Diversity, security, and adaptability in energy systems: a comparative analysis of four countries in Asia

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Abstract: In ecology study, numerous ecologists have been concerned with the concept of diversity in studying the structure and functions of ecosystems for a very long time. Diversification can be seen as a long-term survival strategy of ecosystems by allowing high flexibility and adaptability. Similarly, diversity is also seen as an important characteristic of a stable socio-economic system. In energy policy, diversity plays important roles in energy supply security, efficiency of energy use, and adaptability of energy system. Many of the trends reflect the increasing significance of renewable energy relative to conventional energy sources, and it will increase diversity of energy supply. It is also beneficial for a system both through extending choice and increasing competition. However, changing the structure of energy sources and increase energy diversity for strategic system security can be difficult for the countries which highly depend on the imported energy. This paper considers that the diverse distributions of energy flows in a system can open up more possibilities and channels for cooperation and interdependency in energy utilization. Not only diversity of supply side, but also diversity of demand side is critical for an energy system because increasing variance and balance of the energy consumers enhances efficiency and adaptability. In this paper, we develop a quantitative analysis method to explore both of supply and demand sides of energy system structure for four Asian countries, Japan, Korea, Taiwan and Indonesia based on the OECD data set from 1987 to 2006. The tremendous growth Asian countries have seen in recent decades required a huge amount of energy. Energy systems of Japan, Korea, and Taiwan are short of indigenous energy sources and highly dependent on imported energy sources except Indonesia. Indonesia's indigenous energy source reserves support national economy as a source of energy, industrial raw material and export goods. And then Indonesia's renewable energy also can be as a source of energy to support energy use. Furthermore, we are not only to compare the diversity temporal patterns of national energy supply and use, but also to compare the industry sector diversity temporal patterns of energy use of these countries.

Keywords: *Energy system, Diversity, Security, Adaptability*

1. Introduction

In recent years, there have been many interests in energy security due to the high oil prices and the geopolitical supply tensions. Security of energy supply can be defined as a system's ability to provide a flow of energy to meet demand in an economy in a manner and price that does not disrupt the course of the economy [1]. Many of the trends reflect the increasing significance of energy sources, including renewable energy, relative to conventional energy sources (including coal, oil, natural gas, and nuclear). Measuring security of energy supply is therefore becoming an important topic on the studies of energy policy. Diversity in energy (fuel) type and geographic sources is thought to be an important means of hedge against supply risks [2,3] and is used frequently as a key indicator to assess energy security. For example, Stirling's application of the Shannon-Wiener diversity index to electricity resources provides some useful insights into how government and electric utilities can objectively measure diversity and thereby gauge the effectiveness of their own investments in alternative resources [4].

Stirling (1999)[5] argues that an index of energy diversity should consider three key elements: Variety (the number of categories into which the quantity in question is partitioned), Balance (the pattern in the apportionment (spread) of that quantity across the relevant categories), and Disparity (the nature and degree to which the categories themselves are different from each other). Both through extending choice and increasing competition, energy diversity is thought as an important characteristic in energy supply security, financial risk, efficiency of energy use, and the environment [4,6]. Increasing diversity of energy supply is beneficial for a system both through extending choice and increasing competition. It is traditionally argued that diversity is best achieved by a mix of fuel sources and by a preference for domestic over imported energy supplies [7].Grubb et al. (2006) [1] calculated diversity of fuel source mix to represent one dimension of security-robustness against interruptions of any one source and applied diversity indices to electricity system scenarios. Furthermore, diversity is considered as an important property of energy system which provides resilience against physical supply disruptions. Global energy disruptions are more and more translated into price shocks, which can spill over from one market to another [3].

In ecological researches, however, measuring diversity is not a new method for studying ecosystem properties. Numerous ecologists have been concerned ecological diversity in studying the structure and functions of ecosystems [8,9,10,11,12]. From a systematic perspective, diversity of interacting components builds feedback loops and these loops regulate materials absorption, storage and release and landscape structure construction[13,14]. Webs of connections and feed-back information are the basis of system's self-regulation. Following a succession adjustment period, feedbacks regulate absorption, storage and release of materials, and construction of landscape structures [13]. A diversified ecosystem system is therefore considered as a more resilient and stable system. By allowing high flexibility and adaptability, the existence of diversity can be seen as a l ong-term survival strategy for systems as a consequence of permanently changing environmental condition [15]. Ecosystems either adapt to their internal scarcity by optimizing the use of the scarce resources or are flexible and able to changing environmental conditions [15,16].

Additionally, one can transfer the knowledge and the understanding from biological sciences to social sciences based on t he analogies between biological and socioeconomic evolution [17]. Matutinović (2001) [17]argued that the functional properties of diversity in socioeconomic system are analogous to that of biological evolution: (1) adaptation to different environment, (2) avoidance of head-to-head competition, (3) efficient use of energy and resources and (4) providing a range of responses to new selective pressures. Socioeconomic system diversity is therefore expected to generally increase during development and to improve efficiency, productivity and output of the system [18,19]. In order to studying the relationships between diversity and socioeconomic development, Templet (1999) [19] defined diversity of economic system as the number of sectors by using energy and the equitability of the energy flows among them. He adopted an energy flow network method and development capacity formula [18] to investigate the relationships among economic diversity, output and development policy. His conclusion is that economic system is generally capable for making more efficient use of energy and reducing energy intensity as the diversity rises.

Based on ecological theory of diversity and the analogies between ecological and energy systems, diversity of interacting components in energy systems is thought as an important property to build feedback loops regulating energy use, storage, and release. Diversity of energy system can enhance the energy efficiency and open up t he channels for the cooperation of energy use. A diversified energy system is therefore considered as a m ore resilient and adaptable system to cope with disturbances. However, most of recent studies on energy diversity are generally focused on t he issues of energy supply. The importance for diversifying systemic components and building feedback loops in energy systems were gotten fewer attentions in energy policy studies. Moreover, for the countries which highly depend on the imported energy, changing the structure of energy sources to increase energy diversity for strategic system security is relatively difficult. This paper therefore considered that not only the diversity of energy sources (supply side) but also the diversity of energy use (demand side) is critical for an energy system because increasing variance and balance of the energy consumers enhances efficiency and adaptability. In this paper, we develop a quantitative analysis of diversity to explore both of supply and demand sides of energy systems for four Asian countries, Japan, Korea, Indonesia and Taiwan based on the data sets from 1987 to 2006. Furthermore, we are not only to compare the diversity temporal patterns of national energy supply and use, but also to compare the industry sector diversity temporal patterns of energy use of these countries.

2. Methodology

2.1. Diversity indicators

The index mostly used to measure diversity is the Shannon–Wiener index:

$$H = -\sum_i p_i \ln p_i$$

with p_i representing the share of fuel *i* in the energy mix or the market share of supplier *i*. The higher the value of *H*, the more (dual concept) diverse the system is. This index rises monotonically with increasing variety and balance.Ecologists frequently apply diversity as an index of ecosystem stability [14]. Templet (1999) [19] use the Shannon and Weaver (1949) equation to capture how many deferent types of economic activities exit within the system and how equitably energy is distributed between them. The Shannon-Weiner index was considered to be the most satisfactory measure of energy diversity because it incorporates the concepts of variety and balance [4].

In this study, we also use the Shannon–Wiener index to calculate the diversity of energy consumption and industry sector. We consider that the diverse distributions of energy flows in a system can open up more possibilities and channels for cooperation and interdependency in energy utilization. Not only diversity of supply side but also diversity of demand side is critical for an energy system because increasing variance and balance of the energy consumers enhances efficiency and adaptability.

2.2. Data sets of four countries in Asia

Our quantitative analysis method primarily based on the OECD data sets: Energy balances of OECD and non-OECD countries, from 1987 to 2006 [20,21]. Year presented the energy balances in various sources of energy and different origins and uses. In energy supply side, six types of energy supply source data (see Fig.1.) are analyzed diversity index in these four countries by year (see Fig.2.). In energy consumption side, energy demand data of these four countries is collected into five categories labeled industrial, transport, residential, commerce and public services, and agriculture sector. Then, we calculate energy demand data by economic sectors (see Table.1.) and analyzed diversity index in these four countries by year (see Fig.3.). Energy demand data of industry sector are also collected into 13 categories labeled iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, transport equipment, machinery, mining and quarrying, food and tobacco, paper, pulp and printing, wood and wood products, construction, textile and leather, and non-specified. To analysis diversity index trend in these three countries highly depend on imported energy, we calculate these data sets and draw the lines of result by year (see Fig.4.).

Japan is the world's second largest economy after the United States in 2009 [22]. Gross domestic product (GDP) per capita of Japan increases almost two fold between 1987 (i.e. $20,025) and 2009 (i.e. $39,372) [23]. Because of low self-sufficiency index (0.1788 in 2008), Japan is the first-largest net importer of coal (114.19 Mtoe) in 2008, and increases coal use for power generation; Japan is also the second-largest net importer of oil (224.82 Mtoe) in the world [20], and most all the oil is imported from the Middle East. Above all, the aim of Japan's energy policy will achieve the 3E's goal-energy security, economic growth and environmental protection-in an integrated manner [24].

Korea has experienced tremendous economic growth over the last three decades. GDP per capita of Korea increases over six fold between 1987 (i.e. $3,366) and 2009 (i.e. $22,055) [23]. As low self-sufficiency index (0.1971 in 2008) like Japan, Korea's energy policies currently promote a stable energy supply, market efficiency through competition, and implementation of an environmentally friendly energy system with the end-goal of sustainable development [20,25].

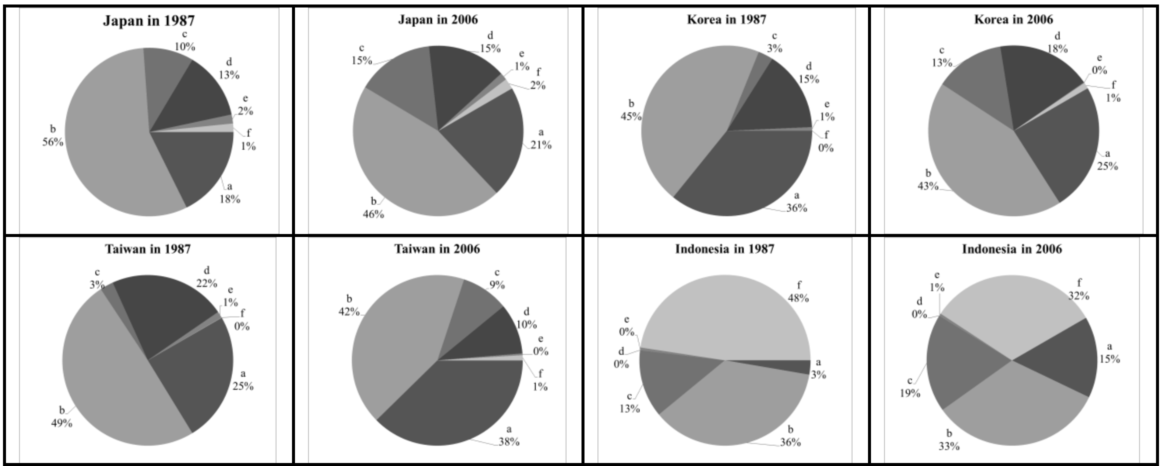
Taiwan is one of the most densely populated areas in the world, and GDP per capita of Taiwan increases over three fold between 1987 (i.e. $5,276) and 2009 (i.e. $18,867) [23]. There are no oil or coal reserves in Taiwan, but gas reserves are around 8.4 billion cubic meters [24]. Here, Taiwan has very limited domestic energy resources and relies on imports for most energy requirements. According to IEA's indicator, Taiwan's total energy self–sufficiency index is 0.12 in 2008 [21]. In 2009, Taiwan draw up the "Master Plan on Energy Conservation and GHG Emission Reduction" [26] and set up the national reduction targets as energy efficiency, emission reduction and low carbon energy. One of these targets is reducing energy intensity by 2% per annum and totally reducing 25% in 2015. Further reduce energy intensity by 50% in 2025 with technological breakthrough and administrative measures.

Indonesia's GDP per capita of Indonesia is $511 in 1987; it is $2,323 in 2009[23](IMF estimated). Indigenous oil, gas and coal reserves have played an important role in Indonesia's economy as a source of energy, industrial raw material and foreign exchange. In 2008, oil and gas exports contributed the largest share (21.1%) of Indonesia's total exports of USD 136.76 billion, followed by minerals (including coal) at 18.8% [24]. According to IEA's indicator, Indonesia's total energy self–sufficiency index is 1.75 in 2008 [21].

3. Results of energy analysis

3.1. Diversity index of energy supply side

Total primary energy supply (TPES) of four countries respectively increases rate of 41.24% (Japan), 224.29% (Korea), 176.79% (Taiwan), and 136.88% (Indonesia) between 1987 and 2006. Comparing to four countries' supply fuel shares in 1987 and 2006 (see Fig. 1.), TPES in Japan, Korea and Taiwan is dominated by oil and coal, through the portion of natural gas has increased rapidly in recent year. Japan and Korea both increase nuclear energy supply, however, Taiwan decreases the nuclear supply and Indonesia does not have the energy supply in TPES. Relative to conventional energy supply, the renewable energy supply share (including hydro, geothermal, solar, wind, etc.) of Indonesia's TPES is much higher than Japan, Korea and Taiwan. The renewable energy supply shares of Indonesia's TPES in 2006 are 33%, but other three countries' are below 3%.



a. Coal and coal products / b. Oil and products / c. Natural gas / d. Nuclear /
e. Hydro / f. Geothermal, solar, wind, etc.

Fig.1. Fuel shares in these four Asia countries (source: IEA, 2010).

A representative set of country's supply diversities are shown in Fig 2 over time. Comparing to diversity of four countries' energy supply, Japan's diversity index trend is the highest and it is going steadily. Indonesia's diversity trend is going up continuously, and in 2006 its diversity index is the highest of the four countries. Before 1994, Taiwan's diversity trend is going down and it reaches the lowest point in 2002. After 2002, it goes up quickly, but in 2006 its diversity index is the lowest of the four countries. Korea's diversity number is lowest in 1992, but it has a peak in 1994, then, after 1997 it is going up straightly.

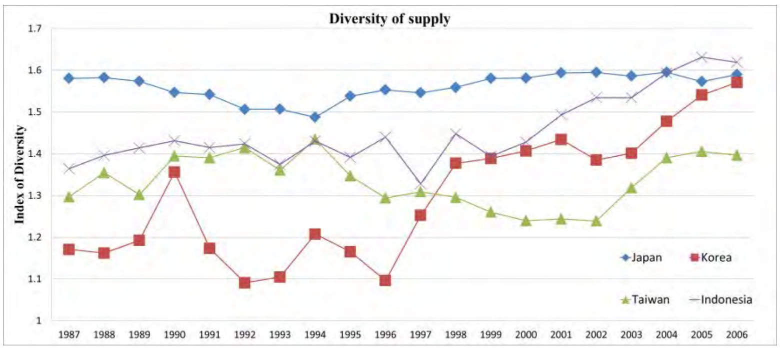


Fig.2. Country diversity of energy supply by year.

3.2. Diversity index of energy consumption side

Total final energy consumption (TFC) of four countries respectively increase rate of 39.40% (Japan), 170.99% (Korea), 128.72% (Taiwan), and 120.36% (Indonesia) between 1987 and 2006. By sector of energy use, industry sector are the large share of energy consumption, accounting for almost or over 30% of total demand, and the industry sector of Indonesia has the distinct growth rate of energy use(see Table 1). By energy source, oil products are the most important one of energy consumption, accounting for over 50% of total energy demand in Japan, Korea and Taiwan. Oil products and bio-energy are accounting separately for 34.2% and 35.44% of total energy demand in Indonesia.

A representative set of country's demand diversities are shown in Fig 3 over time. Comparing to diversity of four countries' energy consumption, the diversity index in Korea is the highest of the four countries. The diversity index trends of Korea and Japan are similar, and these lines go down gently. Taiwan's diversity index trend climbs up gently, and Indonesia's diversity index climbs up obviously.

Table 1. Sector of energy use. (Source: IEA, 2010)

Sector of Energy Use	Japan		Korea		Taiwan		Indonesia	
	1987	2006	1987	2006	1987	2006	1987	2006
Industry sector (%)	40%	33%	31%	36%	51%	44%	13%	28%
Transport sector (%)	28%	29%	23%	28%	25%	30%	15%	21%
Residential sector (%)	16%	15%	32%	17%	11%	11%	70%	46%
Commerce and public services sector (%)	12%	22%	10%	16%	6%	8%	1%	3%
Agriculture sector (%)	4%	1%	4%	3%	7%	7%	1%	2%
Total final consumption (only energy use) (Mtoe)	224.89	313.50	41.78	113.22	21.76	49.77	55.45	122.19

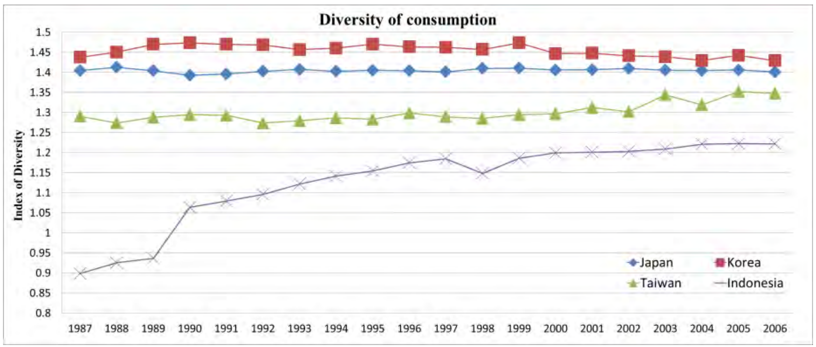


Fig.3 Diversity of national energy consumption

Due to Japan, Korea and Taiwan highly depend on the imported energy, except Indonesia. And all three countries face rapidly economic development and their energy supply and demand rate increase significantly. In the same way, industry sector of three countries is the primary energy consumer (see Table.1.) Therefore, we focus on industry sector diversity index trend in three countries, and analysis the meaning of them. As shown in Fig 4 over time, Korea's line climbs up continuously, but Japan and Taiwan go down steadily.

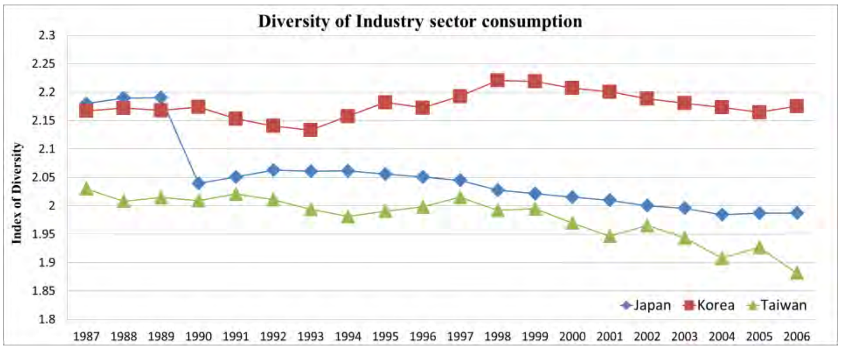


Fig.4. Country industry sector diversity of energy consumption by year.

4. Discussion and conclusion

4.1. Discussion and Conclusion

The fuel shares of these four Asia countries are shown in Figure 1 in this paper, and our quantitative analysis method primarily based on the OECD data sets from 1987 to 2006. Energy systems of Japan, Korea, and Taiwan are short of indigenous energy sources and highly dependent on imported energy sources except Indonesia. Indonesia's indigenous energy source reserves have played an important role in national economy as a source of energy, industrial raw material and export goods. And then Indonesia's renewable energy also can be as a source of energy to support energy use. These three countries are usually other-directed for the imported energy types, price, and geographic sources and are sensitive to the fluctuations of international fuel supply. Therefore, it is difficult for them to change the structures of energy sources to increase diversity for their strategic energy security. The restricted variation of fuel-type diversity of energy supply of Japan, Korea, and Taiwan are revealed in Figure 2. However, the diversity index pattern of an indigenous energy system as Indonesia reveals a more flexible characteristic.

Recent years, all the total energy consumptions of these four countries were dramatically increased. Industrial sectors are the main energy consumers in Japan, Korea, and Taiwan. The energy consumption of commerce and public services sectors in these countries increase a little bit (see table 1). In Indonesia the residential sector is the main energy consumer. This study calculated the diversity index for national energy consumption (demand side) and the results showed that the temporal patterns of energy diversity in demand side of Japan, Korea, and Taiwan remained steady over two decades. However, energy diversity of Indonesia rose due to the significant decrease of residential sector and the raise of the energy consumption in industrial and transportation sectors (see Fig. 3).

Furthermore, this study also investigates diversity of energy use in the industrial sectors because the industrial sector of Japan, Korea, and Taiwan is the main energy consumer. The results show that energy diversity of Taiwanese industrial sector was going down due to the concentration of energy use in the iron and steel sector as well as the chemical and petrochemical sector (see Fig. 4). The energy diversity of Japanese industrial sector was also going down because several industrial production sectors were shrinking in past two decades. Relatively, diversity of Korean industrial sector was remained steady. The decreasing diversity of Industrial sector indicates a centralization of energy flow in the dominated industrial production.

Based on the analyses of energy diversity of fuel types, the results show that changing the structure of energy sources and increase energy diversity for energy security is difficult for the countries which are highly dependent on imported energy source. However, from the analogies of the concept of diversity between ecological and socioeconomic systems we argue that the diversified distributions of energy flows in an energy system can open up more possibilities and channels for cooperation and interdependency in energy utilization. The diversity of energy distribution in demand side is critical for an energy system. Diversity can increase variance and balance of the energy consumers and enhances energy efficiency. Moreover, diversity also improves the internal adaptability for coping with energy scarcity and external disturbances.

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