1, 2019, from http://www.energyxxi.org/sites/default/files/energyrisk_intl_2016.pdf

Griffith, B., Long, N., Torcellini, P., Judkoff, R., Crawley, D., & Ryan, J. (2007). Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings. *Technical Report NREL/TP-550-41957*, (December), 100–111.

Gurzu, A. (2019). Nord Stream 2: Who fared best. *Politico*. Retrieved March 3, 2019, from https://www.politico.eu/article/the-winners-and-losers/

Halloran, R. (1974, February 11). Effects of Oil Crisis Are Severe in South Korea. *The New York Times*. Retrieved March 1, 2019, from https://www.nytimes.com/1974/02/11/archives/effects-of-oil-crisis-are-severe-in-south-korea-impact-of-oil.html

Hirao, S. (2002). Death of domestic coal leaves legacy for future. *The Japan Times*. Retrieved March 1, 2019, from https://www.japantimes.co.jp/news/2002/01/03/business/death-of-domestic-coal-leaves-legacy-for-future/

Hofstrand, D. (2008). Liquid Fuel Measurements and Conversions. *Ag Decision Maker*. Retrieved March 1, 2019, from https://www.extension.iastate.edu/AGDM/wholefarm/pdf/c6-87.pdf

Horwitz, J. (2017). Taiwan, at the heart of the world's tech supply chain, has a serious electricity problem. *Qwartz*. Retrieved March 13, 2019, from https://qz.com/1054921/taiwan-at-the-heart-of-the-worlds-tech-supply-chain-has-a-serious-electricity-problem/

Hsu, C. (2017). Interview: Energy transition risky, industry federation head says. *Liberty Times Net.* Retrieved April 3, 2019, from https://news.ltn.com.tw/news/focus/breakingnews/2141080

Hsu, E., & Lin, M. (2015). Oil expected from Chad as Taiwan strives for energy self-sufficiency. *Focus Taiwan.* Retrieved April 3, 2019, from http://focustaiwan.tw/news/aeco/201510250017.aspx

Huang, Y., & Lin, K. (2017). *Taiwan's uranium reserves to be disposed of in 2 years: minister*. Retrieved April 5, 2019, from http://focustaiwan.tw/news/aeco/201711060025.aspx

Hughes, L. (2014). *Globalizing Oil*. Cambridge: Cambridge University Press.

Hwang, E. (2016). *탄광의 역사 (History of Coal Mining)*. Retrieved March 1, 2019, from http://theme.archives.go.kr/next/koreaOfRecord/CoalMine.do

Im, J. Y. (2016). Production cut quickly reduces Korea's coal stockpiles. *The Korea Herald.* Retrieved March 1, 2019, from http://www.koreaherald.com/view.php?ud=20160610000509

Industrial Technology Research Institute. (2009). *Hydropower*. Retrieved April 3, 2019, from https://web.archive.org/web/20131030115624/http://www.re.org.tw/Eng/hydro.aspx

Industrial Technology Research Institute. (2019). *Thousand Wind Turbines Project*. Retrieved April 2, 2019, from https://www.twtpo.org.tw/eng/Home/

Institute for Sustainable Energy Policies. (2018). *The share of renewable energy in total power generation in Japan in 2017 [Flash Report]*. Retrieved March 1, 2019, from https://www.isep.or.jp/en/library/3362

International Atomic Energy Agency; United Nations Department of Economic and Social Affairs; International Energy Agency; Eurostat; European Environment Agency. (2005). *Energy indicators for sustainable development: Guidelines and Methodologies*.

International Atomic Energy Agency. (2018). *Japan*. Retrieved March 1, 2019, from https://cnpp.iaea.org/countryprofiles/japan/japan.htm

International Atomic Energy Agency. (2019). *List of Uranium Deposits*. Retrieved March 3, 2019, from https://infcis.iaea.org/UDEPO/Deposits

International Atomic Energy Agency/Nuclear Energy Agency. (2016). *Uranium 2016: Resources, Production and Demand*. Retrieved March 1, 2019, from http://www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf

International Energy Agency. (2011). *The IEA Model of Short-term Energy Security (MOSES) - Primary Energy Sources and Secondary Fuels*. https://doi.org/10.1787/5k9h0wd2ghlv-en

International Energy Agency. (2014). Energy Supply Security: Emergency Response of IEA Countries 2014. *IEA Publications,* 606. Retrieved March 1, 2019, from https://www.iea.org/publications/freepublications/publication/energy-supply-security-the-emergency-response-of-iea-countries-2014.html%5Cnhttps://www.iea.org/publications/freepublications/publication/ENERGYSUPPLYSECURITY2014.pdf

International Energy Agency. (2016). *Energy prices and taxes - Fourth Quarter 2016*.

International Energy Agency. (2017a). *Renewable Portfolio Standard (RPS)*. Retrieved March 1, 2019, from https://www.iea.org/policiesandmeasures/pams/korea/name-39025-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s&s=dHlwZT1yZSZzdGF0dXM9T2s

International Energy Agency. (2017b). *Renewables 2017. Market Report Series*.

International Energy Agency. (2018a). *Energy prices and taxes - Fourth Quarter 2018*.

International Energy Agency. (2018b). *Japan: Renewables and waste for 2016*. Retrieved March 1, 2019, from https://www.iea.org/statistics/?country=JAPAN&year=2016&category=Electricity&indicator=RenewGenBySource&mode=table&dataTable=RENEWABLES

International Energy Agency. (2018c). *Korea: Renewables and waste for 2016*. Retrieved March 3, 2019, from https://www.iea.org/statistics/?country=KOREA&year=2016&category=Renewables&indicator=RenewGenBySource&mode=table&dataTable=RENEWABLES

International Energy Agency. (2018d). *Statistics Resources: Unit Converter*. Retrieved March 1, 2019, from https://www.iea.org/statistics/resources/unitconverter/

International Energy Agency. (2019a). *Balances definitions: Total primary energy supply*. Retrieved March 1, 2019, from https://www.iea.org/statistics/resources/balancedefinitions/

International Energy Agency. (2019b). *Frequently Asked Questions*. Retrieved March 1, 2019, from https://www.iea.org/statistics/resources/questionnaires/faq/

International Energy Agency Photovoltaic Power Systems Programme. (2018). *2018 Snapshot of Global Photovoltaic Markets*. Retrieved March 1, 2019, from http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2017.pdf

International Gas Union. (2012). *Natural Gas Conversion Guide*. Retrieved March 1, 2019, from http://members.igu.org/old/IGU%20Events/wgc/wgc-2012/wgc-2012-proceedings/publications/igu-publications/natural-gas-conversion-guide/view/++widget++form.widgets.download/@@download/Natural-Gas-Conversion-Guide.pdf

International Gas Union. (2017). *Natural Gas Facts & Figures*. Retrieved April 2, 2019, from https://www.igu.org/resources-data

International Monetary Fund. (2019a). *Implied PPP conversion rate (National currency per international dollar).*

International Monetary Fund. (2019b). *Report for Selected Countries and Subjects*. Retrieved April 6, 2019, from https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/weorept.aspx?pr.x=57&pr.y=8&sy=2015&ey=2019&scsm=1&ssd=1&sort=country&ds=.&br=1&c=528&s=NGDP_RPCH%2CNGDPD%2CPPPGDP%2CNGDPDPC%2CPPPPC&grp=0&a=

International Monetary Fund. (2019c). *World Economic Outlook Database*. Retrieved March 1, 2019, from https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/weorept.aspx?sy=2016&ey=2023&scsm=1&ssd=1&sort=country&ds=.&br=1&pr1.x=30&pr1.y=5&c=158&s=NGDP_R%2CNGDPD%2CPPPGDP&grp=0&a=

International Trade Administration. (2016). *2016 Top Markets Report Renewable Energy Country Case Study Japan, 1–4*. Retrieved March 1, 2019, from https://www.trade.gov/topmarkets/pdf/Renewable_Energy_Japan.pdf

International Trade Administration. (2018a). *Japan - Liquefied Natural Gas (LNG)*. Retrieved March 1, 2019, from https://www.export.gov/article?id=Japan-Liquefied-Natural-Gas-LNG

International Trade Administration. (2018b). *Japan - Renewable Energy*. Retrieved March 1, 2019, from https://www.export.gov/article?id=Japan-Renewable-Energy

Jansen, J. C., & Seebregts, A. J. (2010). Long-term energy services security: What is it and how can it be measured and valued? *Energy Policy*, Vol. *38*(4), 1654–1664.

Japan for Sustainability. (2017). *Current Status of Renewable Energy in Japan.* Retrieved March 1, 2019, from https://www.japanfs.org/en/news/archives/news_id035824.html

Japan International Cooperation Agency. (2018). *Safe Water for All*.

Japan Nuclear Fuel Limited. (2018). *Uranium Enrichment*. Retrieved January 16, 2019, from https://www.jnfl.co.jp/en/business/uran/

Japan Oil, Gas and Metals National Corporation. (2016). *Petroleum Stockpiling*. Retrieved March 1, 2019, from http://www.jogmec.go.jp/content/300320107.pdf

Japan Oil, Gas and Metals National Corporation. (2017). *Stockpiling System*. Retrieved March 1, 2019, from http://www.jogmec.go.jp/english/stockpiling/stockpiling_10_000002.html

Jurich, K. (2016). CO2 Emission Factors for Fossil Fuels. *Climate Change*, Vol. *28*, 48. Retrieved March 1, 2019, from https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf

Kainou, K. (2012). *総合エネルギー統計の解説 / 2010年度改訂版 (Comments on the Comprehensive Energy Statistics / Fiscal Year 2010 Revised Edition)*. Retrieved March 1, 2019, from http://www.rieti.go.jp/users/kainou-kazunari/download/pdf/2010EBXIGRF.pdf

Kemmler, A., & Spreng, D. (2007). Energy indicators for tracking sustainability in developing countries. *Energy Policy*, Vol. *35*(4), 2466–2480.

Khatib, H. (2009). Energy Security. *World Energy Assessment: Energy and the Challenge of Sustainability*, 111–131.

Kim, Y. P., & Lee, G. (2018). Trend of air quality in Seoul: Policy and science. *Aerosol and Air Quality Research*, Vol. *18*(9), 2141–2156.

Kimura, M. (2018). Colonial Development of Modern Industry in Korea, 1910-1939/40. *Japan Review*, Vol. *2*(2).

Koji, M. (2016). Coal Trends. *Institute of Energy Economics Energy Journal*, (22), 1–13.

Komiyama, R., & Fujii, Y. (2017). Assessment of post-Fukushima renewable energy policy in Japan's nation-wide power grid. *Energy Policy*, Vol. *101*(May 2016), 594–611.

Korea Electric Power Corporation. (2017a). *2017 Sustainability Report*. Retrieved March 1, 2019, from https://home.kepco.co.kr/kepco/cmmn/fms/FileDown.do?atchFileId=FILE_000000021205037&fileSn=0

Korea Electric Power Corporation. (2017b). *한국전력통계 Statistics of Electric Power in Korea (2016)*. Retrieved March 1, 2019, from https://home.kepco.co.kr/kepco/cmmn/fms/FileDownSecure.do?atchFileId=f9f2eb4f9d45c7b1845eedecc63adabd0b7a18254bd287f6cec4ed7de8bd397ae1&fileSn=937cd56e0cd938f2cfe8a850a125a575f1

Korea Electric Power Corporation. (2018). *한국전력통계 Statistics of Electric Power in Korea (2017)*. Retrieved March 1, 2019, from https://home.kepco.co.kr/kepco/cmmn/fms/FileDownSecure.do?atchFileId=cf8d89e2fbd8d2dbd7e3ef5dde0da22e57cdf4062348b01c7d32c6290933c857e7&fileSn=2c67c556df4912e1c4ee5e2241c6c24af3

Korea Energy Economics Institute. (2017). *2017 Energy Info Korea*. Retrieved March 1, 2019, from http://www.keei.re.kr/keei/download/EnergyInfo2017.pdf

Korea Energy Economics Institute. (2018). *2018 에너지통계 연보 (2018 Yearbook of Energy Statistics)*. Retrieved March 1, 2019, from http://www.keei.re.kr/keei/download/YES2018.pdf

Korea Energy Management Corporation. (2009). *Renewable Portfolio Standards (RPS)*. Retrieved March 1, 2019, from http://www.kemco.or.kr/new_eng/pg02/pg02040705.asp

Korea Forest Service. (2018). *2018 임업통계연보 Statistical Yearbook of Forestry*. Retrieved March 1, 2019, from http://english.forest.go.kr/newkfsweb/cmm/fms/FileDown.do;jsessionid=ywSwYn5apVZ5j2PUI1f8ZK8Pa1f2iZ7arwzgyZJKhU2acsde035Ht11iqasThojH.frswas02_servlet_engine11?atchFileId=FILE_000000000732165&fileSn=0

Korea Hydro & Nuclear Power. (2018). *Plant Status*. Retrieved March 1, 2019, from http://www.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101

Korea National Oil Corporation. (2018). *Domestic E&P.* Retrieved March 1, 2019, from http://www.knoc.co.kr/ENG/sub04/sub04_2_3.jsp

Korea National Oil Corporation. (2019). *Operation of Stockpiling Facilities*. Retrieved March 1, 2019, from http://www.knoc.co.kr/ENG/sub03/sub03_3_3.jsp

Korean Coal Corporation. (2017a). *국내 석탄산업 및 무연탄 생산 현황(생산개발팀) (Production Status of Domestic Coal Industry and Anthracite (Production Development Team))*. Retrieved March 1, 2019, from https://www.kocoal.or.kr/board/download.php?table=1083&number=4875

Korean Coal Corporation. (2017b). *연혁 (History)*. Retrieved March 1, 2019, from https://www.kocoal.or.kr/page/70

Korean Coal Corporation. (2019). *국내 민영탄광 소개 (Introduction to Domestic Private Coal Mining)*. Retrieved March 1, 2019, from https://www.kocoal.or.kr/v2/intro/?m=2&page=1

Korean Statistical Information Service. (2018a). *Air emissions by industry and household (Greenhouse Gas)*. Retrieved March 3, 2019, from http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01#SelectStatsBoxDiv

Korean Statistical Information Service. (2018b). *Air emissions by year (Air Pollutant).* Retrieved March 3, 2019, from http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01#SelectStatsBoxDiv

Korean Statistical Information Service. (2018c). *GDP and GNI by Economic Activities (not seasonally adjusted ,current prices, quarterly & annual)*. Retrieved March 5, 2019, from http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01&statId=2002002&themaId=#SelectStatsBoxDiv

Korean Statistical Information Service. (2018d). *Population, Households and Housing Units*. Retrieved March 1, 2019, from http://kosis.kr/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ZTITLE&parmTabId=M_01_01#SelectStatsBoxDiv

Korean Statistical Information Service. (2018e). *Used Amount by Purpose and Supply Capacity by Water Source*. Retrieved March 3, 2019, from http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01#SelectStatsBoxDiv

Korean Statistical Information Service. (2019a). *Degree of Air Pollution (Sulfurous Acid Gas)*. Retrieved March 3, 2019, from http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01#SelectStatsBoxDiv

Korean Statistical Information Service. (2019b). *Main Annual Indicators (reference year 2010)*. Retrieved March 3, 2019, from http://kosis.kr/statHtml/statHtml.do?orgId=301&tblId=DT_102Y002&vw_cd=MT_ETITLE&list_id=&scrId=&seqNo=&language=en&obj_var_id=&itm_id=&conn_path=A6&path=%252Feng%252F

Kruyt, B., Van Vuuren, D. P., de Vries, H. J. M., & Groenenberg, H. (2009). Indicators for energy security. *Energy Policy*, Vol. *37*(6), 2166–2181.

Kuo, C. S. (2012). *The Mineral Industry of Japan*.

Kushiro Coal Mine Co. Ltd. (2019). *Company Profile*. Retrieved March 1, 2019, from http://www.k-coal.co.jp/company.html

Kwon, H. S., & Hong, S. H. (2015). *Coal-Securing Strategy of Major Asian Coal Importers and the Countermeasures of South Korea*. *Policy Issue Paper* (Vol. 14). Retrieved March 1, 2019, from http://www.keei.re.kr/main.nsf/index_en.html

Kyodo News. (2013). Memorial marks 1963 mine disaster. *The Japan Times.* Retrieved February 6, 2019, from https://www.japantimes.co.jp/news/2013/11/09/national/memorial-marks-1963-mine-disaster/#.WFwsVlPhDIV

Lankov, A. (2007). At Coalface of Heating. *The Korea Times*. Retrieved March 1, 2019, from http://www.koreatimes.co.kr/www/news/opinon/2008/04/165_5149.html

Lind, J. (1997). *Securing Asian Energy Investments: Geopolitics and Implications for Business Strategy*. *The MIT Japan Program*.

Löschel, A., Moslener, U., & Rübbelke, D. T. G. (2010). Indicators of energy security in industrialised countries. *Energy Policy*, Vol. *38*(4), 1665–1671.

Martchamadol, J., & Kumar, S. (2013). An aggregated energy security performance indicator. *Applied Energy*, Vol. *103*, 653–670.

Materia, S. (2017). *The Future Is Renewable: Targets and Policies By Country*. Retrieved March 1, 2019, from http://philllipriley.com.au/featured/research/.

McCurry, J. (2015). Can Japan’s climate policy get back on track after Fukushima? *The Guardian.* Retrieved March 3, 2019, from https://www.theguardian.com/environment/2015/apr/17/can-japans-climate-policy-get-back-on-track-after-fukushima

Mihut, M. I., & Daniel, D. L. (2013). First Oil Shock Impact on the Japanese Economy. *Procedia Economics and Finance*, Vol. *3*(12), 1042–1048.

Ministry for the Environment. (2018). *Japan’s National Greenhouse Gas Emissions in Fiscal Year 2016*. Retrieved March 1, 2019, from https://www.env.go.jp/press/files/en/762.pdf

Ministry of Economic Affairs. Petroleum Administration Act (2014). Retrieved March 1, 2019, from https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0020019

Ministry of Economy, Trade and Industry. (2016a). *総合エネルギー統計 簡易表 (General Energy Statistics [Simplified])*. Retrieved March 1, 2019, from https://www.enecho.meti.go.jp/statistics/total_energy/results.html

Ministry of Economy, Trade and Industry. (2016b). *電気事業者の発電所数、出力 (Electricity businesses' number and output of power plants)*.

Ministry of Economy ,Trade and Industry. (2018a). *Japan's Energy 2017*. Retrieved March 1, 2019, from http://www.enecho.meti.go.jp/en/category/brochures/pdf/japan_energy_2017.pdf

Ministry of Economy, Trade and Industry. (2018b). *エネルギー白書2018 (Energy White Paper 2018)*. Retrieved March 1, 2019, from https://www.enecho.meti.go.jp/about/whitepaper/2018pdf/

Ministry of Environment. (2016). *상수도 현대화 사업 (Waterworks Modernization Project)*. Retrieved March 1, 2019, from http://www.me.go.kr/home/file/readDownloadFile.do?fileId=130910&fileSeq=1&openYn=Y

Ministry of Foreign Affairs. (1981). *ROC still digging hard to find more oil, gas*. Retrieved March 30, 2019, from https://web.archive.org/web/20141006073353/http://taiwaninfo.nat.gov.tw/fp.asp?xItem=126335&CtNode=103

Ministry of Land, Infrastructure, Transport and Tourism. (2008). *Current State of Water Resources in Japan*. Retrieved March 1, 2019, from https://www.mlit.go.jp/tochimizushigen/mizsei/water_resources/contents/current_state.html

Ministry of the Environment. (2017). *平成29年版環境統計集 (2017 Environmental Statistics Compilation)*. Retrieved March 1, 2019, from https://www.env.go.jp/doc/toukei/contents/tbldata/h29/2017-6.html

Ministry of the Environment. (2018). *平成30年版 環境・循環型社会・生物多様性白書 (2018 Environment, Recycling and Biodiversity White Paper),* 197–228. Retrieved March 1, 2019, from http://www.env.go.jp/policy/hakusyo/h30/pdf/full.pdf

Ministry of Trade Industry and Energy. (2016). *석탄산업 장기계획('16~'20) (Long Term Plan for the Coal Industry (2016 - 2020))*. Retrieved March 1, 2019, from http://www.motie.go.kr/common/download.do?fid=bbs&bbs_cd_n=6&bbs_seq_n=63888&file_seq_n=1

Ministry of Trade, Industry and Energy. (2017a). *The 8th Basic Plan for Long-term Electricity Supply and Demand*. Retrieved March 1, 2019, from https://www.kpx.or.kr/www/downloadBbsFile.do?atchmnflNo=30051

Ministry of Trade, Industry and Energy. (2017b). *석탄비축사업사전타당성연구 (Preleminary feasibility study on the coal stockpiling business)*. Retrieved March 1, 2019, from http://www.prism.go.kr/homepage/researchCommon/downloadResearchAttachFile.do;jsessionid=EEE0691ED8008E956526CC0A42B26222.node02?work_key=001&file_type=CPR&seq_no=001&pdf_conv_yn=N&research_id=1450000-201800004

Mizoguchi, T. (1979). Economic Growth of Korea under the Japanese Occupation. *Hitotsubashi Journal of Economics*, Vol. *20*(1), 1–19.

Moya, D., Aldás, C., López, G., & Kaparaju, P. (2017). Municipal solid waste as a valuable renewable energy resource: A worldwide opportunity of energy recovery by using Waste-To-Energy Technologies. *Energy Procedia*, Vol. *134*, 286–295.

Mükusch, C. (2011). *Vernetzte Energiesicherheit*. Wiesbaden, Germany: VS Verlag.

World Coal Reserves Lack Credibility. (1997). *Energy Exploration & Exploitation*, Vol. *15*(3), 268–271.

Narula, K., & Reddy, B. S. (2015). Three blind men and an elephant: The case of energy indices to measure energy security and energy sustainability. *Energy*, Vol. *80*, 148–158.

Narula, K., & Reddy, B. S. (2016). A SES (sustainable energy security) index for developing countries. *Energy*, Vol. *94*, 326–343.

National Congress of Industrial Heritage. (2015). *Coal Mining.* Retrieved February 3, 2019, from http://www.japansmeijiindustrialrevolution.com/en/site/coalmining/index.html

Nautilus Institute for Security and Sustainable Development. (1998). *Executive Summary: A Framework For Energy Security Analysis and Application to a Case Study of Japan*. Retrieved March 1, 2019, from http://oldsite.nautilus.org/archives/pares/PARES_Executive_Summary.PDF

Norman, H. E. (2000). *Japan's Emergence as a Modern State*. (L. T. Woods, Ed.) (60th Anniv). Vancouver: UBC Press.

Nuclear Regulation Authority. (2015). *我が国における２０１４年の保障措置活動の実施結果及び国際原子力機関 （IAEA）による「２０１４年版保障措置声明」の公表について(About Japan's Annoucement of the 2014 Safeguard Implementation Results and the IAEA 2014 Safeguard Report)*. Retrieved March 1, 2019, from http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2015/siryo28/siryo1.pdf

Office of Energy Efficiency. (2008). *Energy Efficiency Trends in Canada 1990 to 2005*. Retrieved March 1, 2019, from http://oee.nrcan.gc.ca/publications/statistics/trends07/pdf/toc_e.pdf

Ölz, S., Sims, R., & Kirchner, N. (2007). Contribution of Renewables to Energy Security. *IEA Information Paper*, (April), 74.

Organisation for Economic Cooperation and Development/ International Energy Agency. (2009). *Lessons learned from the energy policies of IEA countries: Key cross-cutting issues 2007/2008*.

Organisation for Economic Cooperation and Development/International Energy Agency. (2014). *Energy Supply Security: Emergency Response of IEA Countries*. Retrieved March 1, 2019, from https://www.iea.org/publications/freepublications/publication/energy-supply-security-the-emergency-response-of-iea-countries-2014.html%5Cnhttps://www.iea.org/publications/freepublications/publication/ENERGYSUPPLYSECURITY2014.pdf

Organisation for Economic Cooperation and Development. (2018a). *Gross domestic product (GDP)*. Retrieved March 1, 2019, from https://data.oecd.org/gdp/gross-domestic-product-gdp.htm

Organisation for Economic Cooperation and Development. (2018b). *Primary energy supply (indicator)*. Retrieved March 1, 2019, from https://data.oecd.org/energy/primary-energy-supply.htm

Organisation for Economic Cooperation and Development. (2019a). *Aggregate National Accounts, SNA 2008 (or SNA 1993)*. Retrieved March 1, 2019, from https://www.oecd-ilibrary.org/economics/data/aggregate-national-accounts-sna-2008_na-ana08-data-en

Organisation for Economic Cooperation and Development. (2019b). *Purchasing power parities (PPP)*. Retrieved March 1, 2019, from https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm

Organization of the Petroleum Exporting Countries. (2019). *Conversion factors.* Retrieved March 1, 2019, from https://www.opec.org/library/Annual Statistical Bulletin/interactive/current/FileZ/cfpage.htm

Pan, C., & Kao, E. (2017). Taiwan’s 1st offshore wind farm to boost capacity 1,500% by 2019. *Focus Taiwan.* Retrieved April 3, 2019, from http://focustaiwan.tw/news/aeco/201708060010.aspx

Paravantis, J. A., Ballis, A., Tsirigotis, D., Kontoulis, N., & Dourmas, V. (2018). A Geopolitical Review of Definitions, Dimensions and Indicators of Energy Security. *2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*.

Park, E. S., & Chung, S. K. (2014). Experience and challenge of underground oil/gas storage caverns in Korea. *Geosystem Engineering,* Vol. *17*(5), 294–302.

Patel, S. (2017). Who Has the World’s Most Efficient Coal Power Plant Fleet? *Powermag.* Retrieved February 20, 2019, from https://www.powermag.com/who-has-the-worlds-most-efficient-coal-power-plant-fleet/

Petroleum Association of Japan. (2015). *Petroleum Industry in Japan*. *Petroleum Association of Japan*. Retrieved March 1, 2019, from http://www.paj.gr.jp/english/data/paj2013.pdf

Qatar Petroleum. (2018). Conversion Factors. Retrieved March 1, 2019, from https://qp.com.qa/en/Pages/ConversionFactor.aspx

Rehfuess, E., Mehta, S., & Prüss-Üstün, A. (2006). Assessing household solid fuel use: Multiple implications for the Millennium Development Goals. *Environmental Health Perspectives*, Vol. *114*(3), 373–378.

Ren, J., & Sovacool, B. K. (2014). Quantifying, measuring, and strategizing energy security: Determining the most meaningful dimensions and metrics. *Energy*, Vol. *76*, 838–849.

REN21. (2017). *Renewables 2017 Global Status Report*.

Research Institute of Innovative Technology for the Earth. (2018). *非エネルギー利用 (Non-energy use)*. Retrieved January 5, 2019, from https://www.rite.or.jp/system/learn-energy/non-energy/

Richter, A. (2017). *South Koreas first geothermal plant at Pohang could start operation this year*. Retrieved February 26, 2019, from http://www.thinkgeoenergy.com/south-koreas-first-geothermal-plant-at-pohang-could-start-operation-this-year/

Rizzo, S. (2019). What's actually in the 'Green New Deal' from Democrats? *The Washington Post.* Retrieved March 3, 2019, from https://www.washingtonpost.com/politics/2019/02/11/whats-actually-green-new-deal-democrats/?utm_term=.d8070fd2ae54

Russian Federation Foreign Intelligence Service. (1995). *The Nuclear Potential of Individual Countries.* Retrieved April 5, 2019, from https://fas.org/irp/threat/svr_nuke.htm#taiwan

Sawa, T. (2018). The future shape of Japan's energy policy. *The Japan Times.* Retrieved March 1, 2019, from https://www.japantimes.co.jp/opinion/2018/07/12/commentary/japan-commentary/future-shape-japans-energy-policy/

Smiech, S., & Papiez, M. (2014). *Exploratory data analysis of energy security in the EU member countries in the period 2000-2010*. Cracow University.

Sovacool, B. K. (2011). Evaluating energy security in the Asia pacific: Towards a more comprehensive approach. *Energy Policy*, Vol. *39*(11), 7472–7479.

Sovacool, B. K. (2013). Assessing energy security performance in the Asia Pacific, 1990-2010. *Renewable and Sustainable Energy Reviews*, Vol. *17*, 228–247.

Sovacool, B. K., & Mukherjee, I. (2011). Conceptualizing and measuring energy security: A synthesized approach. *Energy*, Vol. *36*(8), 5343–5355.

Stantec. (2017). *Connecting Rural Taiwan to the Public Drinking Water Supply*. Retrieved April 6, 2019, from https://www.stantec.com/en/projects/taiwan-projects/connecting-rural-taiwan-to-the-public-drinking-water-supply

Statistics Bureau - Ministry of Internal Affairs and Communications. (2018). *Statistical Handbook of Japan 2018*. Retrieved March 1, 2019, from https://www.stat.go.jp/english/data/handbook/index.html

Statistics Bureau - Ministry of Internal Affairs and Communications. (2019). *Japan Statistical Yearbook 2019*. Retrieved March 1, 2019, from http://www.stat.go.jp/english/data/nenkan/68nenkan/1431-03.html

Taipei Times. (2013). China agrees to supply Kinmen Island with water. *The Taipei Times*. Retrieved April 6, 2019, from http://www.taipeitimes.com/News/taiwan/archives/2013/09/04/2003571331

Taiwan Water Corporation. (2017). *The Statistical Yearbook of Taiwan Water Corporation 2016*. Retrieved March 1, 2019, from https://www.water.gov.tw/lp.aspx?CtNode=5580&CtUnit=3771&BaseDSD=7&mp=en

The Environmental Council of the States. (2019). *Refinery Processing Gain*. Retrieved April 2, 2019, from http://www.ematrix.erg.com/glossary.aspx?serial=970

Thorarinsson, L. (2018). *A Review of the Evolution of the Japanese Oil Industry , Oil Policy and its Relationship with the Middle East*. Oxford Institute for Energy Studies.

Tokyo Electric Power Company. (2016). *Electricity Supply Facilities*. Retrieved March 1, 2019, from https://www4.tepco.co.jp/en/corpinfo/illustrated/electricity-supply/transmission-distribution-loss-e.html

Tokyo Electric Power Company. (2019). *Electricity Rate Plans.* Retrieved March 1, 2019, from https://www7.tepco.co.jp/ep/rates/electricbill-e.html

Tokyo Gas Group. (2018). *Tokyo Gas Group CSR Report 2018*. Retrieved March 1, 2019, from https://tokyo-gas.disclosure.site/en/themes/470

Tongsopit, S., Kittner, N., Chang, Y., Aksornkij, A., & Wangjiraniran, W. (2016). Energy security in ASEAN: A quantitative approach for sustainable energy policy. *Energy Policy*, Vol. *90*, 60–72.

Topf, A. (2012). *Once-idled Japanese coal mines back in business*. Retrieved March 1, 2019, from http://www.mining.com/once-idled-japanese-coal-mines-back-in-business/

Tsai, F., & Hsu, E. (2018). Taipower, CPC join hands to explore geothermal power in Yilan. *Focus Taiwan.* Retrieved April 3, 2019, from http://focustaiwan.tw/search/201811070018.aspx?q=geothermal

Twidell, J., & Weir, T. (2006). *Renewable Energy Resources* (2nd ed.). Taylor & Francis.

U.S. Energy Information Administration. (2008). *Taiwan*. Retrieved March 1, 2019, from https://china.usc.edu/sites/default/files/legacy/AppImages/eia-taiwan-brief-2008.pdf

U.S. Energy Information Administration. (2016). *Taiwan: Overview*. Retrieved March 29, 2019, from https://www.eia.gov/beta/international/analysis.php?iso=TWN

U.S. Energy Information Administration. (2017). *Country Analysis Brief: Japan*. Retrieved March 1, 2019, from https://www.eia.gov/beta/international/analysis_includes/countries_long/Japan/japan.pdf

U.S. Energy Information Administration. (2018a). *Country Analysis Brief: South Korea*. Retrieved March 1, 2019, from https://www.eia.gov/beta/international/analysis_includes/countries_long/United_Arab_Emirates/uae.pdf

U.S. Energy Information Administration. (2018b). *Electricity Explained Use of Electricity*. Retrieved March 1, 2019, from https://www.eia.gov/energyexplained/index.php?page=electricity_use

U.S. Energy Information Administration. (2018c). *Glossary*. Retrieved March 1, 2019, from https://www.eia.gov/tools/glossary/index.php

U.S. Environmental Protection Agency, & Coalbed Methane Outreach Program. (2015). *Coal Mine Methane Country Profiles*. Retrieved March 1, 2019, from http://www.globalmethane.org/documents/Toolsres_coal_overview_fullreport.pdf

United Nations. (2008). *Principles and Recommendations for Population and Housing Censuses* (Revision 2). New York. Retrieved March 1, 2019, from https://unstats.un.org/unsd/demographic/sources/census/docs/P&R_Rev2.pdf

United Nations Children Fund, & World Health Organisation. (2017). *Progress on Drinking Water, Sanitation and Hygiene*.

United Nations Department of Economic and Social Affairs Statistics Division. (2016). Conversion factors. *Energy Balances 2016*. New York.

United Nations Economic Commission for Europe. (2014). *Guidelines for the Application of Environmental Indicators*. Retrieved March 1, 2019, from http://www.unece.org/env/indicators.html

United Nations Statistics Division. (2012). *Population using solid fuels, percentage*. Retrieved March 1, 2019, from https://millenniumindicators.un.org/unsd/mdg/SeriesDetail.aspx?srid=712

United Nations Statistics Division. (2019a). *Electricity, net installed capacity of electric power plants.* Retrieved February 11, 2019, from http://data.un.org/Data.aspx?d=EDATA&f=cmID%3AEC%3BtrID%3A13332

United Nations Statistics Division. (2019b). *UN Comtrade Database*. Retrieved March 1, 2019, from https://comtrade.un.org/data

Urabe, Y., Kawamura, T., Sakanoue, T., Uno, O., & Matsuzaki, Y. (2016). Gas Supply Infrastructure. In Y. Kato, M. Koyama, Y. Fukushima, & T. Nakagaki (Eds.), *Energy Technology Roadmaps of Japan: Future Energy Systems Based on Feasible Technologies Beyond 2030* (pp. 197–217). Springer.

URENCO. (2019). *The URENCO SWU Calculator*. Retrieved March 1, 2019, from https://urenco.com/swu-calculator/

Valdés, J. (2018). Arbitrariness in Multidimensional Energy Security Indicators. *Ecological Economics*, Vol. *145*(October 2016), 263–273.

Vivoda, V. (2010). Evaluating energy security in the Asia-Pacific region: A novel methodological approach. *Energy Policy*, Vol. *38*(9), 5258–5263.

Vivoda, V. (2014). *Energy Security in Japan: Challenges After Fukushima* (1st Edition). London: Routledge.

Von Hippel, D., Hayes, P., Williams, J. H., Savage, T., & Suzuki, T. (2010). Evaluating the Energy Security Impacts of Energy Policies. In B. K. Sovacool (Ed.), *The Routledge Handbook of Energy Security*. London: Routledge.

Von Hippel, D., Suzuki, T., Williams, J. H., Savage, T., & Hayes, P. (2011). Energy security and sustainability in Northeast Asia. *Energy Policy*, Vol. *39*(11), 6719–6730.

Water Resource Agency. (2017). *106年各標的用水統計年報 (2017 Annual Report on Water Usage)*. Retrieved March 1, 2019, from http://wuss.wra.gov.tw/annualreports/201900241-%E7%AC%AC%E4%B8%80%E7%AF%87%20%E5%8F%B0%E7%81%A3%E5%9C%B0%E5%8D%80%E6%B0%91%E5%9C%8B106%E5%B9%B4%E5%90%84%E6%A8%99%E7%9A%84%E7%94%A8%E6%B0%B4%E7%B5%B1%E8%A8%88%E5%B9%B4%E5%A0%B1%20.pdf

World Bank. (2019a). *Access to electricity (% of population)*. Retrieved March 1, 2019, from https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS

World Bank. (2019b). *Electric power transmission and distribution losses (% of output)*. Retrieved February 1, 2019, from https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2014&locations=JP&start=1960&view=chart

World Bank. (2019c). *World Development Indicators*. Retrieved March 1, 2019, from https://databank.worldbank.org/data/reports.aspx?source=2&series=NY.GDP.MKTP.CD&country=JPN

World Energy Council. (2019). *Energy Trilemma Index Taiwan*. Retrieved April 5, 2019, from https://www.worldenergy.org/data/trilemma-index/country/taiwan/

World Health Organisation. (2013). *Global Health Observatory Data Repository*. Retrieved March 1, 2019, from http://apps.who.int/gho/data/view.main.1701?lang=en

World Health Organisation/United Nations Children's Fund Joint Monitoring Programme for Water Supply Sanitation and Hygiene. (2017a). *Estimates on the use of water, sanitation and hygiene in Japan*. Retrieved March 1, 2019, from https://washdata.org/data/household#!/jpn

World Health Organisation/United Nations Children's Fund Joint Monitoring Programme for Water Supply Sanitation and Hygiene. (2017b). *Estimates on the use of water, sanitation and hygiene in Republic of Korea*. Retrieved March 1, 2019, from https://washdata.org/data/household#!/kor

World Nuclear Association. (2018a). *Heat Values of Various Fuels*. Retrieved March 1, 2019, from http://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx

World Nuclear Association. (2018b). *Nuclear Power in Japan*. Retrieved March 1, 2019, from http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx

World Nuclear Association. (2018c). *Nuclear Power in Taiwan*. Retrieved April 3, 2019, from http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx

World Nuclear Association. (2018d). *Processing of Used Nuclear Fuel*. Retrieved March 1, 2019, from http://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx

World Nuclear Association. (2019a). *Nuclear Power in Germany*. Retrieved March 3, 2019, from http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx

World Nuclear Association. (2019b). *Nuclear Power in South Korea*. Retrieved March 1, 2019, from http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx

Wu, J. (2000). Supply-Demand of Mineral Resources in Taiwan. In B. Ghose & B. Dhar (Eds.), *Mining, Challenges of the 21st Century* (pp. 147–159). New Delhi: A.P.H. Publishing Corporation.

Xu, C., & Bell, L. (2017). *Worldwide oil, natural gas reserves inch higher in 2017.* Retrieved March 1, 2019, from https://aemstatic-ww2.azureedge.net/content/dam/ogj/print-articles/volume-115/issue-12/wwtable.jpg.scale.LAR

Yang, S. (1985). Petroleum Exploration and Development in Taiwan. *Energy Exploration & Exploitation*, Vol. *3*(3), 231–236.

Yu, J. M. (2017). Taiwan power outage affected 151 companies, caused $3 million in damages. *Reuters.* Retrieved March 13, 2019, from https://www.reuters.com/article/us-taiwan-power-outages/taiwan-power-outage-affected-151-companies-caused-3-million-in-damages-idUSKCN1AX0S3

Yu, S. (2002). Into blackness: Taiwan's mining history at risk of being forgotten. *The Taipei Times.* Retrieved March 31, 2019, from http://www.taipeitimes.com/News/feat/archives/2002/09/29/0000170075/1

Zastrow, M. (2018). South Korea's most-destructive quake probably triggered by geothermal plant. *Nature.* Retrieved February 26, 2019, from https://www.nature.com/articles/d41586-018-04963-y

Zhang, Z. X. (2003). Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. *Energy Economics*, Vol. *25*(6), 625–638.