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Assessing the Level of Energy Security for South Korea's Future Energy Transition Pathways

- The Co-benefits of Climate Change Policies -

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이 논문을 도시계획학 석사 학위논문으로 제출함

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2017년 12월

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Abstract

This study aimed to quantitatively assess the different levels of energy security in South Korea for various energy pathways that it may choose to follow in the future. It starts by identifying and categorizing the factors that define the various dimensions of South Korea's energy security primarily by examining issues that revolve around South Korea's current and future energy systems. Scenarios were selected to assess energy security levels for South Korea's future energy pathways under the conditions that they were comprehensive, acceptable, viable, and posed implications at the same time. Indicators were selected and categorized based on several criteria including their affiliation with the scenarios, data availability, validity in the literature, and perhaps most importantly, in context with the risks prevalent in South Korea's current and future energy system. Indicator values obtained from the scenario projections were calculated based on proven metrics from past studies, which were then converted to ordinal values via minimum-maximum normalization to allow for an integrated and comparative assessment. The results of the study revealed clear signs of changes in the levels of energy security depending on the different pathways taken as represented by each of the scenarios.

Key words: energy security, climate change, energy transition, LEAP, co-benefits

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Chapter I. Introduction

1. Background and Purpose of Study

In 2015, international society agreed upon a united goal to respond to the eminent threats of climate change and limit the global temperature rise to 2℃ until 2100. As of today, 197 Parties have signed the Paris agreement and 148 countries have ratified it.[1] Fossil fuels, which have been at the heart of industrialization throughout the past century, are known to produce carbon dioxide along with various other greenhouse gases that are the main drivers of climate change. Transition towards a clean and renewable energy system is thus a means of mitigating climate change from a broader perspective.

On December 2016, the South Korean government announced the “First Climate Change Response Plan” and the “2030 National Greenhouse Gas Reduction Roadmap”. These national plans were primarily designed to meet the Nationally Distributed Contributions (NDCs) submitted for the Paris Agreement in 2016, and contain systematic roadmaps that need to be followed in order to achieve the targeted emission reductions by 2035. However, skeptics have been critical toward the below average efforts proposed by the South Korean government. There are also concerns that even these goals may not be achieved considering the current course of events and actions (Climate Action Tracker, 2017).

Internally, energy security is becoming a serious issue in South Korea. Although there is no universally agreed definition of energy security in the

1 UNFCCC website, updated for June 2017

academic field, there is a growing consensus on the fact that it should be viewed from a more diverse perspective (Cox E., 2016; Krishnan R., 2016; Sovacool B., 2016). Unlike in the past where the risk was solely confined to that of the supply-side of management, studies over the past couple of decades tended to approach the concept from multiple dimensions including risks relevant to that of the environment, technology, demand-side management, socio-cultural factors, international relations and more (Hippel et al, 2011). A previous review on the literature also reveals that the concept is "highly context-dependent" (Ang et al., 2014). Hence, in viewing the level of energy security and in context with South Korea's future energy sustainability, it is important to assess current issues that revolve around the entire energy system from multiple perspectives.

Currently, around 95% of the entire energy used in South Korea is sourced from abroad, most of which comes from the Middle East where political instability has peeked during the past decade. Also, in 2016, IEA reported that South Korea was the 9th largest energy consumer in the entire world with over 268Mtoe of total final energy consumed, and 7th largest CO_2 emitter with around 11.26tCO_2/capita released in 2014 (IEAa, 2016). Recent outbreaks of earthquakes in the Gyeongsang Province raised concerns for the safety of nuclear power plants, and the ever so prominent air pollution calls for serious health alerts amongst the entire population.

Under such circumstances, South Korea is faced with major decisions to be made in the coming years with respect to transition of its energy system. Given the external and internal context, it seems almost inevitable for South Korea to make some kind of a change, but questions remain as to what degree and direction the change must strive towards. Several studies in the past have attempted to provision various futures for South Korea's energy pathways (WWF Korea, 2017; Jacobson, 2016; Greenpeace, 2012; Park et al., 2014), providing alternate scenarios with different energy mix and demand accordingly. However, none have yet to assess quantitatively, each of its scenarios with respect to the concept of energy security. Also, although many studies have been conducted with a focus on quantitative assessment of the current and past levels of energy security in different regions, not many have attempted to evaluate it in terms of future projections.

Hence, this study aims to quantitatively analyze the different levels of energy security in South Korea for various energy pathways that we may choose to follow. The co-benefits of climate change policies tend to appear locally, in short-term, and with relative certainty in terms of magnitude and timing. Hence an effort to measure the level of such co-benefits of energy transitions in South Korea may allow for a more accurate assessment of the entire benefits posed by the climate change mitigation plans on a national scale.

2. Scope of Research

Policies for energy transition can be interpreted in various ways, and in many cases, are recognized as climate change mitigation policies. From such viewpoint, energy transition produces co-benefits across various parts of the society including employment, health, environment, and energy security. Despite the various forms and magnitude of co-benefits from energy transition, this study only focuses on the effects on the level of energy security.

Recently, WWF Korea published a report “Republic of Korea 2050 Energy Strategy for a Sustainable Future: Korea Energy Vision 2050” (WWF Korea, 2017). The report suggested three major energy pathways that differed from each other in terms of proportion of renewable energy in the entire energy system from the supply side, and the level final energy consumption from the demand side. The basic statistics and assumptions used in the report were mostly adopted from the IEA’s annual projections (IEAb, 2016), and in cases of data unavailability, some national figures (KEEI, 2017) were accounted for. This study will explore through the three scenarios suggested in the report, namely the Moderate Transition Scenario (MTS), Advanced Transition Scenario (ATS), and Visionary Transition Scenario VTS, with respect to the level of energy security in multiple dimensions.

As is the case for each scenario, the scale of the analysis is national and the period of study is until the year 2050. The standard year for analysis was selected for the most recent year given the conditions that all data necessary for analysis were available. In the case of unavailability of any critical information or data, the most recent year with all data available was selected as the standard year. Although the study mainly focused on the quantitative analyses of the different levels of energy security in South Korea under various energy pathways, discussions also include other factors of co-benefits in brief.

3. Research Method

The analysis in this study can be segmented into four major parts. The first part focuses on identifying and categorizing the factors that define the various dimensions of South Korea's energy system, with an emphasis on the concepts of energy security. This was done under close examination and critical assessment of past studies and reports. The second part consists of explaining various future scenarios to be analyzed. Many scenarios in previous studies related to South Korea's future energy pathways have been reviewed in Chapter II, of which the most adequate ones have been selected for analysis. The third part of the study contains details regarding the selection of appropriate indicators that can represent the multi-dimensional features of the concept of energy security in the context of South Korea's future sustainability. The last part of the analysis focused on normalizing and aggregating the results of the indices for each scenario for the years 2014, 2030, and 2050. <Figure 1.> illustrates the conceptual framework of the approach used in the study, and the details are thoroughly outlined in Chapter 3 of the article.

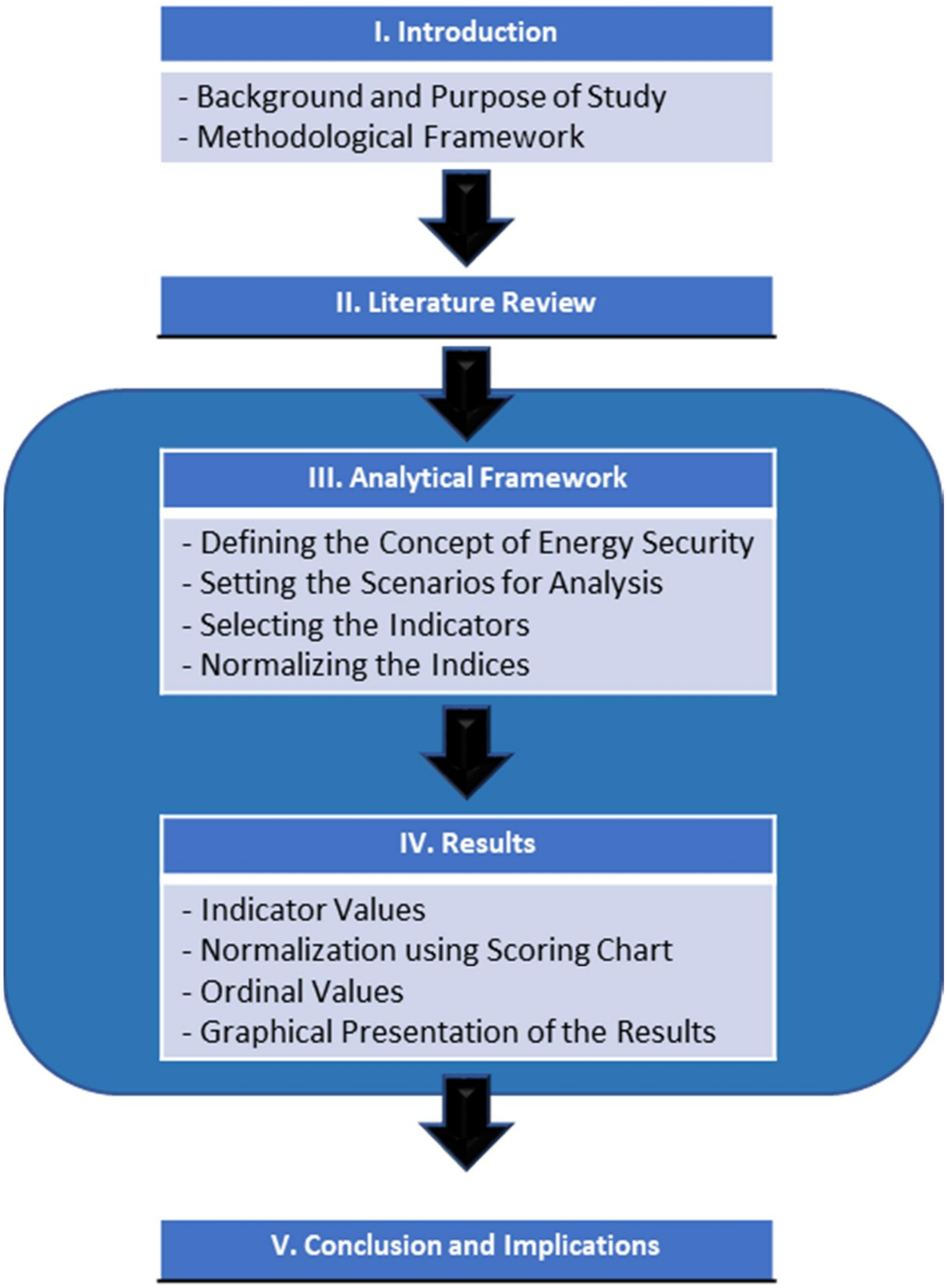

Figure 1. Conceptual Framework of the Analysis

Chapter II. Literature Review

1. Modelling Energy Transition and Projection Pathways

Predicting future energy demand and supply of a region or country entails vast uncertainties. Hence, it is important to select variables and data, to be used as interpreters of the various phenomenon that may occur in energy systems due to intended changes or impacts, with careful considerations. Over the past few years, many studies have sought to project future energy transition pathways for various purposes. World Wildlife Fund (WWF), starting with the Climate Solution Report in 2007, has published several country reports under the theme of 100% renewable energy system by 2050 (WWF, 2007; WWF, 2009; WWF, 2011; WWF, 2015a; WWF, 2015b; Nakata et al., 2003). A group of scientists at Stanford University gathered to project 100% renewable energy scenarios by 2050 for 139 countries around the world (Jacobson, 2016). In South Korea, Park et al. (2014) projected the effects and the likely benefits of transition to low carbon energy system by 2050 (Park et al., 2014). Civil society, such as the Greenpeace, also sought to envision a decarbonized future for South Korea under various scenarios (Greenpeace, 2012). Descriptions on each of these studies have been outlined in <Table 1>.

Table 1. Literature on energy transition and projection of pathways

Author	Year	Title	Description
Jacobson et	2016	100% Clean and	Develops roadmaps to transform the

al.		Renewable Wind, Water, and Sunsight (WWS) All-Sector Energy Roadmaps for 139 Countries of the World	all-purpose energy (electricity, transportation, heating/cooling, industry, agriculture/forestry/fishing) infrastructures of 139 countries to ones powered by wind, water, and sunlight
WWF	2011	The Energy Report: 100% Renewable Energy by 2050	Analyzes the possible pathway for the world to realize 100% renewable energy by 2050, along with the possible effects and means to achieve such goal
Greenpeace	2012	A sustainable energy outlook for South Korea	Studies GHG emissions and other socio-economic impacts of 100% renewable energy scenarios by 2050
Park et al.	2014	Effect of economic growth, industrial structure, efficiency improvement, decarbonization of power sector and fuel substitution for the transition to low carbon society by 2050	This paper analyzed transition pathways toward a low carbon society in Korea to meet the global 2℃ climate target

The studies share a similarity in that they first propose a certain goal, and follow to seek ways to meet such accomplishments. For instance, Jacobson et al. (2016), WWF (2011), and Greenpeace (2012) all set the future scene at 100% renewable energy world and seek to find appropriate pathways to achieving the target. The focus of these studies is not on the likely impacts of such pathways, but the pathways themselves. Park et al. (2014) is slightly unique from these studies in that it sets the future scene according to the visions set forth by the government and the international society. However, although most of the studies presented some form of co-benefits from energy transitions under the scenarios, they often used numbers simply adopted from other studies, sometimes only qualitative, which in some instances, were too brief to be considered seriously. It was also found that these studies often tended to miss out on the importance of the changes in the level of energy security for each scenario.

2. Evaluating the Level of Energy Security

Methodologies used in measuring the level of energy security vary by studies, and it seems evident that there is yet to be a mutually agreed framework or method to analyze it (Yao and Chang, 2014). Reviewing past studies on energy security reveals that in order to analyze it, one must first define and clarify what the term ‘energy security’ means. In the past, energy security was often viewed from the perspectives of the level of supply stability. Hence it was relatively simple to measure its degree under various circumstances. However, a large proportion of the emerging studies tend to categorize energy security into a much broader scale, emphasizing on the needs to address the issue from multiple dimensions (Hippel et al., 2011). <Table 2> outlines some of the studies that took such multi-dimensional approaches.

Table 2. Literature on quantitative evaluation of energy security

Author	Year	Title	Description
Yao and Chang	2014	Energy security in China: A quantitative analysis and policy implications	Examines how China’s energy security has changed over 30 years of reform and the opening period. It constructs a 4-As quantitative evaluation framework—the availability of energy resources, the applicability of technology, the acceptability by society, and the affordability of energy resources.
Sovacool et al.	2011	Evaluating energy security performance from 1990 to 2010 for eighteen countries	Provides an index for evaluating national energy security policies and performance among a number of countries
Mondal et al	2010	The future choice of technologies and co-	Examines the impacts of CO2 emission reduction on future technology selection

		benefits of CO2 emission reduction in Bangladesh power sector	and energy use in Bangladesh power sector up to 2035 considering the base year 2005.
Hippel et al	2011	Energy security and sustainability in Northeast Asia	Develops a broader definition of Energy Security, and describes an analytical framework designed to help to compare the energy security characteristics of different quantitative energy paths as developed using software tools such as the LEAP
Dowling and Russ	2012	The benefit from reduced energy import bills and the importance of energy prices in GHG reduction scenarios	Focuses on the role of major Asian economies in the global effort to reduce greenhouse gas emissions and the benefits to their economies from reduced energy import bills; Uses POLES model
Kim et al.	2014	Analysis of energy security by diversity indices	Estimates South Korea's level of energy security in terms of energy diversity (fuel diversity) using the 4 As

As mentioned above, there is no defined methodology or framework that have been agreed upon for analyzing the level of energy security. Although extensive review of existing literatures revealed that the sub-categories in most of the quantitative approaches were nonetheless similar in terms of their definition and units of measurement, the number of dimensions that was looked into in each of the studies varied from a single dimension to as many as seven dimensions. For instance, Ang et al. (2014) suggests that energy security should be assessed from seven dimensions including energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency. The World Energy Council insists on viewing the concept from three perspectives comprising energy equity, security, and environmental sustainability in their annual publication "World Trilemma Index" (WEC, 2016). Many studies, including Yao and Chang (2014), sought to review the sub-categories that have been considered in past studies and use a framework known as the 4 As comprising the dimensions of availability, affordability, applicability, and acceptability.

3. Mainstreaming Co-benefits into Climate Change Policies

In recent years, the term ‘co-benefits’ had widely been accepted and used across various disciplines of studies including the field of climate change. However, it is also true that there is no common definition of the term that has been agreed upon (Mayrhofer et al., 2015). It is important to clarify such notions prior to analyzing the level of energy security for different pathways, as it may allow for a better understanding on the meaning of the results in terms of policy implications and the goals set forth under the concept of sustainable development.

Energy transition in a country usually takes place under the broader scheme of climate change policies. However, even prior to initiating such schemes, it is often true that decision makers are met with strong resistance from the public due to concerns such as a possible increase in energy prices. As of consequence, many of the NDCs submitted by the participating parties to the Paris agreement are insufficient to meet the goals of reducing the long-term global temperature rise to within 2℃. Some countries, including South Korea, are even assessed as being doubtful in achieving the NDC goals that have been set by their own governments (Climate Action Tracker, 2017).

The concept of co-benefits opens a whole new arena of possibilities for supporting the needs of climate change policies and thus energy transition. Benefits of climate change mitigation actions often accrue over time, but their effects only appear throughout a much longer period of time-span, which is difficult to be felt directly by the public. Such benefits are also spread out quite unevenly across different parts of the world, and the magnitude and timing of benefits occurring are not easy to predict with precision. On the other hand, the co-benefits of climate change policies tend to appear locally, in short-term, and quite certainly in terms of the magnitude and timing of appearance.

Table 3. Literature on the co-benefits of climate change mitigation actions

Author	Year	Title	Description
Mayrhofer et al.	2015	The science and politics of co-benefits in climate policy	Reviews and categorizes past studies on co-benefits and climate change; suggesting the pros and cons of the concept
IPCC AR5	2014	Chapter 7: Energy Systems	Reviews on the co-benefits, risks and spillovers of climate change mitigation actions
Pittel and Rubbelke	2008	Climate policy and ancillary benefits: a survey and integration into the modelling of international negotiations on climate change	Identifies ancillary benefits of climate policy to provide important incentives to attend a new international protocol and more
Bollen et al.	2009	Local air pollution and global climate change: a combined cost-benefit analysis	Reviews on and assesses the implications of co-benefits from climate change mitigation action in lineation with health impacts
Kim et al.	2016	The implications of Co-benefits for Forest Carbon Offsetting in Korea	Investigates how co-benefits can be categorized and integrated into carbon-offsetting standards

Chapter III. Analytical Framework

This quantitative analysis seeked to assess the level of energy security from economic, social, and environmental dimensions, allowing for a linkage between the choices we make under different scenarios and implications for a sustainable future. Analyses and discussions on the level of energy security of a country in future terms may require a holistic and integrated approach.

In this study, the analytical framework is divided into four major parts. (1) The first part focuses on identifying and categorizing the factors that define the various dimensions of South Korea's energy system, with an emphasis on the concepts of energy security. Since defining and assessing the level of energy security should be context specific, issues that revolve around South Korea's current and future energy systems were thoroughly examined. (2) The second part consists of details on the various future scenarios that were used to assess energy security levels for South Korea's future energy pathways. The scenarios from WWF Korea's recent publication (WWF Korea, 2017) were adopted for the reasons that they were comprehensive, acceptable, viable, and posed implications at the same time. (3) The third part of the chapter contains information on the selection and categorization of the indicators that have been used in the analysis. The indicators were selected based on several criteria including affiliation with the scenarios, data availability, validity in the literature, and perhaps most importantly, in context with the risks prevalent in South Korea's energy system. (4) The last part of the chapter provides methods and evidences for normalization and aggregation of the figures denoted by each of the indices selected in part (3).

1. Defining the Concept of Energy Security for South Korea

In defining the concept of energy security, it is important to identify the subjects to which the discussion is being made. Previous attempts to define energy security over the past half century in academic terms have failed to come up with a unified solution. However, they tended to revolve around the central idea of providing answers to the following questions: "To protect what, from what risks, and for which values (Cherp et al., 2014)?"

1) To protect what:

Today, South Korea's energy system is complexed and compounded with the everyday lives of its people, as are the risks it entails. In fact, one could argue that the supply and demand of energy governs the macro and micro economic behaviors of almost all economic bodies in the country. In 2015, more than 62% (136.7MTOE) of the total final energy (218.6MTOE) was consumed by the industry sector, of which 86% was from the manufacturing industries that are the key drivers of South Korea's economy (KEEI, 2016).

Table 4. South Korea's Final Energy Consumption by Sector in 2015

Year	Total	Industry	Transportation	Residential and Commercial	Public and Others
2015	218,608 (100%)	136,724 (62.5%)	40,292 (18.4%)	36,439 (16.7%)	5,152 (2.4%)

Source: Partly extracted from KEEI (2016)

The quality of life of its people is also heavily affected by the energy system, not only in terms of the safety of supply and affordability, but also due to other factors such as employment or risks of nuclear accidents. Air pollution, including

CO_2 emissions is also directly related to the energy system, which also links to South Korea's roles and responsibilities as a member of the international coalition to fight against the threats of climate change.

2) From what risks:

Geographically, South Korea is surrounded by sea across three sides, with North Korea blocking the only route to the mainland, posing threats of uncertainties regarding the stability of energy supply. Despite its highly energy intensive economy, there are hardly any sources of natural gas or oil reserves to be found in the region. In 2015, almost 95% of the total primary energy was sourced through import. Regarding crude oil, which accounts for almost 40% of the entire primary energy, more than 82% was imported from the Middle East (KEEI, 2016) where political instability has peaked during the past decade.

Geo-politically, it lies at the heart of conflict with the two Koreas technically still at war. Tensions are constantly on the rise with North Korea's consequent nuclear tests over the past years and the situation is drawing upon international attention, including that of the Trump regime and the neighboring China.

South Korea boasts a population of more than 51 million people in an area of just around 10 million hectares, which is less than a quarter of the size of California[2]. In this densely populated region, there are currently 24 nuclear power plants actively on the run[3] with more still under construction or in preparation for launch. Most of the reactors are built across the southern-east coast of the Gyeong-buk province, as shown in <Figure 2>, where the frequency and intensity of earthquake outbreaks have been on the rise in recent years. In fact,

2 KOSIS, http://kosis.kr/index/index.jsp

3 KAIF, http://www.kaif.or.kr/?c=dat&s=6

the earthquake that hit the Gyeong-ju city of the Gyeong-buk province on September 2016 was the largest in magnitude (5.8MI) to be ever recorded in South Korea, whilst the other that hit Po-hang city in the same region on November 2017 was recorded to be the second largest one (5.4 MI)[4].

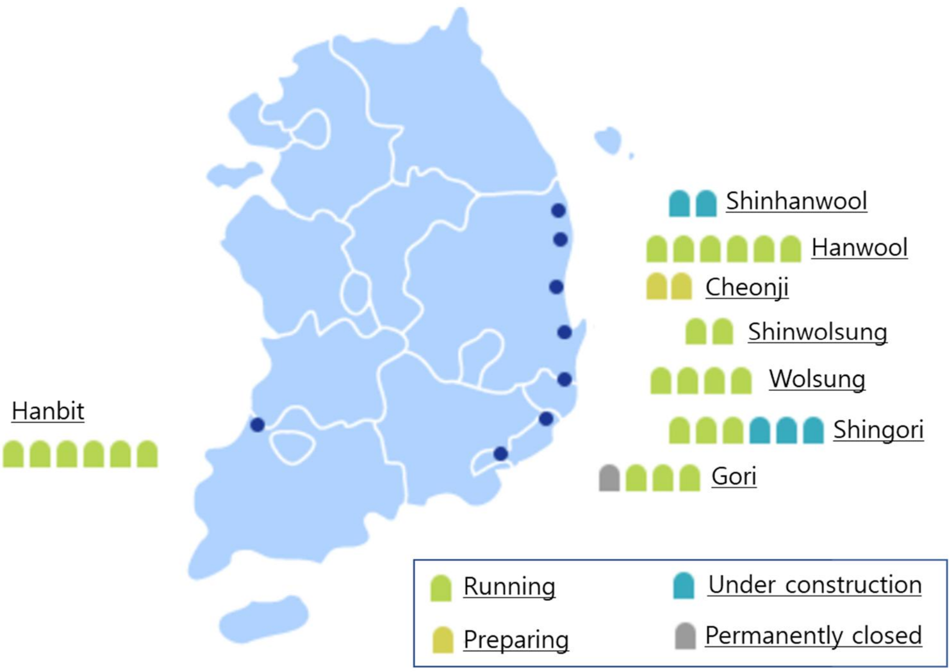

Figure 2. Nuclear Reactors in South Korea

Source: KAIF (2017.08.1), http://www.kaif.or.kr/?c=dat&s=6

On the other hand, air pollution continues to pose serious threats to South Korea in both economic and social terms. In 2016, OECD warned that of all the OECD member countries, South Korea's economy is likely to pay the largest price from air pollution in 2060 (OECD, 2016). According to the report, premature deaths due to air pollution in the year 2010 was approximately 17,000 in South Korea, and the number is expected to rise to nearly 54,000 by 2060 if no

[4] KMA, http://www.kma.go.kr/weather/earthquake_volcano/scalelist.jsp

actions are taken to improve the level of air quality in the region. The report also noted that the economic consequences, which include premature deaths, lost labor days, and disability-adjusted life years (DALY) in monetary terms, would amount to nearly 0.63% of the GDP in 2060, which is the highest amongst all OECD member states (OECD, 2016).

3) For which values:

In 2016, the South Korean government announced the "First Climate Change Response Plan" and the "2030 National Greenhouse Gas Reduction Roadmap" as a response to the obligations set forth at the Paris agreement in 2015. The government is also preparing to announce, in the coming months, "The 8th Basic Plan of Long-term Electricity Supply and Demand" along with the "Renewable Energy Roadmap 3020", which is expected to include infrastructural changes to generate 48.7GW of electricity from renewable sources within the next 13 years[5]. This roadmap, if announced accordingly, would signal an increase in the proportion of renewable energy in power generation to nearly 20% of the entire national production by 2020.

Such agendas and initiatives set forth by the South Korean government in recent years indicate that its values are directed towards similar paths paved by the concept of sustainable development and the values that it pertains. They also, in part, signify the willingness of the government to meet the expectations and its role as a member of the international society to collaborate against the threats of climate change and seek for a globally sustainable future.

The recent ad-hoc committee that was launched to receive public opinion on the construction of two nuclear reactors, which were temporarily ceased due to

5 Green Daily (2017.12.03), http://www.greendaily.co.kr/news/article.html?id=20171203130006

increasing public anxiety, resulted in more votes to recommence constructions. However, such an outcome was largely due to the fact that significant amount of money was already invested for the construction of these reactors, and does not undermine the growing consensus for de-nuclearization in the peninsula. For instance, a recent poll conducted by Real Meter on October showed that more than 60% of the people supported the de-nuclearization policies of the government, while less than 30% of the people voted against it[6].

4) Dimensions of South Korea's Energy Security

The fundamental issues that revolve around South Korea's energy system today is summarized in <Table 5>.

Table 5. Factors defining the concept of energy security for South Korea

Category	Factors
To Protect What?	- Economic stability (macro and micro) - Health and security of the people - Social well-being - Employment - Governance - International responsibility
From What Risks?	- Energy shortage (import deficiency) - Geo-political instability - Nuclear accidents - Air pollution - Economic stagnation or collapse
For Which Values?	- Sustainable development - International collaboration - Social responsibility

6 Real Meter, (2017.10.23) http://www.realmeter.net/

Having reviewed on (1) the current situation that South Korea's energy system faces, (2) the potential risks that need to be avoided (3) and the values that are desired to be proclaimed, it seems evident that safe and stable supply of energy is a vital factor for maintaining the sustainability of South Korea's energy system. The dimension of "Availability" is a key to assessing energy security levels as it encompasses a broad range of the entire energy system, including risks from shortage of energy supply, possibilities of economic instability, and even geo-political instability that may strike as of consequence. Even the quality of life of the people is heavily dependent on stable supply of energy, as energy has embedded itself as a crucial factor in their daily behaviors. Hence, "Availability" should be considered as an important dimension in defining the concept of energy security for South Korea.

"Affordability" of energy is another factor of critical importance. The security of an energy system would not entail any risks if only the sources of energy were affordable at any given time. The dimension of "Affordability" in an energy system affects, and is affected by, the stability, magnitude, and structure of the region's economy. South Korea is heavily industrialized and its economy is largely dependent on highly energy intensive industries. It should also be noted that most of South Korea's primary energy source relies on import from the Middle East, where political instability often leads to the instability of energy prices. Under such circumstances, "Affordability" of energy becomes an important factor to be accounted for when defining the concept of energy security for South Korea.

The last dimension to be considered when defining South Korea's energy security level is the "Acceptability" of the energy system. The recent changes in values set forth by the government and supported by the people point towards the goal of attaining more sustainable and safe sources of energy. Health concerns from air pollution and risks from nuclear accidents, along with the threats of climate change are all an integral part of this dimension of South Korea's energy system, at least in the long-run.

2. Setting the Scenarios for Analysis

In context with the current situations facing South Korea's energy system, the three dimensions of South Korea's energy security have been identified and defined as: availability, affordability, and acceptability. Now, keeping in terms with the purpose of this study, to assess the different levels of energy security for South Korea's future energy pathways, scenarios that depict changes in the levels of South Korea's future energy transition need to be selected to meet the adequacy of the analysis. The scenarios must (1) entail critical and detailed information necessary for assessing the different dimensions of South Korea's energy security, (2) be up to date and projected with the usage of recent data, (3) illustrate pathways on the long-run, (4) provide multiple scenarios to allow for inter-comparison between different pathways reflecting on the different choices made, (5) and be publicly disclosed to prevent violation of research ethics.

Hence, in this study, the scenarios proposed by WWF Korea in their recent publication, "Republic of Korea 2050 Energy Strategy for a Sustainable Future" (WWF Korea, 2017), were selected to assess the future levels of South Korea's energy security. Each of the scenarios proposed in the report depicts different levels of energy transition in terms of the proportion of renewable energy in the entire energy system, makes projections until the year 2050, provides data for both the supply and the demand side of the energy system, and includes environmental factors such as carbon dioxide emissions in the projections.

In the report, a total of four scenarios including the Business-as-Usual (BAU) scenario were suggested, with major differences stemming primarily from variations in the total amount of energy demand and supply due to changes in the supply mix and various other assumptions. Depending on the proportion of renewable energy in the total energy supply system, the scenarios were named as follows: Moderate Transition Scenario (MTS), Advanced Transition Scenario

(ATS), and Visionary Transition Scenario (VTS). Detailed descriptions for each of the scenarios are summarized in <Table 6>.

Table 6. Scenarios for South Korea's Future Energy Pathways

Scenario	Description and Sources
BAU	- Input data were sourced mostly from the projections made by KEEI in their report "Long-term Energy Outlook 2016" - Data on the level of final energy consumption for the standard year (2014) were sourced from KEEI's annual report "Energy Balance 2016" - Figures on new energy and non-energy consumptions were exempted from the analysis
MTS	- The level of decrease in demand was assumed to be in parallel with the level of decrease in OECD Europe for the New Policies Scenario projected in IEA's "World Energy Outlook 2016" - Total level of final energy consumption decreased by 7% in 2050 compared to the standard year - Renewable energy accounted for 45% of the total final energy consumption in 2050 - Gas usage in the building sector was assumed to be on equal levels with that of OECD Europe
ATS	- The level of decrease in demand was assumed to be in parallel with the level of decrease in OECD Europe for the De-carbonization Scenario projected in IEA's "World Energy Outlook 2016" - Total level of final energy consumption decreased by 24% in 2050 compared to the standard year - Renewable energy accounted for 55% of the total final energy consumption in 2050
VTS	- The level of decrease in demand was assumed to be in parallel with the level of decrease in OECD Europe for the De-carbonization Scenario projected in IEA's "World Energy Outlook 2016" - Total level of final energy consumption decreased by 24% in 2050 compared to the standard year - Renewable energy accounted for 100% of the total final energy consumption in 2050

Source: WWF Korea (2017)

3. Selecting the Indicators

As can be seen from the literature review in Chapter II and the first part of this chapter, it is evident that energy security can no longer be evaluated solely from the supply side of management. Today, the term 'energy security' encompasses a much broader dimension including that of the "social, economic, and environmental risks related to the energy system of a region or a country" (Hippel et al., 2009). Such multi-dimensional qualities of energy security make it difficult to quantitively assess its level especially in terms of future time-scales.

In this study, a set of indicators were selected to compare the current and future status of the energy security levels of South Korea's energy system considering the context to which the discussion is being made. The three dimensions that define the level of energy security for South Korea were dissected into smaller sub-components to illustrate the distinct characteristics of each dimension, and indicators were selected for each of these sub-components to depict their features accordingly.

1) Criteria for the Selection of Indicators

To begin with, articles on the quantitative assessment of energy security between the years 2001 to 2017 were reviewed, and a collection of the entire set of indicators that have been used in past studies, at least once, was recorded. Most of this part of the study relied on the previous study (Sovacool et al., 2011) that had already completed a vast collection of relevant indicators, to which more recently proposed and used indicators were added (Cox E., 2016; World Energy Council, 2016; Ang et al., 2014; Yao and Chang, 2014; Cherp et al., 2014). As a result, a total of 372 indicators were collected from 104 studies that have been reviewed, from which the final set of indicators were selected.

Selection of appropriate indicators amongst the large list was made considering their relevance to the subject of analysis, and their representativeness for each of the three dimensions. The base principles adopted in the selection of the indicators in this study referenced those taken by the World Energy Council (2016), in their annual publication of energy security levels for different countries across the world, and are as follows:

1) Reflects each of the dimensions of South Korea's energy security equally
2) Able to assess long-term scenarios
3) Can be expressed quantitatively
4) Able to show vulnerabilities or risks of the energy system
5) Availability of data and/or information

To be more specific, indicators that represented similar values or risks were exempted primarily as to avoid errors from double-counting. Secondly, factors that were considered as being inappropriate for explaining the status of energy security in South Korea were excluded from the list. For example, since South Korea hardly possesses any natural reserves, indicators measuring the level of reserves, or reserves to production ratio were not considered. Also, indicators that were not suitable in the geopolitical context of South Korea were omitted. These include indicators such as electricity import or grid. Many indicators resembling risks that do not change with times or according to scenarios were not considered, as well as indicators that were either too meticulous or too general. Finally, some indicators were excluded due to unavailability of data.

2) Dimension I: Availability

The availability of resources reflects on factors that have traditionally been considered as determining the level of energy security in the past. It remains to be one of the most critical dimensions to be considered when analyzing the level of energy security regardless of context, and no studies in the past have been conducted in the field without its inclusion. Also, as noted in the first part of this Chapter, stability and security of supply is vital for South Korea especially considering its highly energy intensive economy and large import dependency of primary sources. Hence, this study also includes the dimension of availability for assessment.

The availability dimension was divide into four sub-categories to be able to resemble some of its core aspects with distinct indicators, including the (1) security of supply, (2) import dependency, (3) diversification of energy sources, and (4) the level of energy consumption. The security of supply was calculated as the total primary energy supply per capita. Import dependency, which signifies the level of self-sufficiency of an energy system was calculated as a percentage of imported primary energy to the total level primary energy production. Herfindhal-Herschman Index, which is often used to measure the level of market diversity, was adopted to indicate stability of energy supply via diversification of energy sources. The level of final energy consumption per capita was also selected to assess the availability of energy from the demand side of management.

Metrics for the calculation of the indices were also referenced from the past studies that were mentioned above (Cox E., 2017; World Energy Council, 2016; Ang et al., 2014; Yao and Chang, 2014; Cherp et al., 2014; Sovacool et al., 2011).

3) Dimension II: Affordability

Energy can only be made available for use when it is affordable, and thus affordability is an important aspect that determines the level of energy security in any context. However, many of the indicators suggested and used in past studies to measure the level of affordability were inadequate for use in this analysis as they mostly did not consider assessment of the dimension in future terms. It was also required that the selected indicators were integrated and adopted in the scenarios that were used in this analysis providing sufficient amount of data for assessment. Given the circumstances, a set of indicators that best described the characteristics of the affordability dimension were selected to represent the sub-categories of (1) procurement, (2) access, (3) price efficiency, and (4) cost of energy transition.

The procurement component was measured as the net fuel import to GDP, whilst access was calculated according to the level of annual household electricity consumption. Efficiency in monetary terms was denoted by the total final energy consumption per real GDP, and the total cost of energy transition was adopted from WWF Korea (2017).

4) Dimension III: Acceptability

Another core dimension that defines the level of South Korea's energy security is Acceptability. Although it is true that emphasis has been laid upon the importance of environmental and social aspects in assessing the level of energy security in recent years, this study incorporates the two aspects into a single dimension of acceptability as was done in few other cases in the past (Tongsopit et al., 2016; Yao and Chang, 2014; Kruyt et al., 2009). This was largely due to the fact that many of the social indicators proposed in the past studies were either uncountable (i.e. qualitative) or lacked data for the specific purposes of analysis in this study. Also, since the output of this study is characterized to be an integrated and aggregated assessment of the different dimensions of energy security, segregation of the environmental and social aspects of the energy system may have reduced the emphasis on the importance of availability and affordability in measuring the level of energy security.

The acceptability was also divided into four sub-categories including measures for (1) climate change, (2) air pollution, (3) share of renewable energy, and (4) safety. Impacts related to climate change was measured using the total amount of carbon dioxide emissions from energy production and use, whilst the level of SO2 was considered as the indicator for air pollution referencing from past studies (Yao and Chang, 2014; Sovacool et al., 2011). The share of renewable energy in the total final energy consumption was included to resemble both the environmental sustainability and social values as described in the first part of this Chapter, and the share of nuclear energy in the total electricity generation was chosen to indicate on the risks from nuclear accidents. Yao and Chang (2014) explain that the share of nuclear energy in the total electricity generation reflects on "how the population accepts nuclear energy in their community." However, the same indicator included in this study is denoted as reflecting on the component of safety, considering the sudden rise of frequency and magnitude of earthquakes in South Korea as described above.

<Table 7> provides a summary on the dimensions, components, and thus the indicators that were selected and used in this analysis for the assessment of South Korea's future energy security levels for different pathways.

Table 7. Indicators Selected for the Assessment of South Koreas Future Energy Security

Dimension	Component	Metric	Unit
Availability	Security of supply	Total primary energy supply per capita	MTOE / capita
	Dependency	Import to primary supply	%
	Diversification	Herfindhal-Herschman Index	%
	Consumption	Total final energy consumption per capita	MTOE/capita
Affordability	Efficiency	Energy Intensity	TFEC / GDP

	Access	Annual household electricity consumption	kWh
	Cost	Net accumulated cost of energy transition	Won
	Procurement	Net fuel import to GDP	Fuel imports / GDP
Acceptability	Climate Change	Total energy related CO_2 emissions	Metric tons of CO_2
	Safety	Share of nuclear energy in the total electricity generation	%
	Renewables	Share of renewable energy in TFEC	%
	Pollution	Total energy related SO_2 emissions	Metric tons of SO_2/MTOE

4. Normalizing the Indices

The results for each of the sub-categorical indicators shown in <Table 5> were mostly found via LEAP and the scenarios proposed by WWF Korea (2017), although in some cases, further calculations were conducted based on the output data obtained from it. However, the resulting units for each sub-category are different, and to be able to carry out a quantitative analysis on the level of energy security for different levels of energy transition in a comprehensive and integrated manner, these numbers need to be coded and normalized on a scale of ordinal values.

In this study, the above indicators have been equally weighted and converted into a scoring range of 1~10 to make the results of the analysis comparable. This allows for a comparison of the level of energy security between different dimensions, for each scenario, and for the specific periods of interest. Equal weighting was adopted under the consideration that variations in the weighting of different components may result in a biased output, depending on the rationale that deems one component superior over the other.

Minimum-maximum normalization was used to perform linear transformation of the indicator results, and a score scale was developed to convert indicator results into ordinal values for the years 2014, 2030, and 2050.

Chapter IV. Results

1. Indicator Results

To begin with, each of the indicators was calculated based on the data projected from the adopted scenarios, using the metrics that evidenced from usage in past studies (Cox E., 2016; World Energy Council, 2016; Ang et al., 2014; Yao and Chang, 2014; Cherp et al., 2014; Sovacool et al., 2011). To be more specific, primary data on the levels of total final energy consumption, imports, net accumulated costs of energy transition, electricity consumption, CO2 emissions, and energy mix for the years 2030 and 2050 were adopted from the projections made by the scenarios from WWF Korea (2017). These figures were then converted to indicator values via the metrics provided in <Table 7>. As for the calculation of SO2 emissions, national emission coefficients provided by the National Institute of Environmental Research were used[7]. The results have been organized into separate tables from <Table 8> to <Table 11> for the years 2014, 2030, and 2050, for each scenario.

2. Linear Transformation of the Results

The results of the indicator values were transformed into ordinal values for

[7] NIER, https://www.neir.go.kr/

inter-comparisons between the scenarios, and between different timescales. As mentioned in the previous chapter, the values were transformed linearly into a scale of 1 to 10. In order to do this, a scoring chart was created using the min-maximum

Table 8. Indicator Results for the Business-as-Usual Scenario

Dimension	Component	Simple Indicators and Metrics	Metrics	Units	2014	2030	2050
Availability	Security of Supply	Total primary energy supply per capita	TPES/Population	MTOE/Million	4.17931	4.892239	6.44711
	Diversification	Diversification in energy (electricity) production	Herfindhal-Herschman		0.30187	0.32809	0.28945
	Dependency	Import to primary supply	%		0.9846	0.9796	0.9695
	Consumption	Total final energy consumption per capita	TFEC/Population	MTOE/Million	2.551724	2.839009	3.523962
Affordability	Procurement	Net fuel import to GDP	Fuel Imports/GDP	MTOE/Trillion Won	0.15	0.13	0.1
	Cost	Net accumulated cost of energy transition (accumulated cost)	Trillion Won		0	968.4444	2179
	Access	Annual household electricity consumption (in kWh)	TWh/Million household		25.25114	28.51071	30.24465
	Efficiency	Energy intensity (Total final energy consumption per GDP)	TFEC/GDP	MTOE/Trillion Won	0.09075	0.072067	0.051979
Acceptability	Climate Change	CO2 emissions from energy production and use (total)	MtCO2eq		540.6	626.7	640.2
	Pollution	SO2 emissions from energy production and use	Tonnes/MTOE		0.343161	0.38119	0.43467
	Renewables	Share of renewable energy in TFEC	%		2.46	3.082222	4
	Safety	Share of nuclear energy in the total electricity generation	%		32	36.11246	42

Table 9. Indicator Results for the Moderate Transition Scenario

Dimension	Component	Simple Indicators and Metrics	Metrics	Units	2014	2030	2050
Availability	Security of Supply	Total primary energy supply per capita	TPES/Population	MTOE/Million	4.17931	3.681457	3.325714
	Diversification	Diversification in energy (electricity) production	Herfindhal-Herschman		0.30187	0.18732	0.24708
	Dependency	Import to primary supply	%		0.9846	0.9423	0.8354
	Consumption	Total final energy consumption per capita	TFEC/Population	MTOE/Million	2.551724	2.476342	2.43562
Affordability	Procurement	Net fuel import to GDP	Fuel Imports/GDP	MTOE/Trillion Won	0.15	0.1	0.05
	Cost	Net accumulated cost of energy transition (accumulated cost)	Trillion Won		0	958.6667	2157
	Access	Annual household electricity consumption (in kWh)	TWh/Million household		25.25114	25.88638	28.04015
	Efficiency	Energy intensity (Total final energy consumption per GDP)	TFEC/GDP	MTOE/Trillion Won	0.09075	0.062861	0.035926
Acceptability	Climate Change	CO_2 emissions from energy production and use (total)	$MtCO_2eq$		540.6	455	269.2
	Pollution	SO_2 emissions from energy production and use	Tonnes/MTOE		0.343161	0.24142	0.15557
	Renewables	Share of renewable energy in TFEC	%		2.46	21.30444	45
	Safety	Share of nuclear energy in the total electricity generation	%		32	32	32

Table 10. Indicator Results for the Advanced Transition Scenario

Dimension	Component	Simple Indicators and Metrics	Metrics	Units	2014	2030	2050
Availability	Security of Supply	Total primary energy supply per capita	TPES/Population	MTOE/Million	4.17931	3.424567	2.589363
	Diversification	Diversification in energy (electricity) production	Herfindhal-Herschman		0.30187	0.19002	0.28077
	Dependency	Import to primary supply	%		0.9846	0.9002	0.7686
	Consumption	Total final energy consumption per capita	TFEC/Population	MTOE/Million	2.551724	2.317674	1.990573
Affordability	Procurement	Net fuel import to GDP	Fuel Imports/GDP	MTOE/Trillion Won	0.15	0.09	0.04
	Cost	Net accumulated cost of energy transition (accumulated cost)	Trillion Won		0	899.1111	2023
	Access	Annual household electricity consumption (in kWh)	TWh/Million household		25.25114	23.97119	22.91872
	Efficiency	Energy intensity (Total final energy consumption per GDP)	TFEC/GDP	MTOE/Trillion Won	0.09075	0.058833	0.029361
Acceptability	Climate Change	CO2 emissions from energy production and use (total)	MtCO2eq		540.6	421.4	173.8
	Pollution	SO2 emissions from energy production and use	Tonnes/MTOE		0.343161	0.20183	0.10393
	Renewables	Share of renewable energy in TFEC	%		2.46	25.74889	55
	Safety	Share of nuclear energy in the total electricity generation	%		32	24	16

Table 11. Indicator Results for the Visionary Transition Scenario

Dimension	Component	Simple Indicators and Metrics	Metrics	Units	2014	2030	2050
Availability	Security of Supply	Total primary energy supply per capita	TPES/Population	MTOE/Million	4.17931	3.129899	1.282544
	Diversification	Diversification in energy (electricity) production	Herfindhal-Herschman		0.30187	0.18317	0
	Dependency	Import to primary supply	%		0.9846	0.9846	0.8124
	Consumption	Total final energy consumption per capita	TFEC/Population	MTOE/Million	2.551724	2.317674	1.990573
Affordability	Procurement	Net fuel import to GDP	Fuel Imports/GDP	MTOE/Trillion Won	0.15	0.08	0.02
	Cost	Net accumulated cost of energy transition (accumulated cost)	Trillion Won		0	1001.333	2253
	Access	Annual household electricity consumption (in kWh)	TWh/Million household		25.25114	29.96761	38.0769
	Efficiency	Energy intensity (Total final energy consumption per GDP)	TFEC/GDP	MTOE/Trillion Won	0.09075	0.058833	0.029361
Acceptability	Climate Change	CO2 emissions from energy production and use (total)	MtCO2eq		540.6	376.7	44.9
	Pollution	SO2 emissions from energy production and use	Tonnes/MTOE		0.34316	0.19351	0
	Renewables	Share of renewable energy in TFEC	%		2.46	45.7489	100
	Safety	Share of nuclear energy in the total electricity generation	%		32	16	0

approach. For each indicator results, the highest value was allocated a score of 10, whereas the lowest value was given a score of 1. The rest of the figures for the same indicator describing a different scenario and/or a different timespan were allocated appropriate scores according to the chart. Details on the ranges that were used in this analysis for scoring indicator performances can be found in <Table 12>.

After normalizing the indicator values into ordinal scale, the results for each of the scenarios were aggregated to allow for inter-comparison of the different levels of energy security between the scenarios, and between different time span. It is notable that the scores for the “cost” category within the “Affordability” dimension is missing from this aggregated result. This was because the “cost” component was calculated via ‘accumulated net cost’ of energy transition starting from the year 2014. Hence in calculating the average value of the affordability dimension, for the years 2014 and 2030, only values for the other three components were considered. Average scores were calculated for each dimension, for each year, and for each scenario. <Table 13> summarizes on the results of this aggregation.

3. Graphical Assessment of the Energy Security Levels

The average ordinal values aggregated in <Table 13> were plotted on the triangular graphs as shown in Figures 2 to 5. As can be seen from these graphs, the energy security level in 2014 is stagnant as it is the standard year for analysis with all the figures being equal across different scenarios. Affordability stands out to be the strongest dimension amongst the three, while acceptability received the lowest score of 2.25 out of 10. The status of the energy security level in 2014 was marked in all other graphs for comparison.

In the case of the BAU, there is not much change in 2030 in comparison to the energy security levels in 2014. Affordability remained to be the strongest point,

Table 12. Scoring Chart for Normalizing the Indicator Values

Dimension	Indicators	Ordinal Value Scoring Scale									
		1	2	3	4	5	6	7	8	9	10
Availability	Security of Supply	1.28 - 1.797	1.797 - 2.314	2.314 - 2.831	2.831 - 3.348	3.348 - 3.865	3.865 - 4.382	4.382 - 4.899	4.899 - 5.416	5.416 - 5.933	5.933 - 6.45
	Diversification	0.412 - 0.389	0.389 - 0.366	0.366 - 0.343	0.343 - 0.320	0.320 - 0.298	0.298 - 0.275	0.275 - 0.252	0.252 - 0.229	0.229 - 0.206	0.206 - 0.183
	Dependency	0.985 - 0.887	0.887 - 0.788	0.788 - 0.690	0.690 - 0.591	0.591 - 0.493	0.493 - 0.394	0.394 - 0.296	0.296 - 0.197	0.197 - 0.099	0.099 - 0
	Consumption	1.991 - 2.144	2.144 - 2.298	2.298 - 2.451	2.451 - 2.604	2.604 - 2.758	2.758 - 2.911	2.911 - 3.064	3.064 - 3.217	3.217 - 3.371	3.371 - 3.524
Affordability	Procurement	0.02 - 0.033	0.033 - 0.046	0.046 - 0.059	0.059 - 0.072	0.072 - 0.085	0.085 - 0.098	0.098 - 0.111	0.111 - 0.124	0.124 - 0.137	0.137 - 0.15
	Cost	2253 - 2230	2230 - 2207	2207 - 2184	2184 - 2161	2161 - 2138	2138 - 2115	2115 - 2092	2092 - 2069	2069 - 2046	2046 - 2023
	Access	22.919 - 24.435	24.435 - 25.951	25.951 - 27.466	27.466 - 28.982	28.982 - 30.498	30.498 - 32.014	32.014 - 33.530	33.530 - 35.045	35.045 - 36.561	36.561 - 38.077
	Efficiency	0.0294 - 0.0355	0.0355 - 0.0417	0.0417 - 0.0478	0.0478 - 0.0540	0.0540 - 0.0601	0.0601 - 0.0662	0.0662 - 0.0724	0.0724 - 0.0785	0.0785 - 0.0847	0.0847 - 0.0908
Acceptability	Climate Change	640.2 - 580.7	580.7 - 521.1	521.1 - 461.6	461.6 - 402.1	402.1 - 342.6	342.6 - 283.0	283.0 - 223.5	223.5 - 164.0	164.0 - 104.4	104.4 - 44.9
	Pollution	0.4347 - 0.3912	0.3912 - 0.3478	0.3478 - 0.3043	0.3043 - 0.2608	0.2608 - 0.2174	0.2174 - 0.1739	0.1739 - 0.1304	0.1304 - 0.0869	0.0869 - 0.0435	0.0435 - 0
	Renewables	2.46 - 12.21	12.21 - 21.97	21.97 - 31.72	31.72 - 41.48	41.48 - 51.23	51.23 - 60.98	60.98 - 70.74	70.74 - 80.49	80.49 - 90.25	90.25 - 100
	Safety	42 - 37.8	37.8 - 33.6	33.6 - 29.4	29.4 - 25.2	25.2 - 21.0	21.0 - 16.8	16.4 - 12.6	12.6 - 8.4	8.4 - 4.2	4.2 - 0

Table 13. Ordinal Indicator Scores

Year 2030	Indicators	2014	Scenarios (2030)				Scenarios (2050)			
			BAU	MTS	ATS	VTS	BAU	MTS	ATS	VTS
Availability	Security of Supply	6	7	5	4	4	10	4	3	1
	Diversification	5	4	10	10	10	6	8	6	1
	Dependency	1	1	1	1	2	1	2	3	10
	Consumption	4	6	3	3	1	10	4	3	1
	AVERAGE	4	4.5	4.75	4.5	4.25	6.75	4.5	3.75	3.25
Affordability	Procurement	10	9	7	6	5	7	3	2	1
	Cost	-	-	-	-	-	4	5	10	1
	Access	2	4	2	1	5	5	4	1	10
	Efficiency	10	7	7	5	5	4	2	1	1
	AVERAGE	7.33	6.67	5.33	4	5	5	3.5	3.5	3.25
Acceptability	Climate Change	2	1	4	4	5	1	7	8	10
	Pollution	3	2	5	6	6	1	7	8	10
	Renewables	1	1	2	3	5	1	5	6	10
	Safety	3	2	3	5	7	1	3	7	10
	AVERAGE	2.25	1.5	3.5	4.5	5.75	1	5.5	7.25	10

followed by availability, and acceptability respectively. However, in 2050, there is a dramatic shift in scores where availability increases dramatically whilst both the affordability and acceptability shows a slight decrease. Assessing the changes in values for the sub-components in <Table 13> reveals that the increased level of the availability dimension was due to increase in the security of supply, and security of energy consumption.

In the case of the Moderate Transition Scenario (MTS), availability and acceptability increases while affordability decreases in 2030. In 2050, acceptability shows a dramatic increase and affordability decreases even further, while availability remains to be constant. As mentioned above, the pathways depicted in this scenario include 7% reduction in the total level of final energy consumption along with the renewable energy accounting for about 45% of the total final energy consumed in 2050. This is reflected in <Table 13> as scores regarding CO2 reductions and air quality increased, whilst the decrease in the level of affordability accounted for the reduction in energy efficiency in for the most part.

In the case of the Advanced Transition Scenario (ATS), as the name suggests, the shift in scores tended to be on similar trends to those reviewed in MTS, except that the degree of the changes was slightly larger in scale. ATS is based under the assumptions that there will be a 24% reduction in the total amount of final energy consumption by 2050, along with the renewable energy accounting for about 55% of the total final energy consumed.

In the case of the Visionary Transition Scenario (VTS), which assumes the supply of renewables to reach 100% by 2050, the level of acceptability increases steeply from 2030 to 2050. However, it should be noted that the scores for affordability and availability decrease quite steeply at the same time. The sub-components that showed the sharpest decrease over the period was diversification, which accounted for such a dramatic decrease in the availability dimension whilst security of supply and procurement also decrease quite noticeably.

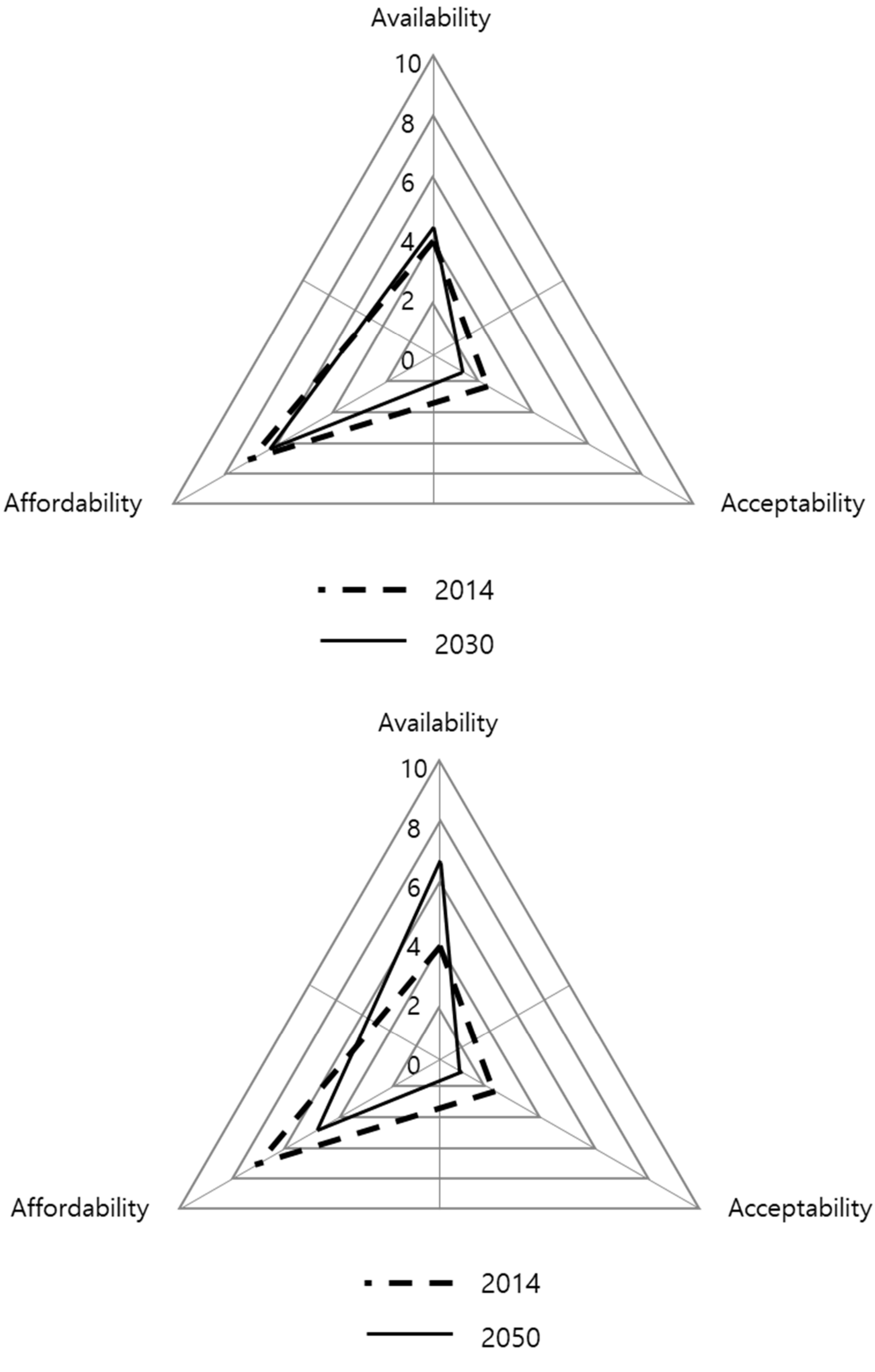

Figure 3. Average Ordinal Indicator Scores for BAU

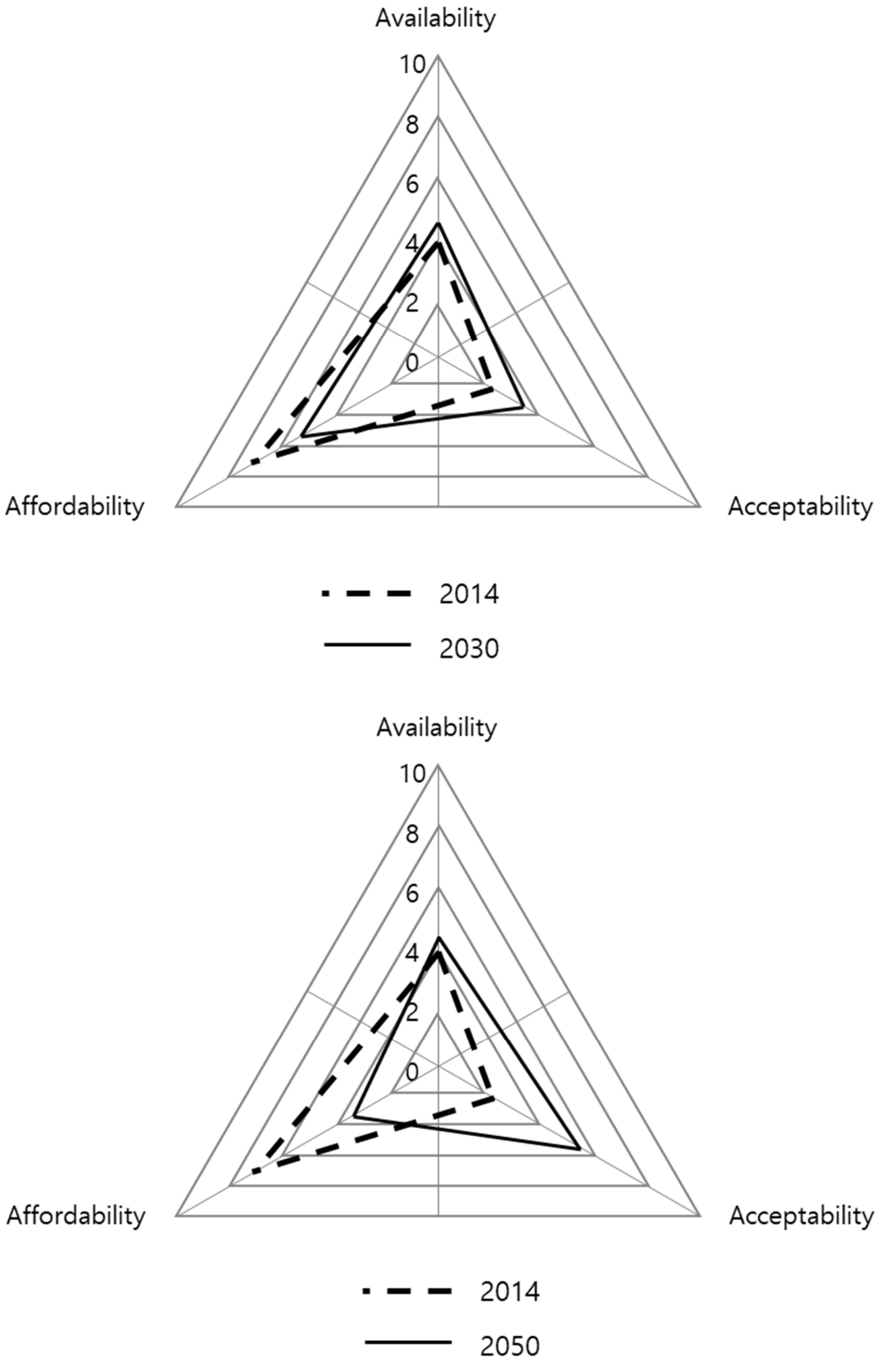

Figure 4. Average Ordinal Indicator Scores for MTS

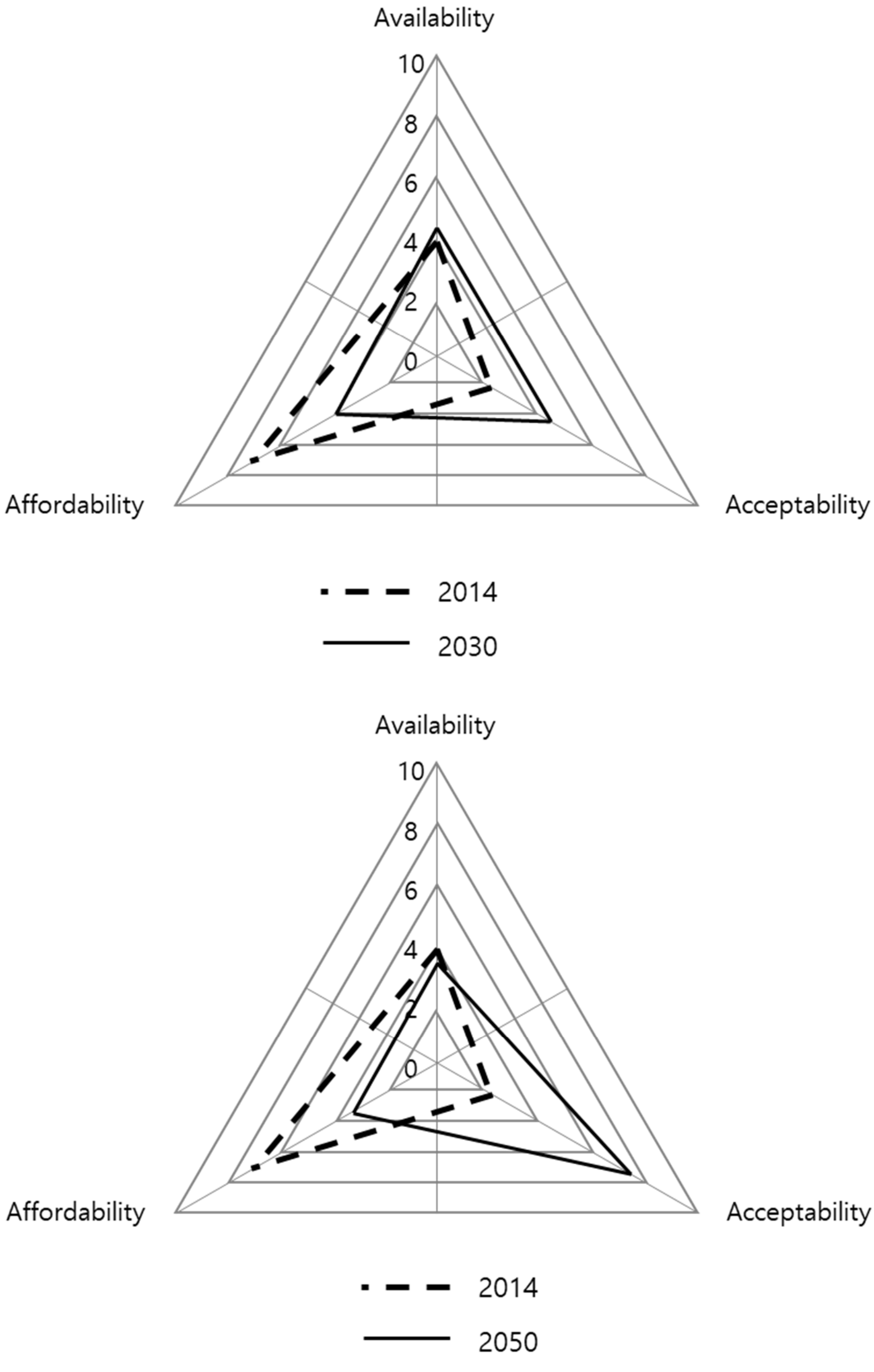

Figure 5. Average Ordinal Indicator Scores for ATS

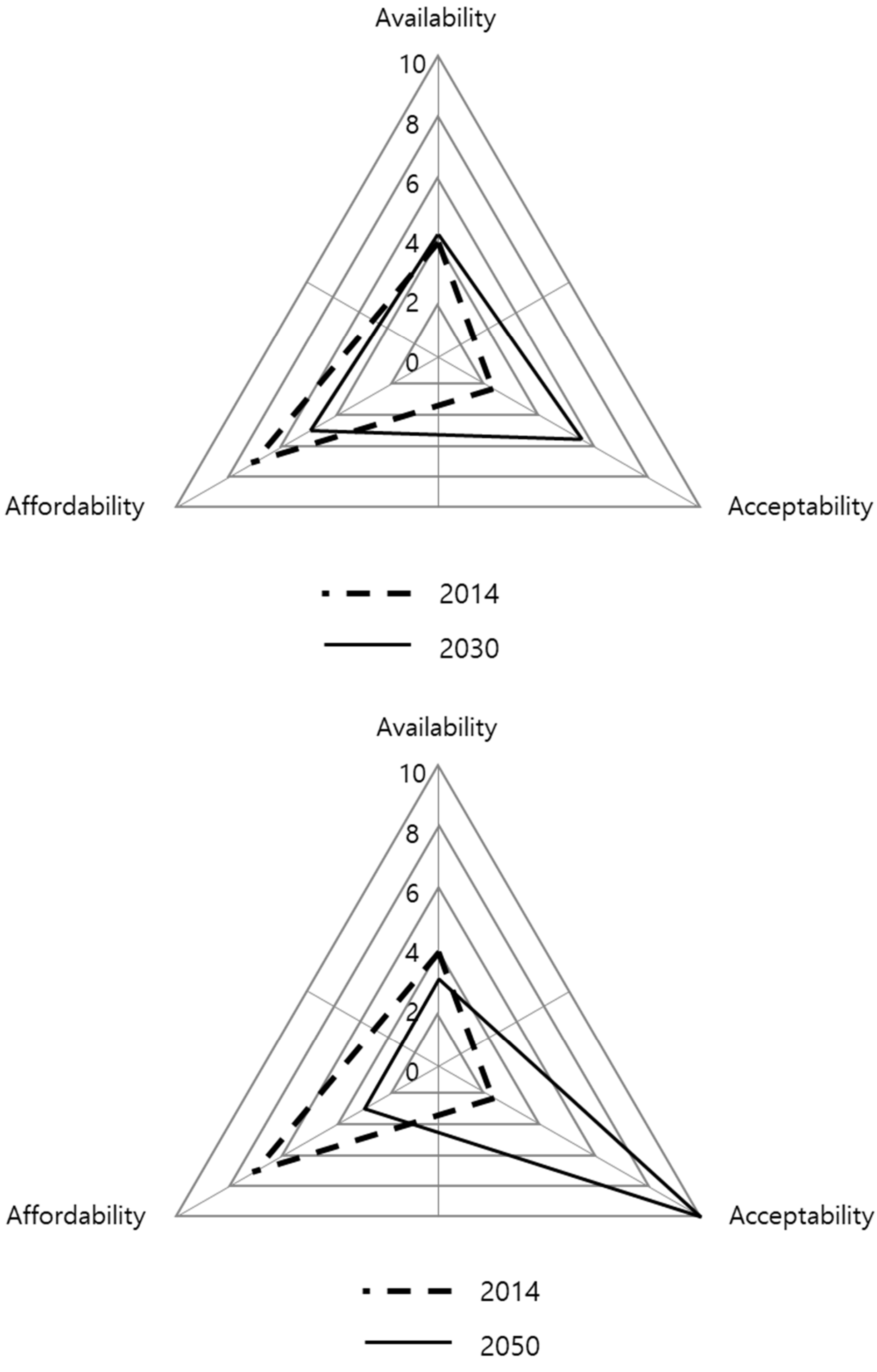

Figure 6. Average Ordinal Indicator Scores for VTS

Chapter V. Implications and Conclusion

Although the study attempted to review the different levels of energy security as a consequence of energy transition in future terms, there are some limitations and possible areas for improvement in the study. For instance, although the study takes place within the time-frame of the future, assessment on the factors of uncertainties were not able to be dealt with as it was considered to be exceeding the scope of the research. Also, unavailability of data related to future projections also rendered selection of some of the indicators in certain cases.

Nonetheless, this study aimed to quantitatively assess the different levels of energy security in South Korea for the various energy pathways that we may choose to follow. It seeked to pursue answers to the questions including: "What is energy security and how can it be defined in the context of South Korea's future energy pathways?", "What are the factors that determine the level of energy security in South Korea?", "How can it be assessed quantitatively?", and "What policy implications can be raised through the assessment and findings?"

As for the process, it started by identifying and categorizing the factors that defined the various dimensions of South Korea's energy system, with an emphasis on the concepts of energy security from past studies. In doing so, issues that revolve around South Korea's current and future energy systems were thoroughly examined.

In the next part, scenarios were selected to assess energy security levels for South Korea's future energy pathways. These scenarios were selected under the reasons that they were comprehensive, acceptable, viable, and posed implications at the same time. Having defined the different dimensions of energy security for South Korea, and having selected the appropriate scenarios to be used for analysis, indicators were selected and categorized. These indicators were selected based on several criteria including their affiliation with the scenarios, data availability, validity in the literature, and perhaps most importantly, in context with the risks prevalent in South Korea's current and future energy system.

Using these indicators, the projections set forth by the 4 scenarios were assessed in Chapter IV. Indicator values obtained from the scenario projections were calculated based on the proven metrics, which were then converted to ordinal values via minimum-maximum normalization to allow for an integrated and comparative assessment. The results of the study revealed clear signs of changes in the levels of energy security depending on the different pathways taken as represented by each of the scenarios.

To give a brief summary of the results, the energy security level of the BAU scenario improved in terms of availability, but at the same time, decreased in terms of both affordability and acceptability. The acceptability dimension of the energy security level of MTS increased at the expense of affordability, while the level of availability remained constant. The VTS showed a remarkable increase in the level of energy security in terms of acceptability, but on the other hand lost vast amounts of scores from the affordability and availability dimensions. In chronological terms, results for the ATS and the VTS tended to show a much more balanced outcome in 2030 compared to those in 2050, signaling on the possible risks that may be posed by changes that occur rather too fast to be considered as being realistic or even efficient.

As mentioned above, energy security is becoming a serious issue in South Korea over the recent years. With around 95% of the entire energy being sourced from abroad, it still remains to be one of the largest energy consumers in the world. Under such circumstances, South Korea has many pathways to choose from, with respect to the different levels of transition of its energy system. However, thorough evaluation on the likely consequences of such changes is needed prior to action to decreases possibilities of risks. In that respect, this study sets a footstep by providing an assessment on the relative levels of energy security depending on the different levels of energy transition in South Korea.

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국문 초록

한국의 미래 에너지 전환 경로에 따른 에너지 안보 수준 분석

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본 연구는 대한민국이 선택 가능한 다양한 미래 에너지 경로에 따른 에너지 안보 수준을 정량적으로 분석하고자 하였다. 우선, 대한민국의 현재와 미래 에너지 시스템을 둘러싼 주요 사안들을 정리하여, 대한민국을 대상으로 한 에너지 안보의 개념을 다양한 차원에서 정의하였다. 분석을 위한 시나리오는 본 연구와의 적합성, 수용 가능성, 데이터 가용성 등을 고려하여 선정하였으며, 각 시나리오에 대한 에너지 안보 수준을 평가하기 위해 기존 문헌에서 사용되었던 기준들을 참고하여 부문별 지표를 선정하여 분석하였다. 시나리오의 각 지표 값들은 통합 및 비교 분석을 위해 최소-최대 정규화법으로 전환시켰으며, 이를 기반으로 도출된 수치들을 시나리오 및 시기별로 비교분석 하였다. 연구의 결과는 각 에너지 전환 경로별로 에너지 안보 수준이 매우 상이한 것으로 나타났으며, 전반적으로 유사한 수준의 변화인 경우에도 시나리오에 따라 에너지 안보의 특정 차원들이 매우 다른 방향으로 전망되는 것을 확인할 수 있었다.

주요어: 에너지 안보, 에너지 전환, LEAP, 기후변화, 공편익

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