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Non-renewable Resources in Asian Economies: Perspectives of Availability, Applicability Acceptability, and Affordability

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Abstract: This paper reviews the factors that determine the sustainability of non-renewable energy production and consumption in Asian economies. It reviews the recent literature on the issue and all of the key findings under the 4As framework (Availability, Applicability, Acceptability, and Affordability) which is derived from the classical Hotelling non-renewable resource economics models. Conclusions derived focus on the implications of the fast growth in non-renewable energy consumption and its outpacing the growth in indigenous production, the uneven distribution of exploitable non-renewable energy resources, the potentials of shale oil and shale gas, the role of coal, renewable energy and nuclear energy, the reform of domestic energy markets, and the environmental impacts of the use of non-renewable energy in the Asian economies.

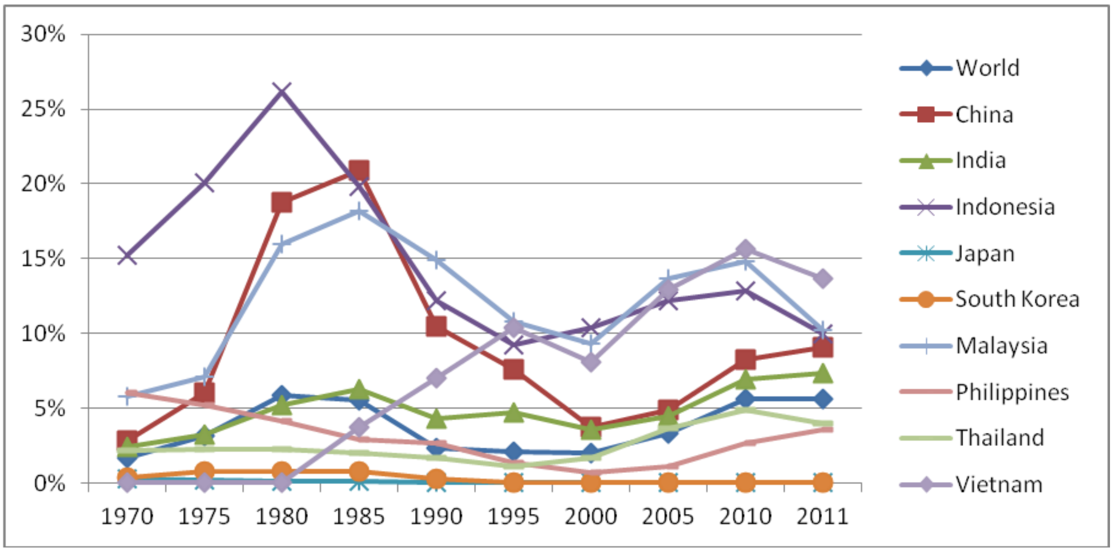
Keywords: Non-renewable energy, Sustainability, Asian economies, 4A framework

JEL Classification: Q01, Q30, Q40

1. Introduction

Asian economies have very different economic structures and levels of economic development. Therefore, these economies' reliance on natural resources varies to a very large extent. Figure 1 presents the natural resource rents as a share of GDP for various Asian countries which show the huge variations among the countries.

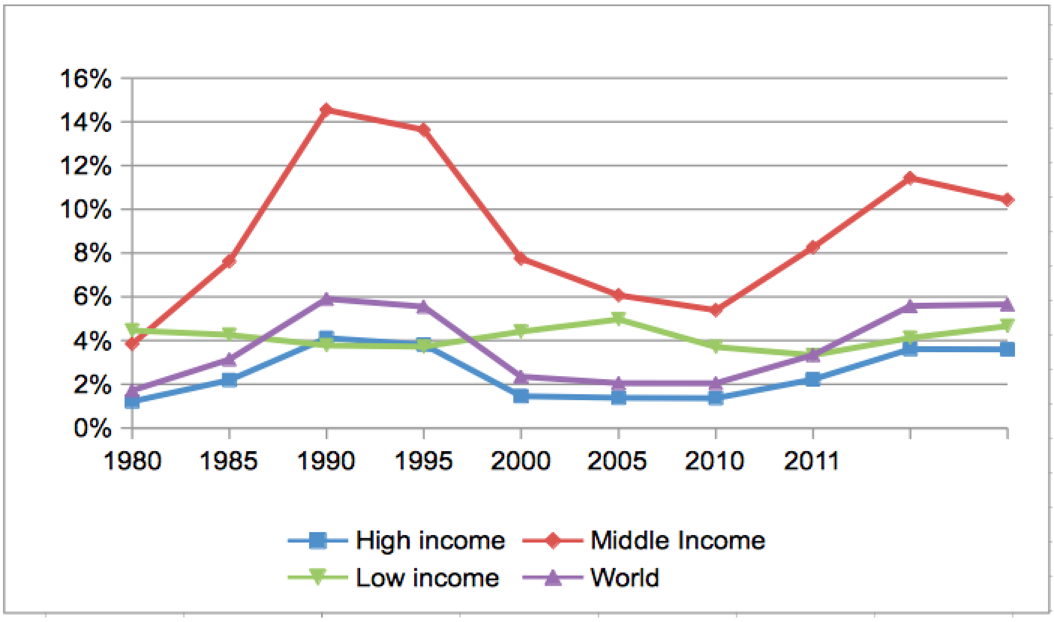
Figure 1: Five-year Average Natural Resource Rents* as a share of GDP



Note: * Natural resource rents of Asian economies (resource extracted * unit rents => resource extracted * (unit price – unit cost)).
Source: World Bank database.

Figure 1 hints that the dependence of an economy on natural resources seems to have an inverted U-shape relationship with the level of economic development. Less developed economies such as the Philippines and more developed economies such as Japan and South Korea seem to be least reliant on natural resources to contribute to GDP while fast developing economies such as China, India, and Vietnam and resource-intensive economies such as Indonesia and Malaysia seem to be highly reliant on the extraction of domestic natural resources to contribute to GDP. Figure 2 summarizes the average natural resource rents of three income groups of economies in the world and reinforces this proposition.

Figure 2: Five-year Average Natural Resource Rents* as a Share of GDP for Different Income Groups



Source: World Bank database.

Table 1 further decomposes the natural resource rents into five categories of sources, out of which the first four are considered non-renewable resources. More importantly, non-renewable energy resources, including oil, natural gas and coal, constitute the majority of the natural resource rents from non-renewable resources. It is also noted that coal plays a greater role in Asian economies such as China, India, Indonesia, and Vietnam than in the case of the world average. Overall, crude oil and coal are the major sources of natural resource rents in Asian economies, followed by minerals and natural gas. Developed Asian economies such as Japan and South Korea have almost zero domestic natural resource or non-renewable resource production. These two economies almost entirely rely on imported non-renewable resources, especially non-renewable energy.

Table 1: Composition of Natural Resource Rents in Asian Economies in 2011

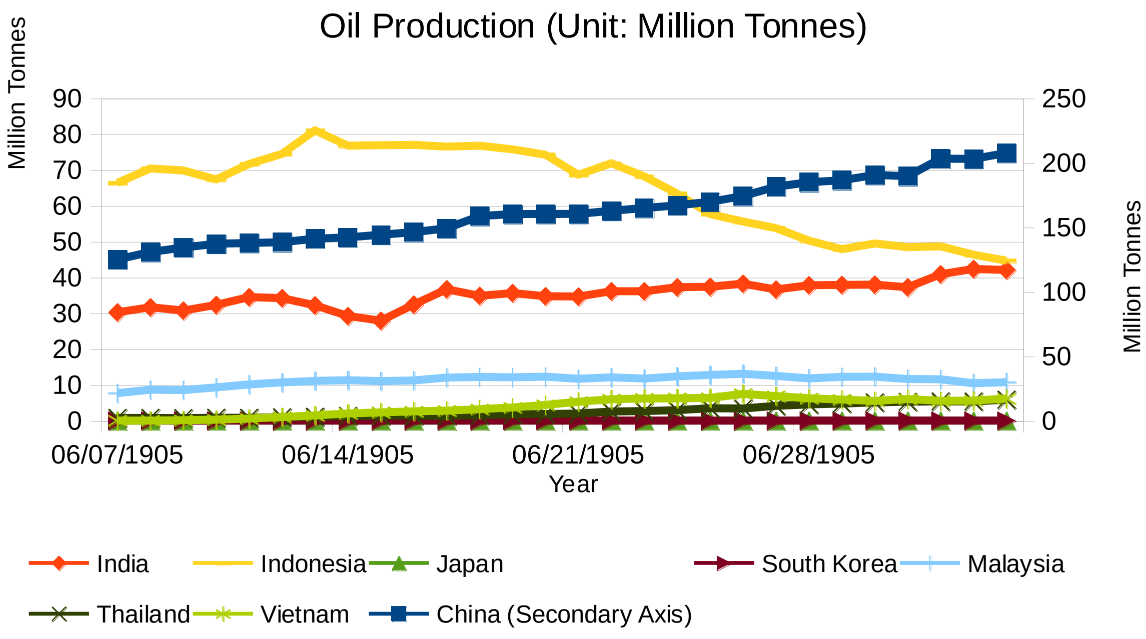
	Total natural resources rents （% of GDP）	Oil rents （% of GDP）	Natural gas rents （% of GDP）	Coal rents （% of GDP）	Mineral rents （% of GDP）	Forest rents （% of GDP）
China	9.1	1.6	0.1	4.4	2.8	0.2
India	7.4	1.3	0.3	3.1	2	0.6
Indonesia	10	3	0.8	4	1.6	0.6
Japan	0	0	0	0	0	0
South Korea	0.1	0	0	0	0	0
Malaysia	10.3	6.4	3.1	0.1	0.2	0.6
Philippines	3.6	0.1	0.3	0.4	2.6	0.2
Thailand	4	2.2	1.3	0.2	0.1	0.3
Vietnam	13.6	7.8	1.1	3.4	0.6	0.7
World	5.7	3.1	0.5	1	1	0.2

Note: Total share may not be exactly equal to the sum of the share of sub-categories due to rounding.

Source: World Bank database.

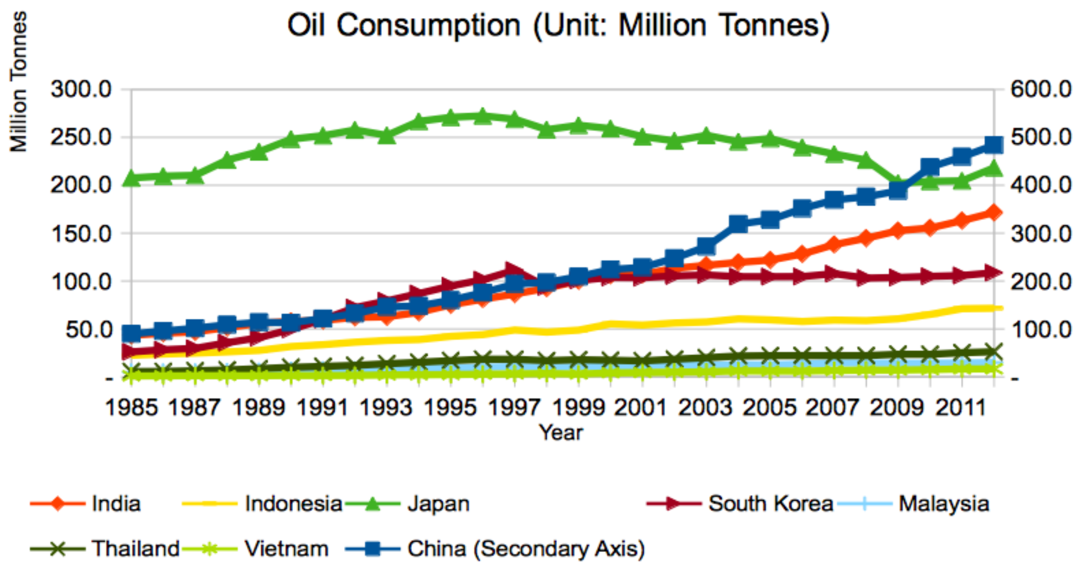
Figures 3 and 4 show specifically the oil production and consumption of Asian economies.

Figure 3: Oil Production of Asian Economies



Source: BP World Energy Statistical Review 2013.

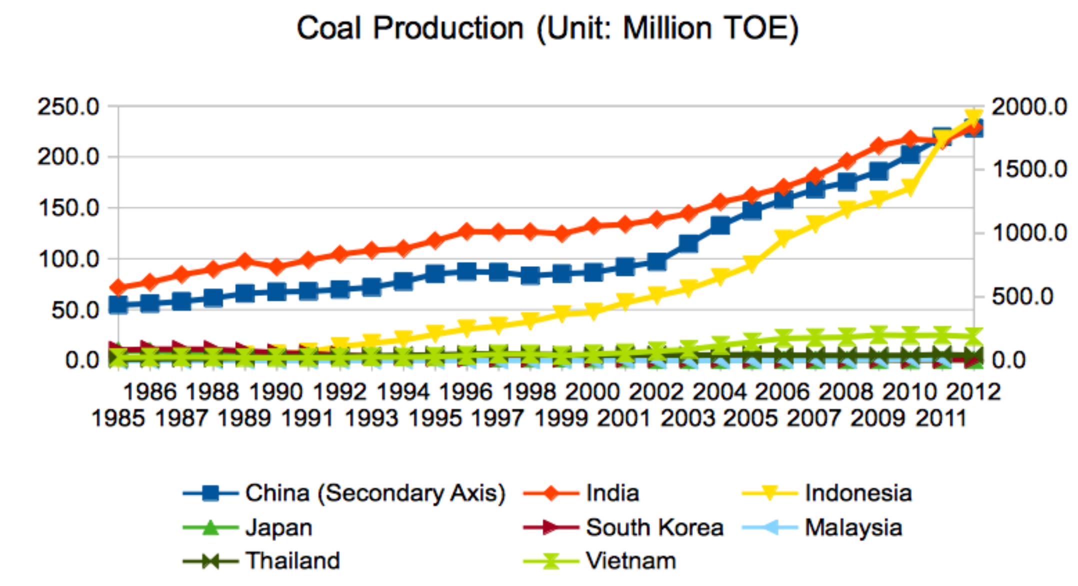
Figure 4: Oil Consumption of Asian Economies



Source: BP World Energy Statistical Review 2013.

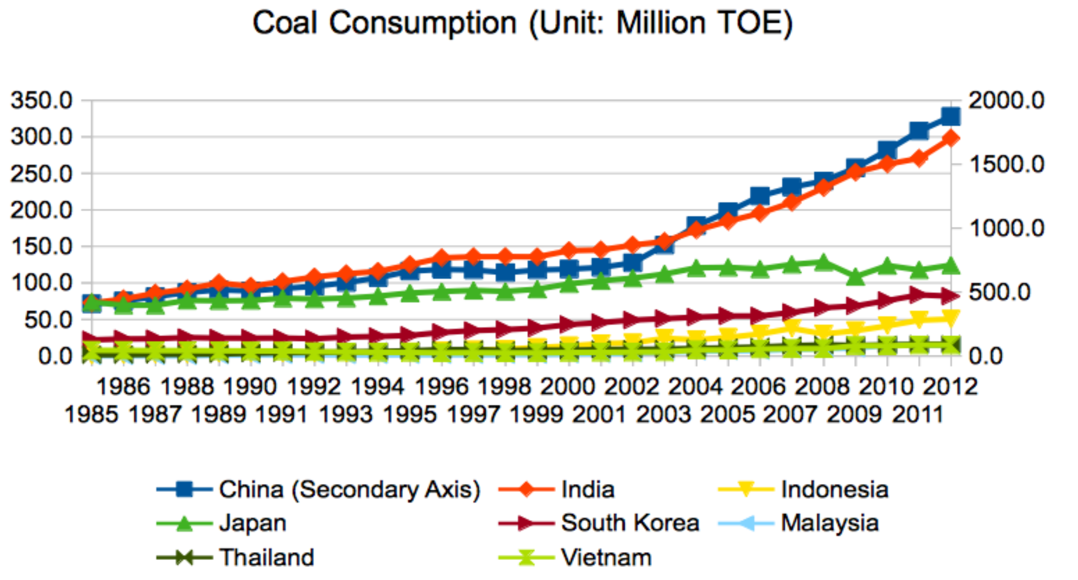
As shown in Figures 3 and 4, Asian economies as a whole consume far more crude oil than they produce. However, the production and consumption of coal are roughly balanced for these Asian economies combined as shown in Figures 5 and 6.

Figure 5: Coal Production of Asian Economies



Source: BP World Energy Statistical Review 2013.

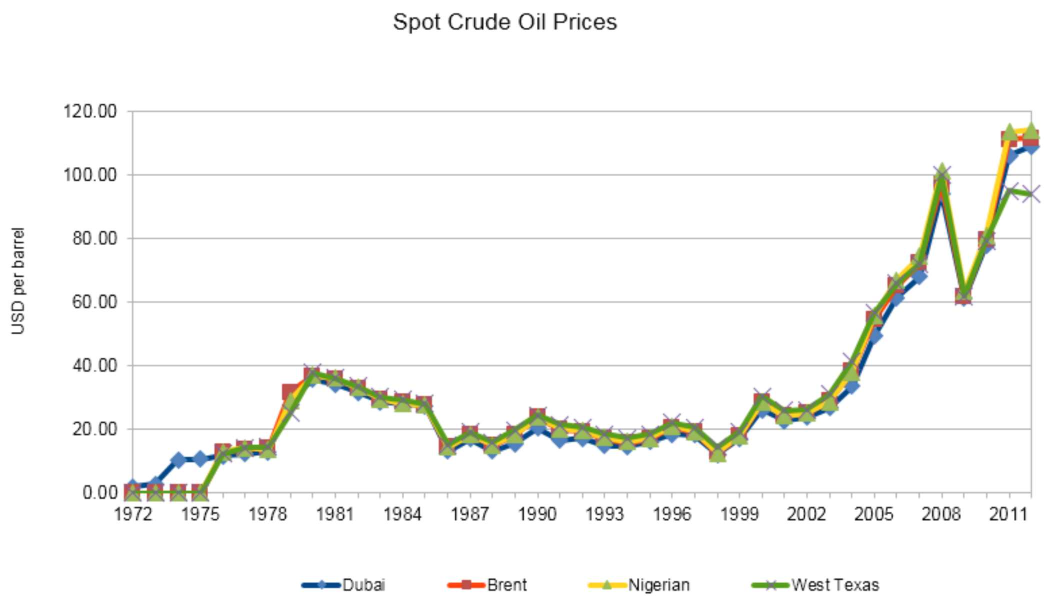
Figure 6: Coal Consumption of Asian Economies



Source: BP World Energy Statistical Review 2013.

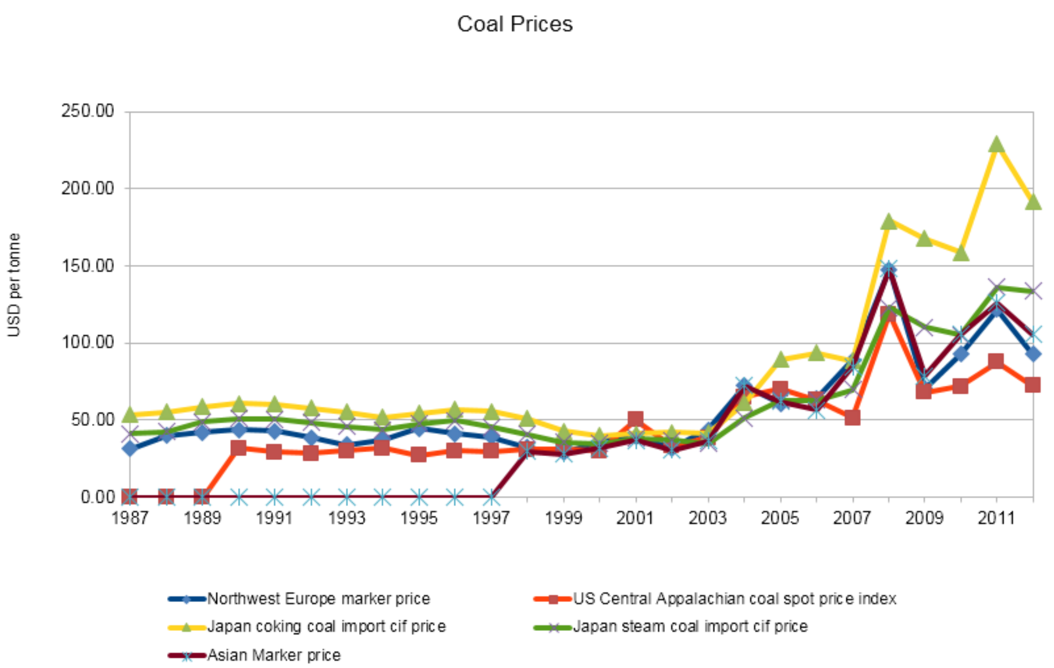
Figures 4, 5 and 6 also show how fast the Asian demand on oil and coal has been growing mainly due to fast economic growth of major economies in the region such as China and India. The surge in demand has also completely changed world markets of energy, especially those of oil and coal in the past decade, causing prices to surge. Figure 7 shows that spot crude oil prices in the 2010s have generally increased by three folds from the levels in the 1980s. Figure 8 shows that Asian coal prices have increased by roughly two folds compared to the levels in the 1980s but slower than the increases in the markets of Japan, Europe and the US, mainly due to relatively abundant reserves and production capacity of coal in the major Asian economies.

Figure 7: Spot Crude Oil Prices 1972 - 2012



Source: BP World Energy Statistical Review 2013.

Figure 8: Coal Prices 1987 – 2012



Source: BP World Energy Statistical Review 2013.

The imbalance of production and consumption in non-renewable resources and high and volatile energy prices raise a few critical questions regarding the sustainability of energy supply. First, will an ever-increasing amount of non-renewable energy be available to Asian economies in the coming decades and if not, what other sources of energy should be introduced in a mass scale to replace non-renewable energy? Second, what energy technologies are likely to be applicable in a mass scale to bring sustainable energy supply to Asian economies? Third, will the future trend of energy mix in Asian economies as well as the technologies that bring such an energy mix be acceptable in the consideration of environmental vulnerability, safety and energy security? And fourth, will such an energy mix and the corresponding technologies be affordable to Asian economies?

This paper focuses on non-renewable energy resources. It reviews the above-mentioned issues by applying a 4As framework to sort and analyzes the information and data from the literature. The 4As are Availability, Applicability, Acceptability, and Affordability, corresponding to the four key questions raised above, respectively.[1]

The rest of the paper is organized as follows. Section 2 introduces the 4As framework, based on a brief discussion of the classical Hotelling non-renewable resource economics models. Section 3 reviews the literature regarding issues under each of the four dimensions. Section 4 derives policy implications for the Asian economies. And Section 5 concludes.

2. Hotelling Rules and 4A-Framework: An Overview

2.1. Theoretical Framework: The Hotelling Models

The Hotelling models are a series of developments based on the seminal work of Harold Hotelling (1931). The basic Hotelling model assumes the finite availability of non-renewable resources (fixed amount of reserves). Based on such an assumption, it establishes a supply side equilibrium condition about the resource price and optimal extraction path. The marginal value of extraction from the resource reserve – the resource price less the marginal extraction cost – should equal the value of not extracting from the resource stock – the marginal opportunity cost of depletion. This opportunity cost of depletion is known as user cost, the *in situ* value, and resource rent. Market equilibrium requires that, in the long run, the in situ value increases at the rate of interest[2] which is externally decided (assuming that extraction cost is independent of the remaining stock). Correspondingly, as an optimal time path of extraction, extraction decreases as the resource price increases over time with a stationary demand curve.

However, there has not been a persistent increase in non-renewable resource prices over the last 125 years. Instead, fluctuations around time trends whose direction can depend upon the time period selected as a vintage point have been observed. Further development of the basic Hotelling model relaxes a few assumptions, as discussed below, to derive more realistic inferences about the paths for resource prices and extraction (Krautkraemer, 1998).

First, technological changes in resource extraction have been empirically proven to drive the cost of extraction downwards (Barnett and Morse, 1962). This extension derives a resource price path that is U-shaped, namely, first decreasing and then increasing.

Second, non-renewable resource stocks should not be assumed as known with certainty, and exploration for new deposits as well as further development of existing deposits are important features of the minerals and non-renewable energy industries.

Third, since the outcome of exploration and development activities cannot be fully anticipated, expectations about the future value of the resource stock can be revised in response to specific exploration outcomes. Revised expectations about the future value can alter the equilibrium resource price and extraction paths.

Fourth, minerals and non-renewable energy industries are capital-intensive, and the timing and size of investments in extractive capital are functions of the anticipated price path and the cost of capital. Once in place, it may be very costly to adjust the extractive capacity in order to change the extraction rate in response to a change in the resource price path. As a result, the short-run supply of a non-renewable resource may be quite inelastic, and changes in market demand will be resolved with price changes rather than quantity changes. Since the cost of extractive capital assets increases with an increase in the rate of interest, it is no longer necessary that an increase in the rate of interest implies more rapid depletion.

Fifth, non-renewable resources generally occur in deposits of various grades. In an extended Hotelling model, the optimal extraction pattern requires exploiting the deposits in strict sequence from high quality ore to low quality ore. Then the optimal response to a price increase can be a decrease of extraction at a higher quality (lower cost) deposit and an increase of extraction at a lower quality (higher cost) deposit so that the average quality of extraction can decline in response to a price increase (Slade, 1988).

Last but not least, the availability of backstop technologies, for example, renewable energy technologies in the case of non-renewable energy deserve a special emphasis in today's circumstances. A backstop technology that provides a substitute for a non-renewable resource at a higher cost can be viewed as a higher cost deposit whose cumulative use is not limited although there may be a finite limit to the availability of the substitute at any particular time. The substitution of solar energy for fossil fuels is the most commonly cited example of a backstop technology. In the absence of stock effects, the in situ value of the non-renewable resource increases at the rate of interest until the non-renewable deposit is exhausted just as the resource price reaches the marginal cost at which the backstop technology is available. With a stock effect, the in situ value for the non-renewable resource can decline over time (Heal, 1976) and may even be non-monotonic (Farzin, 1992). However, the time path for user cost cannot be decreasing if the net benefit function is strictly concave in the resource stock. The arrival of new information about the cost or timing of availability of a backstop technology can revise expectations about the future resource price path. Such can cause the observed time path for user cost to differ from the once-anticipated price path (Swierzbinski and Mendelsohn, 1989b).

Other considerations include uncertainty about future resource price, backstop technology availability and the expectation of them, market imperfection, durable non-renewable resources, environmental externalities of non-renewable resource extraction and consumption, and the changing elasticity of demand with respect to resource price (Kraukraemer, 1998; Gaudet, 2007).

The Hotelling model, as mentioned above, is a supply side equilibrium model which assumes constant demand or simplified function of demand. Such is probably mainly due to the fact that the economics of non-renewable resources in history has mostly been driven by developments in the supply side and demand usually grows at a steady rate over time. Since industrialization in Asia, especially China and India, has to a large extent changed the landscape about resource demand, it is probably now equally important to model the demand side in detail as well so as to see how dynamics from both the supply and demand determine resource prices, extraction paths, exploration activities, and capital investment in exploration and extraction. In addition, there are factors like institutional constraints, social preferences, and geopolitics, which are also critical in determining the sustainability of non-renewable energy production and consumption but are not incorporated in the formal Hotelling models. By putting all these factors into consideration under four dimensions, as will be discussed in detail below, the 4As framework could be more comprehensive and practical as an assessment of the sustainability issue.

2.2. Analytical Framework: 4As Sustainability Assessment for Economies

While it is difficult to directly apply the Hotelling models in quantitatively assessing non-renewable resource sustainability for a specific economy, a 4As framework that includes the following four dimensions is applicable to do so. Each of the four dimensions covers certain key factors which determine resource sustainability, as identified in the formal Hotelling models. Some of these factors would be common to all economies while others would be economy-specific.

The availability of resources refers to the geological existence of the energy resources, especially for energy resources that are inexhaustible in duration but limited in the amount available per unit of time. Availability could be specifically reflected in the following issues:

- proven hydrocarbon reserves: conventional (oil, natural gas and coal) and non-conventional (oil sands, shale gas);
- exploration and production expenditure;
- percentage of domestic crude oil production to total petroleum demand;
- percentage of renewable energy in total energy production.

The applicability of technology refers to technology breakthroughs that can help further exploit proven resources, and ensure the conservation and efficient use of the remaining hydrocarbon reserves, as well as renewable energy sources. Applicability could be specifically reflected in the following issues:

- current energy production and consumption technologies, energy conservation and energy efficiency technologies;
- energy intensity level;
- development of renewable energy technologies (including backstop technologies);
- development of non-renewable energy technologies (including backstop technologies);
- production capacity of renewable energies;
- expenditure on R&D in energy-related technologies: energy production, energy consumption, energy saving, etc.
-

The acceptability of society considers the perception and safety of the general public when any of the energy resources is used. When energy is one of the inputs in production processes or utilization, energy produces both good and bad. Acceptability looks at the tolerance level of the society for the bad in order to enjoy the good produced, and the environmental impacts that are associated with the good.

Acceptability could be specifically reflected in the following issues:

- energy related carbon dioxide emissions;
- number of operating nuclear generating units;
- key pollutant emissions (Air Quality Index) and the environmental concern on coal;
- environmental impacts due to non-renewable energy extraction and production.

The affordability can be addressed in a threefold approach—personal, commercial and national. At the personal level, it evaluates the ability of consumers to pay for the energy services provided. At the commercial level, it refers to the viability of the uptake of renewable technologies. Affordability could be specifically reflected in the following issues:

- per capita energy consumption;
- trade balance of non-renewable energy;
- non-renewable energy market structure and market power;
- average retail prices of electricity (real prices);
- average retail prices of motor gasoline (real prices);
- residential retail prices of natural gas (real prices).

In the next section, the literature addressing the sustainability of non-renewable energy production and consumption in Asian economies would be reviewed and categorized under the 4A framework to give readers an in-depth and comprehensive overview of the development in this issue.

3. Sustainability in Non-renewable Energy for Asian Economies

Availability is conventionally the most critical concern for Asian economies. It used to be equivalent to energy security, which basically means uninterrupted supply to meet increasing domestic demand. In the long run, however, the consideration of the availability of energy supply has to be extended to climate change and other environmental concerns, alternative (complementary or backstop) energy technologies, regional cooperation, and the cost of acquiring appropriate supply (Hippel, *et al.*, 2011b). Thus, the rest of the discussion under the 4As framework also covers technological (institutional) *applicability*, environmental and social *acceptability*, and economic *affordability*. This subsection reviews findings from the literature that fall into each of the four categories.

3.1. Availability

Asian economies face two main challenges regarding availability. First, despite abundant non-renewable energy reserves that used to enable economies in the region to export non-renewable energy, fast growth in energy demand has in recent decades gradually turned them into net importers of non-renewable energy. As a result, the dependence on imported oil and gas has increased gradually and is expected to further increase. Second, the region traditionally lacks collaboration to make the best use of unevenly distributed non-renewable and renewable energy reserves in the region. The institutional framework in terms of energy market integration and infrastructure such as connectivity in power grid and natural gas pipeline networks are not in place. Each economy in the region has been seeking its own energy security in costly ways. These observations are supported by the evidence summarized below.

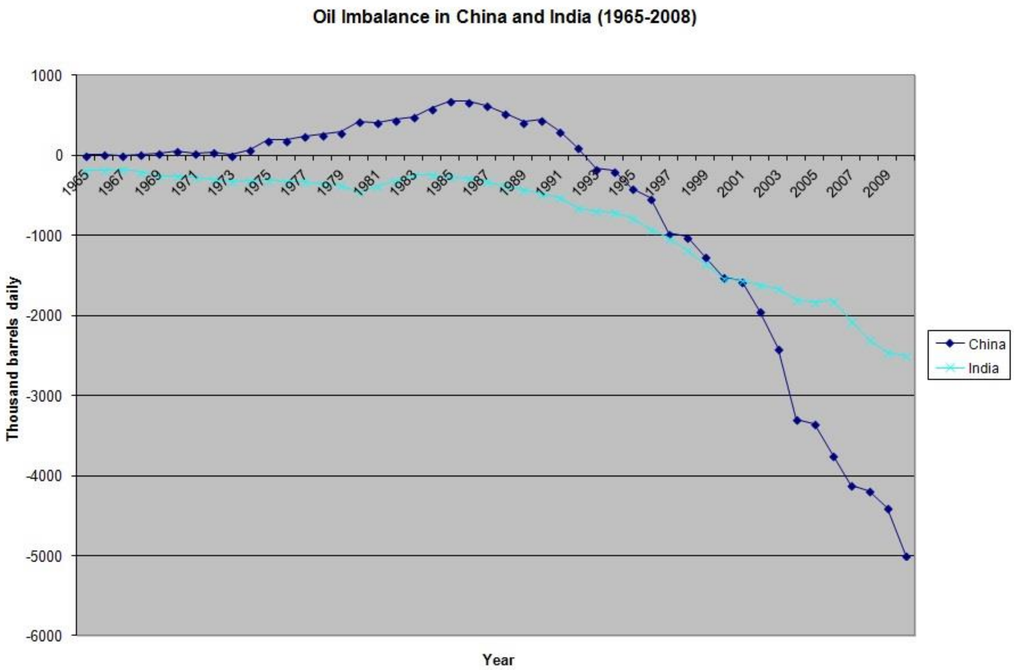
3.1.1. Demand and Supply Situation

Hippel, *et al*. (2011a) study energy security issues of Northeast Asian economies in detail, including Japan, South Korea, North Korea, Mongolia, China, Hong Kong SAR, Taiwan, and Far-east of Russia. The region's energy consumption share in the world has increased from 18.6 percent in 1999 to 25.2 percent in 2007. The study projects that the region's energy consumption will double in the period of 2005-2030 and 90 percent of the increase will come from China. Oil will see the largest growth – more than double – particularly driven by transport energy demand from China. Coal closely follows the trend. Figure 9 shows how such growth of demand has gradually changed the position of China and India in the global oil market from a net exporter to a net importer, with the gap between demand and supply widening at an unprecedented speed.

About 90 percent of the ASEAN primary energy supply has been fulfilled by fossil fuels (coal, oil, and natural gas), of which nearly 60 percent is imported from the Middle East. (Thavasi, 2009).

Cao and Bluth (2013) show that China sources slightly less than 50 percent of its imported oil from the Middle East, 30 percent from Africa, 17 percent from Europe and Western Hemisphere, and less than 5 percent from Asia-Pacific. Asia-Pacific used to play the most critical source of China’s oil imports but its share gradually shrank from over 58 percent to 4.7 percent. None used to come to China from Africa, Europe or Western Hemisphere.

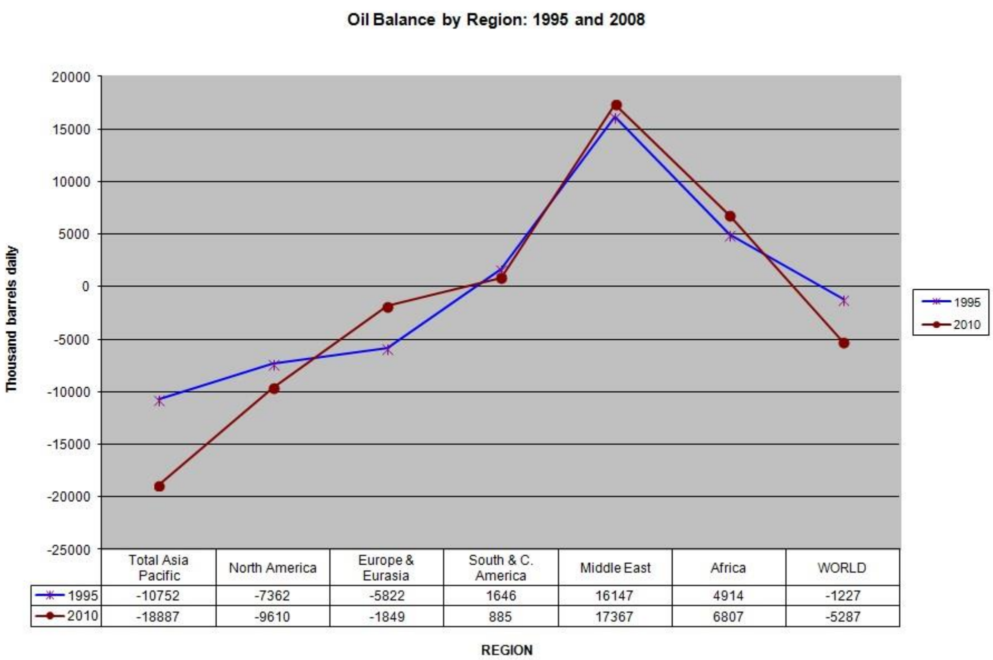
Figure 9: Oil imbalance (production less consumption) in China and India



Source: Authors' estimation based on BP World Energy Statistical Review 2013.

Figure 10 summarizes the position of Asia-Pacific economies combined in the global oil market. It is evident that the region has the largest gap between oil demand and supply and therefore has high dependence on imported oil from other parts of the world.

Figure 10: Oil imbalance (production less consumption) of Different Regions



Source: Authors' estimation based on BP World Energy Statistical Review 2013.

The East Asia and ASEAN regions by themselves have abundant energy resources, both in terms of non-renewables and renewables. The reserves, however, are usually far from economic and population centers. This situation requires both massive infrastructure investment and regional collaborations in tran-national transportation/transmission of energy. For example, infrastructure will be needed to develop and transport energy resources (oil and natural gas) from the Russian Far East to South Korea, China, and Japan. Cooperation is also needed on electricity transmission interconnections, energy-efficiency, renewable energy, nuclear fuel cycle, and the emergency sharing of energy storage across borders (Hippel, *et al*., 2011a; Hippel, *et al*. 2011c).

Japan has established the Energy Silk Road project with China and Turkmenistan and a trans-Asian gas pipeline network, and ASEAN has been pushing for a trans-ASEAN gas pipeline and the ASEAN power grid. Thailand and Myanmar have been cooperating in natural gas exports. The Philippines and Thailand have agreed on bilateral cooperation in maximizing the use of existing oil storage. The BIMST-EC countries (Bangladesh, India, Myanmar, Sri Lanka, Thailand Economic Cooperation) have proposed to explore, develop and distribute the vast and untapped energy resources in these countries through collaboration and trade (Thavasi, 2009).

The Economic Research Institute for ASEAN and East Asia (ERIA) has long been studying Energy Market Integration (EMI) in the ASEAN region. Chang and Li (2013) present the results of simulation of an integrated electricity market in ASEAN with an ASEAN Power Grid (APG) that connects member countries to enable trade in electricity. It is found that the integrated and open electricity market encourages the development of renewable energy in the region especially hydropower and wind energy. Chang and Li (2014) study further policies on top of EMI to incentivize the development of renewable energy in the power sector. The policies examined are feed-in-tariff (FIT), renewable energy portfolio standards (RPS) and carbon pricing. It is found that FIT is more cost-effective in ASEAN if the APG is in place and member countries can freely trade electricity. These policies not only save the cost of energy for countries but also diversify the energy mix and improve energy securities of countries in the region.

3.1.2. Energy Conservation and Energy Efficiency

Energy conservation could be considered as one area that could help in increasing the energy supply of an economy. In the case of South Korea, according to Park, *et al*. (2013), per capita electricity consumption in 2008 was even higher than that of Japan and developed economies in Europe. There is clearly room for conservation.

Electricity consumption has been growing strongly in ASEAN countries due to the increasing scale of industry activities, the structural change of industries and shift from low energy-intensive industries to high energy-intensive industries, and the shift toward more electricity consumption to substitute for other primary energy consumption. If the current trends continue, electricity demand will grow substantially to 1,955 billion kWh in the region by 2030. However, taking Japan as a benchmark for energy efficiency levels achievable, if a comprehensive set of measures that includes both administrative means and market-oriented ones (especially removing subsidies to electricity tariffs) is taken to make sure that energy efficient technologies are adopted and appropriate patterns of energy consuming behavior are developed, levels of future electricity demand in ASEAN economies could be reduced by up to 40 percent (Chang and Li, 2013).

Since it is inevitable that Asian economies will turn to external sources for supply of non-renewable energy, it is necessary to look at the case of Japan. Japan as a country extremely lacks in natural resources, including non-renewable energy. But it has set its energy policies to improve energy security and sustainability, including making it the most energy efficient economy in the world so far. Yet still, its energy policies are pursuing even higher levels of energy efficiency, together with higher energy independence and significantly lower carbon emissions and other GHG emissions.

In 2007, Japan's primary energy mix consisted of 41 percent of petroleum, 22 percent of coal, 18 percent of natural gas, 10 percent of nuclear power, 6 percent of renewable energy, and 3 percent of LPG. In 2010, the Japanese government announced a new Basic Energy Plan (BEP) which focuses on raising Japan's "energy independence ratio" from 38 percent to 70 percent by 2030. The ratio consists of two parts: "energy self-sufficiency ratio" (from the current 18% to 40%) and "selfdeveloped fossil fuel supply ratio" (from the current 26% to future 50%). To achieve these goals, Japan plans to bring about a substantial change in its energy mix by 2030, namely, to double the share of renewable energy and nuclear power together and to reduce the share of non-renewable fossil fuel correspondingly.[3] Moreover, the plan targets to reduce the absolute primary energy consumption of Japan by 13 percent. However, it is noted that after the Fukushima accident, Japan seems not to be keen in utilizing nuclear power in the country.

Since Japan's hydroelectric potential has been largely exploited, the Japanese government will focus on promoting further development of wind, solar and biomass energy. Therefore, the government plans to extend the current feed-in-tariff system, which currently applies only to small-scale electricity generation by photovoltaic (PV) cells, to include wind, geothermal, biomass, and small-to-medium-scale hydroelectric plants. The government would increase its support for the introduction of new renewable technologies, through such means as tax reductions, subsidies, and support for research and development. It would take steps to deregulate the domestic energy market and prepare the power grid for intermittent sources of supply. Other measures that were considered by the government include introducing sustainability standards for biofuels and expanding the introduction of renewable thermal energy.

The new BEP recognizes that Japan will still have to rely to a substantial extent on coal (17% by 2030), which produces the most CO_2 per unit of energy. However, the government would take several steps to reduce CO_2 emissions from coal. It would promote the commercialization of new and more efficient coal burning technologies, such as integrated gasification combined cycle (IGCC), and require that all new coal plants achieve emission levels comparable to IGCC. It would also accelerate the development and commercialization of technology for carbon capture and storage (CCS) and require that new coal plants be CCS-ready and equipped with CCS technology as soon as it becomes available.

To reduce CO_2 emissions in the transportation sector, the government would mobilize all possible policy measures to increase the share of new vehicle sales held by next-generation low emission vehicles such as hybrids, electric vehicles, and vehicles that run on fuel cells, from the current 10 percent up to 50 percent by 2020 and up to 70 percent by 2030. It would seek to expand the use of biofuels to around 3 percent of gasoline consumption by 2020 and higher thereafter. It would seek to increase the share of mid-and long-distance transportation held by rail and coastal shipping from the current 55 percent to 80 percent by 2030.

Japan's residential and commercial sectors are perceived to have the greatest potential for reducing carbon emissions which, between 1990 and 2007, increased by 42 percent and 48 percent, respectively. Measures would include promoting the development of net-zero-energy houses and buildings by 2020 and making them the norm for new construction by 2030. Adoption of highly efficient water heaters and lighting will also be promoted.

Beyond 2030, the new BEP will also look into building next-generation energy and social systems, expanding the use of innovative energy technologies, promoting international energy and environmental cooperation, reforming the structure of the energy industry, promoting public understanding of energy conservation measures, and conducting human resource training. Specifically regarding technologies, it aims at achieving the smart grid and smart communities, promoting the development and installation of smart meters and other energy management systems, diffusing fuel cells and developing a hydrogen supply infrastructure, and accelerating the development and dissemination of innovative energy technologies.

However, in reviewing the feasibility of the ambitious plan, two issues stand out. One, the possibility of increasing the share of nuclear power by either increasing nuclear power capacity or increasing the operation rate of nuclear power plants became lame after the Fukushima nuclear power plant accident. The cost of building and operating nuclear power plants in Japan is also getting higher as the public attitude toward these developments has become more negative.

And two, the industry sector remains the largest energy consumer in Japan, at 46 percent in 2008. However, it has also been the principal target of government efforts to increase energy efficiency since the 1970s – approximately, 90 percent of the energy consumption in the sector has long been covered by the Energy Conservation Law and, partly as a result, the share of energy consumption attributable to the industrial sector has steadily declined, from the 1973 level which was nearly two-thirds. Thus, most of the easy savings in industry have already been exploited.

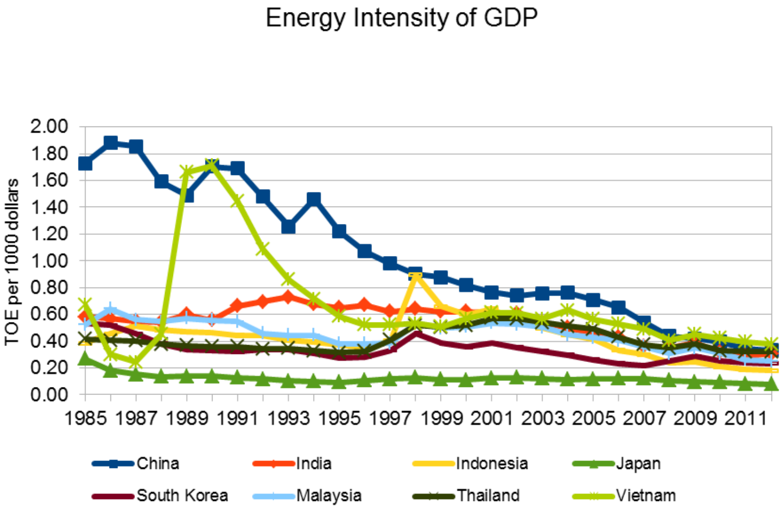
Given the intermittent nature of renewable energy such as photovoltaic solar energy, in the case of Japan, 100 GW of installed photovoltaic capacity is only as effective as 40 GW of conventional base load generation capacities. In addition, concerns remain about the ability of the electricity grid to handle more than a certain amount of electricity from intermittent sources such as solar and wind. For example, in the case of Japan, the existing power system could accommodate enough photovoltaic generating capacity to provide only about six to eight percent of the electricity supply, according to opinions of industrial experts. Thus, greater penetration by renewables may depend on the development of cost-effective, large-scale electric storage capacity (Duffield and Woodall, 2011).

3.2. Applicability

Applicability mainly concerns energy technologies. Three types of technologies would matter most for the sustainability of energy for Asian economies, namely, technologies for the exploration and extraction of non-renewable energy, renewable energy technologies as backstop technologies, and technologies to improve energy efficiency in energy processing, transformation, and final consumption. In as much as Asian economies are not leading in the development or adoption of these technologies, except in some cases for developed economies in the region such as Japan and South Korea, technology transfer/diffusion and adoption in Asian economies is therefore critical in assuring energy sustainability.

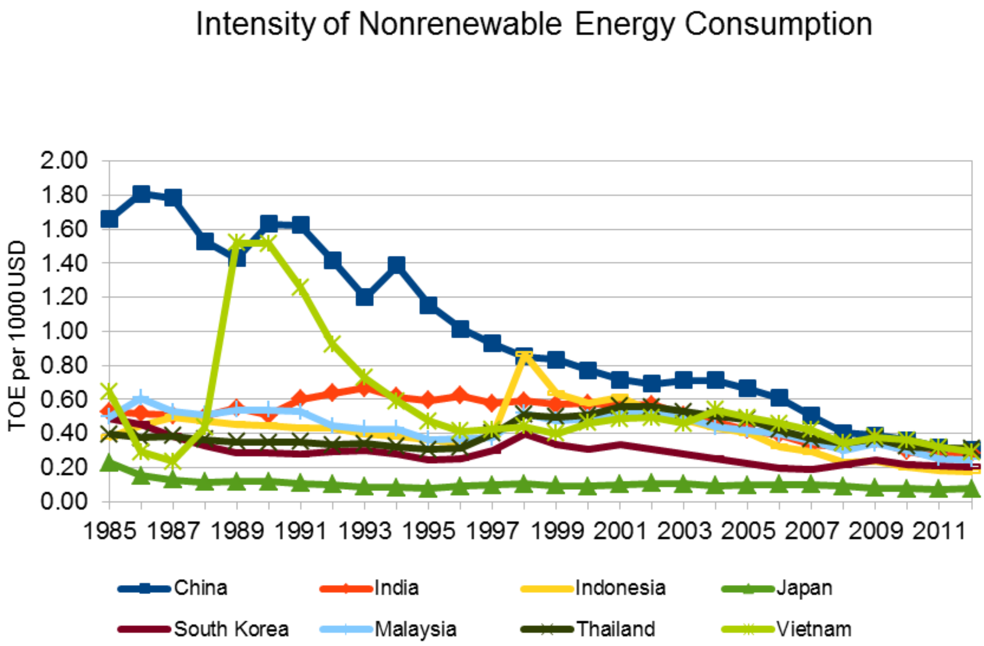
Figures 11, 12, 13 and 14 show specifically how energy intensity, particularly the intensity of non-renewable energy, in Asian economies has changed. The Figures show the intensity of energy consumption and non-renewable energy consumption, respectively, of nominal GDP. It is observed that while the intensity of most Asian economies has declined over time, the energy efficiency gap between those countries and the leading economy in the region, namely Japan, is still significant.

Figure 11: Energy Intensity of GDP of Asian Economies



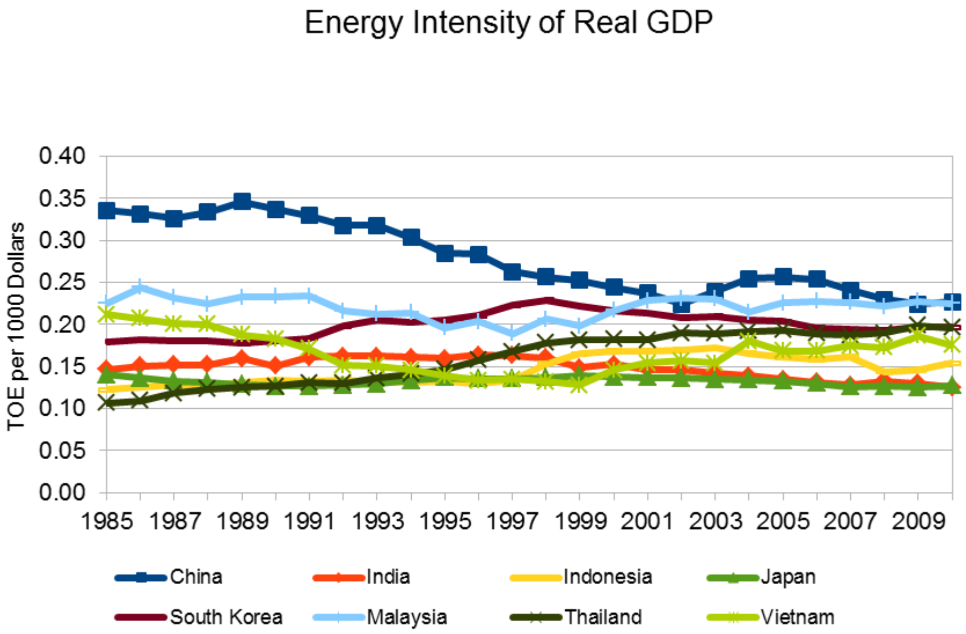
Source: BP World Energy Statistical Review 2013 and PWT database.

Figure 12: Non-renewable Energy Intensity of GDP of Asian Economies



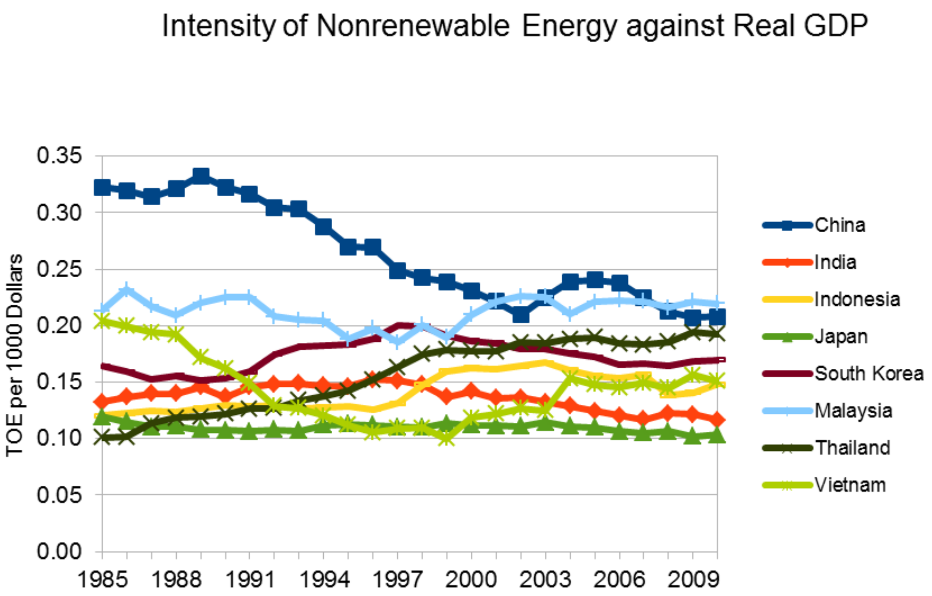
Source: BP World Energy Statistical Review 2013 and PWT database.

Figure 13: Energy Intensity of Real GDP of Asian Economies



Source: BP World Energy Statistical Review 2013 and PWT database.

Figure 14: Non-renewable Energy Intensity of Real GDP of Asian Economies



Source: BP World Energy Statistical Review 2013 and PWT database.

3.2.1. Technological Applicability: Efficiency, Exploration and Extraction Technologies for Non-renewable Energy

Behrens, *et al*. (2007)[4] show that while Asian economies experience a spectacular increase in the absolute amount of natural resource use, their overall intensity of natural resource use declines over time, although slower than other parts of the world. On the global level, material intensity, i.e., resource extraction per unit of GDP, decreased by about 25 percent, indicating the relative decoupling of resource extraction from economic growth.

Specifically, the energy intensity of economies in the region has improved over time due to the replacement of old industrial equipment with newer and more energy efficient equipment, phasing out a smaller, older infrastructure (e.g., power plants), and a gradual shift in the structure of the economy toward less energy-intensive industries. This has been achieved despite the fact that a growing personal wealth among households leads to more household consumption that requires significantly more complementary energy consumption, for example, more road vehicles and per capita transportation use, homes with greater floor space per person, and the construction of more commercial and residential building space per person (Hippel, *et al*., 2011a).

For example, Andrews-Speed (2009) noticed that China has managed to achieve a sustained decline of energy intensity from 1980 to 2001 but the trend was reversed in 2002. He attributed this to both a shift in the structure of the economy to more energy-intensive industries and a decline in the rate of technical innovation.

Shale oil

There is an increasing certainty that conventional oil production has peaked or will peak before 2025. It is thus important to examine unconventional oil resources (shale oil, oil sand, tar sand, and extra heavy oil) and possible production. Mohr and Evans (2010) model the production of unconventional oil and conclude that its projected production will not be sufficient to mitigate the peaking of conventional oil. The production of unconventional oil itself will peak around year 2076 to year 2084.

3.2.2. Shale gas

Shale gas was first commercially produced in 1998 in the United States (U.S.) by applying a process known as “hydraulic fracturing” or “fracking” that involves pumping a huge amount of water mixed with chemicals and sand to fracture rock formations so that trapped oil and gas can be extracted. Since then, the two processes (horizontal drilling and hydraulic fracturing) have become the main drivers for extracting shale resources. And although shale rocks can be found around the world and not only in the US, the success of shale gas production has so far been limited only to the U.S. (Sultan, 2013; World Energy Council, 2012b). In recent years, shale gas has fundamentally reshaped the U.S. natural gas. In April 2012, for instance, gas prices dipped below US$2/Mbtu for the first time in a decade. This is a quarter of the price of European gas sold at US$9/Mbtu. The world’s gas reserve is almost double when a conservative estimation of proven shale gas reserves is taken into account. It is noted that estimated shale gas reserve in Asia and Australia is three times as high as conventional natural gas reserve in the region. But still, as noted above, shale gas production has only been successful largely in the U.S. China has the largest potential but has only just begun to see some limited success in applying the technology.

3.2.3. Energy Efficiency and Clean Energy Technologies

China is the major coal consumer in the region as well as in the world. Coal in China is mainly used for power generation and the rest for the production of iron and steel. Improving the efficiency of energy conversion process and lowering emissions from coal in the power generation sector is critical under the current circumstances. China has thus been investing heavily in the R&D and the application of the relevant technologies.

There are a few clean coal technologies currently being developed in China. The first type refers to high efficiency combustion and advanced power generation technologies (Fluidised Bed Combustion and supercritical boilers) and IGCC (Integrated gassification combined cycle) that are already in wide application. The second type is coal transformation technologies such as gassification and liquefication technologies which are being prototyped and are in the demonstration phase. And the third type is Carbon Capture and Storage (CCS) technologies which are still being researched and prototyped. The latter two types of technologies are currently expensive to apply, even in developed economies. This is particularly true about CCS (Chen and Xu, 2010; NEA and IEA, 2010).

Nuclear power development after the Fukushima accident will expect more stringent regulations as well as escalation in costs to improve safety. Reducing the costs while improving safety is the key for the nuclear power industry to survive and grow. Small Modular Reactors (SMR) that are much cheaper and safer with reduced complexity in design look more preferable. SMR is also more attractive and applicable to developing countries mainly due to lower investment requirement and ease in grid connection (Kessides, 2012).

3.2.4. Renewable Energy Technologies

International institutions such as the World Bank, the International Finance Corporation, the United Nations Industrial Development Organization (UNIDO), and the Asian Development Bank (ADB) have been supporting Asian countries in developing clean/renewable energy and developing the necessary infrastructure. An Asia-Pacific partnership on clean development and climate (AP6), which includes India, China, Japan, South Korea, Australia and the U.S., was launched in 2006 to promote technology transfer, demonstration, and investment in clean energy and more efficient industrial technologies. Japan so far is the dominant supporter of renewable energy in Asia (Thavasi, 2009).

The renewable energy capacity of China, including that of hydropower, wind, solar PV, and biomass, more than doubled by 2010 compared to the 2005 levels, reaching a total of more than 200 GW (190 GW of this is from hydropower) (Cao and Bluth, 2013).

McLellan, *et al*. (2013) review and analyze Japan’s post-Fukushima energy strategy, in which three different scenarios of future energy mix for Japan are proposed, especially regarding the role of nuclear power and renewable energy. Currently, nuclear power is about 27 percent of Japan’s total primary energy supply. In the extreme scenario, nuclear power will be completely phased out by 2030 while renewable energy will see its share increased from the current 10 percent to 35 percent by 2030. Technically, Japan has enough renewable energy resources in terms of solar power and wind power to meet the target share for each of them in the no-nuclear power scenario. If solar PV panels could cover 20 percent of Japan's urban and industrial areas, even at a low efficiency of 10 percent energy conversion rate, the power generated would be enough to meet the target in the extreme scenario.

3.2.5. Institutional Applicability: Regional Cooperation

Hippel, *et al*. (2011c) summarize general factors that determine the success or failure of regional energy cooperation projects, especially focusing on Northeast Asia (NEA). There are seven factors, namely: (1) availability and stability of financing, (2) transparency between nations in project planning and operations, (3) transparent and stable system of product pricing, (4) agreement on the regulations relating to the project, (5) limited negative environmental and local social/economic impacts, (6) demonstrated positive environmental impacts, and (7) mutual net benefits in terms of energy security, economic efficiency and economic development. In addition to these generic factors, there are also a few factors specific to the East Asia region. They are the sophisticated nexus of cultural, historical, economical, territorial, political and geopolitical issues that form the environment where the NEA economies develop and interact with each other, Russia's Eastern energy policy, the influence of the partially built light water reactors in the DPRK, and the ''geopolitics'' of the involvement of the U.S. in the region.

3.3. Acceptability

Acceptability mainly concerns the environmental impacts of the chosen or dominant energy technologies. Besides greenhouse gases, there is also the concern about the safety of nuclear power. Asian economies are slowing down their progress with nuclear power after the Fukushima accident in 2011 and turning more interested in developing clean coal with further diversification to natural gas at the same time.

3.3.1. Impacts of Non-renewable Energy Production and Consumption

Hippel, *et al*. (2011a) point out that fast growth in energy consumption for Asian economies could negatively affect a number of areas, including impacts on global and regional energy markets in terms of surging prices, marine transport bottlenecks and marine pollution, local land use and environmental impacts for energy infrastructure, local and regional air pollution, and greenhouse gas emissions.

According to Cao and Bluth (2013), China's total carbon emissions more than tripled from 1980 to 2005 and carbon emissions per capita also more than doubled. However, the country's carbon intensity of GDP declined drastically, from 2.2 kg/dollar in 1980 to 0.74 kg/dollar in 2000, but slightly increased to 0.76 kg/dollar in 2005.

Specifically in China, coal consumption is responsible for 90 percent of the SO_2 emissions, 70 percent of the dust emissions, 67 percent of the NO_x emissions, and 70 percent of the CO_2 emissions. But as the most abundant energy resource, it will continue to be the dominant energy supply of China for a long time. Therefore, the development and deployment of clean coal technologies are crucial to promote sustainable development in China (Chen and Xu, 2010).

ERIA (2013) tracked the latest energy efficiency and conservation policy proposals by each of the East Asia Summit countries.[5] It is estimated that by 2035, these policies could reduce the future carbon emissions level by 28 percent. Such also applies to the case of China. It is noted that this is merely the number derived from the saving potential from the proposed policies. Technical potential and economic potential of energy savings and therefore carbon emission reductions are much higher.

3.3.2. Acceptability of Nuclear Power

According to Hong, *et al*. (2013a), nuclear power is statistically safer than any other fossil fuel or hydropower electricity generation in terms of number direct fatalities or injuries. Even if the externalities of the fatalities, injuries and evacuations that follow a power plant failure (externalities include resource costs, opportunity costs, mental trauma, food and land contamination, and other possible economic losses) are taken into account, by applying the accident probability, nuclear power implies an implicit cost of electricity of US$1.38 GWh^{-1}. This implicit cost is at a low level when compared with photovoltaic, hydroelectric power, oil power, and coal power which imply implicit cost of US$0.06 GWh^{-1}, US5.87GWh^{-1}$, US$57.7 GWh^{-1}, and US40.4GWh^{-1}$, respectively.

While radioactive wastes are another concern for nuclear power, coal power generation generates uncontrolled low-level radioactive wastes as well due to the trace natural uranium and thorium content of coal ashes. The emissions rate is 1.46

g/MWh (Hong, *et al*., 2013b). This is compared to the controlled high-level radioactive wastes from nuclear power generation, which is estimated as 0.713 g/MWh. In addition, Japan's existing spent-fuel storage capacity is enough to treat nuclear power wastes until mid-2020s. An additional 30,000 tons of storage capacity could enable Japan to sustain until 2050 by when the technologies to recycle and enrich plutonium from the wastes should be readily matured (Kastuta and Suzuki, 2011).

Hong et al. (2013b) propose a quantitative model to assess the sustainability of a country's energy mix for the power sector. The sustainability criteria that are quantified in the model include the levelized cost of electricity, energy security, GHG emissions, fresh water consumption, heated water discharge, land transformation, air pollutants, radioactive waste disposal, solid waste disposal and safety issues. The model is applied to access the sustainability of South Korea's future energy mix in the power sector. By considering all the above mentioned sustainability factors together in the algorithm, it is found that the scenario that maximizes the use of nuclear power yields the fewest overall negative impacts, and the scenario that maximizes renewable energy with fuel cells would have the highest negative impacts. Such negative impacts from maximizing renewable energy are mainly due to the fact that a higher share of renewable energy requires more conventional thermal power generation as a backup capacity and a low load factor means fuel savings would be limited. It is also due to the fact that higher costs of renewable energy have negative impacts on competitiveness of the economy. Kim, *et al*. (2011), however, point out the maximum nuclear scenario will not be able to stabilize the GHG emissions path of South Korea. In addition, the feasibility of maximum nuclear share in South Korea as well as in other parts of the world will be increasingly uncertain because of the evolving influence of civil society debates over the future of nuclear power and the nuclear fuel cycle and waste treatment.

Institutional and Market Structure Issues

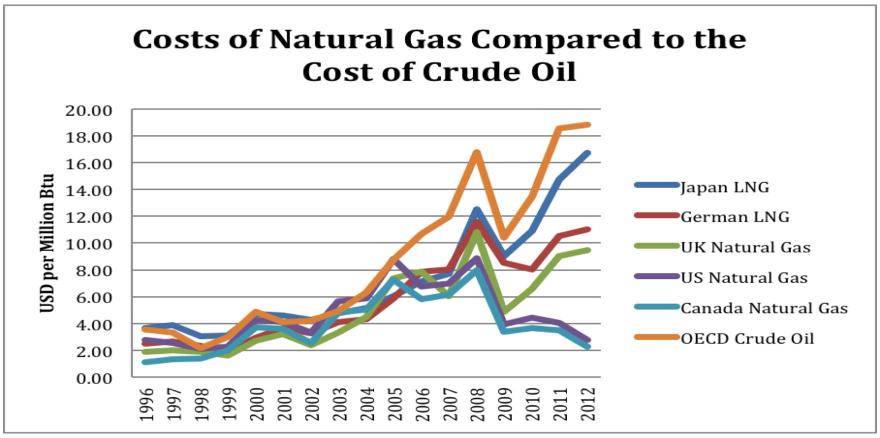
Moe (2012) discusses how the vested interests of stakeholders in the energy market could shape the paths of developments in renewable energy and energy efficiency. In the Japanese case, the solar industry has been far more preferred by insiders of the market than wind. This has made it far harder for the wind industry to rise in Japan. For this reason, energy efficiency technologies, which are not in the way of the interests of insiders and not challenging any vested interest structure, have been the favored approach for over three decades in the economy.

3.4. Affordability

3.4.1. Costs of Non-renewable Energy

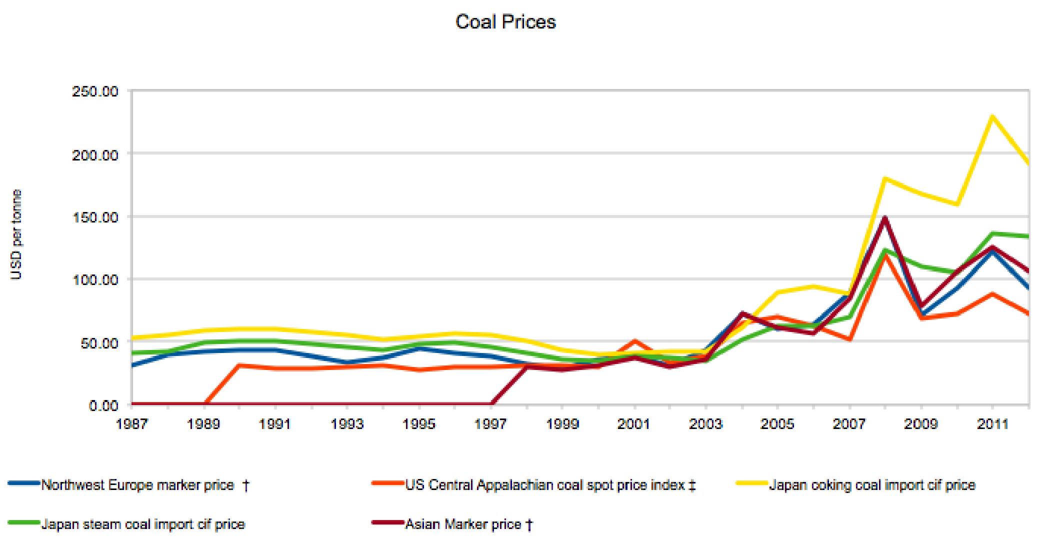
The markets of non-renewable energy in Asia has been fragmented. As a result, the costs of importing non-renewable energy in a certain Asian economy are usually higher than in other parts of the world as shown in Figures 15 and 16. However, these prices seem to apply only to the portion that is acquired from the spot market. To ensure energy security, major Asian economies have been building up overseas non-renewable energy production capacities or shares in foreign supply capacities for decades with prices secured at different levels in the long-term supply contracts of different nature. Such is especially true to coal and natural gas imported to the region. Fragmented markets for non-renewable energy in the region may benefit individual economies in the short run. But in the long run, it means low energy security and the unstable costs of energy. In the natural gas market of the region, the so-called Asian Premium is one of the negative results of the fragmented markets (Chang and Li, 2014; Davoust, 2008).

Figure 15: Cost of Natural Gas in Various Markets of the World Compared to the Cost of Crude Oil



Source: BP World Energy Statistical Review 2013

Figure 16: Cost of Coal in Various Markets of the World



Source: BP World Energy Statistical Review 2013.

At the same time, when it comes to final consumption of non-renewable energy, especially in the form of refined products, most Asian economies provide subsidies out of the concern for social equity (such as India, Malaysia, Thailand and Indonesia) or for the purpose of promoting competitiveness of domestic industries (such as China). As a side effect, these subsidies encourage the use of energy in inefficient ways.

3.4.2. The Cost of Renewable Energy

Park, *et al*. (2013) estimated that for South Korea to achieve 80 percent lower emissions than the 2008 level by 2050 in the power generation sector, the economy has to invest heavily in renewable energy and assume up to 20 percent higher costs of electricity. This result assumes that the economy will gradually phase out nuclear power vis-à-vis the current government's plan to have nuclear contributing some 22 percent of power supply by 2035[6].

After the Fukushima accident in March 2011, the Japanese government has been considering four possible future energy mixes, including a nuclear-free pathway, and three others with 10-35 percent nuclear supply coupled with a larger proportion of renewable energy and fossil fuels to replace nuclear energy. According to Hong, *et al*. (2013a) who apply a multi-criteria decision-making analysis (MCDMA), the nuclear-free pathway is estimated to be the most costly choice to Japan, in terms of economic costs, environmental costs, and social costs.

Renewable energy also has the potential to help the Asian developing economies to relieve their future energy sustainability. Nguyen and Ha-Duong (2009) show that in the case of Vietnam, the economy, which currently relies mainly on natural gas (39%), hydropower (37%), and coal (16%), will turn into mainly relying on coal (44%) followed by natural gas by 2030 in the power generation sector as demand for electricity will increase significantly. However, if renewable energy technologies such as small hydro, geothermal, and thermal biomass are adopted, Vietnam can reduce the share of coal in the future by 5 percent, reduce the total discounted cost of electricity by 2.6 percent (which is a surprising result), reduce total CO2 emissions by 8 percent and reduce the future imports of coal and natural gas. However, wind energy will have a very limited application in the economy despite its over 125GW of technical potential, and grid-connected solar would never be adopted even by 2030.

Hippel, *et al*. (2011a) and Thavasi (2009) emphasize the importance of market structure liberalization in the energy sector of Asian economies. It will not only improve efficiency and minimize the costs of energy but also attract enough financial investment into the sector to expand the energy infrastructure.

4. Policy Implications

4.1. The Future of Energy Supply and Demand

Zhang, *et al*. (2011) provide a comprehensive review of the demand and supply of energy in China as well as the country's sustainable development strategy and policies. The current energy situation of the country can be summarized in five points. First, per capita consumption level is low compared to developed economies. Second, energy consumption grows rapidly but is expected to stabilize around 2050 with low energy efficiency. Third, coal dominates in primary energy mix as the Chinese government constantly emphasizes reliance on domestic energy resources. Fourth, despite government's energy policy on self-reliance, dependence on imported energy, especially oil and natural gas, has been increasing over time. Fifth, energy consumption leads to severe environmental pollution and causes multiple types of economic losses. It is estimated that air pollution by fossil fuels alone causes losses of about 2-3 percent of GDP in the short run. However, no long-run damages estimation is available as yet.

Toward sustainability, the Chinese government has taken measures such as legislation for energy conservation and renewable energy development, shutting down of low-efficiency small plants in the energy-intensive industries, further raising of energy efficiency standards for vehicles, buildings, public passenger transportation systems, and railway transport systems, improvement of fleet management, grant of incentives to alternative fuel and hybrid vehicles, imposition of energy consumption taxes, augmentation of energy savings regulations and standards, improvement of public energy saving awareness, provision of energy conservation information, and tax recessions for energy saving products, technologies and equipments. For the promotion of renewable energy, especially solar and wind, the high cost, intermittency of generation, grid connection, and lagging behind in relevant technologies are the main barriers. In recent years, the government has also prioritized the development of nuclear power, although there were interruptions and delay due to the Fukushima accident in 2011. The challenges to nuclear energy in China mainly include public awareness and acceptance, lagging behind in relevant technologies, and lack of nuclear waste treatment and processing capacities.

China's policymakers are putting a new emphasis on energy efficiency, conservation, renewable energy, and the shift toward natural gas as the principle primary energy source, in the place of coal and oil (Cao and Bluth, 2013). Fan and Xia (2012) find that through the optimization of energy input mix, industry structure, and technological improvements, the country's energy consumption by 2020 could be reduced by as much as 15 percent.

A further note on China's energy efficiency policies is from Andrews-Speed (2009). The economy needs to address a number of existing constraints which include too much reliance on industrial and social policies and the reluctance to use economic and financial instruments, the nature of political decision-making and public administration, a shortage of technical skills to improve energy efficiency, and social attitudes toward energy issues.

In less developed economies such as Vietnam, the government is also adviced to shift to market-based energy pricing and to remove energy subsidies. In devising energy efficiency policies, government is reminded to look into both demand side and supply side energy efficiency while keeping in mind the importance of cross-sectoral opportunities of energy savings (Do and Sharma, 2011).

4.2. Technology and Economic Structure

On the demand side, Asian economies should put emphasis on the development and adoption of energy efficiency technologies in the process of energy consumption. Although eventually thermal dynamics sets limit to how far energy efficiency can go (the minimum energy requirement for processes of production and services activities) and the marginal return to further R&D to improve energy efficiency of a certain energy use process could decline, the opportunities existing in the numerous processes in various sectors of an economy seem endless.

On the supply side, Asian economies have to look into clean coal technologies, unconventional oil and gas technologies, renewable energy technologies, and nuclear technologies simultaneously, as each of these tracks has uncertainty embedded in terms of how soon the technologies will break through and how much potentials these technologies will have. Policies should weigh the relative costs of these technologies, including economic costs, environmental costs, and social costs.

India is a typical low-income developing economy. Its per capita energy consumption is among the lowest in the world, only about 1/3 of China's and 1/15 of the U.S.'s. During 2004-2005, India had about 70 million people who do not have access to electricity. Economies like India usually provide substantial subsidies to energy, especially fossil fuels, and the removal of them is politically difficult. In the case of India, diesel, coal, and electricity are all subsidized and their prices are lower than the costs of production (Parikh, 2012). Such subsidies encourage inefficient use of energy. Ideally, the fund for subsidy should have been used to financially support the development and diffusion of energy conservation technologies and products and renewable energy supply.

5. Conclusions

In this paper, the demand and supply trends of non-renewable resources, especially non-renewable energy in major Asian economies, have been reviewed. The discussion focuses on the sustainability of Asian economies' production and consumption of non-renewable energy by deriving a four dimensional analytical framework based on the implications of the theoretical Hotelling models. The framework aims at practically and comprehensively reviewing factors that determine sustainability of non-renewable energy production and consumption in Asian economies.

Asian economies face many challenges in the future sustainability of the production and consumption of energy, especially non-renewable energy. First, most Asian economies are developing economies and therefore expect high growth in energy demand as industrialization, urbanization, wealth and income levels, standard of living improve while population continues to expand. Second, more economies will change from net non-renewable energy exporters into net importers, and therefore, dependence on imported non-renewable energy is expected to increase steadily. Third, additional exploitable energy resources are unevenly distributed, especially in the areas remote from the centres of energy consumption. International cooperation is increasingly being demanded in order to provide appropriate financial and technological means for the host country to exploit the resource and subsequently move it to consumption centres in neighbouring countries. Fourth, as shale oil and shale gas are still to be proven in this part of the world and with abundant coal reserves, Asian economies inevitably will increase the consumption of coal in absolute terms, although the share of coal may decrease. In this regard, clean coal technologies should be given priority. Fifth, renewable energy resources will gradually be developed in the region, but they will play a limited role. Sixth, economies with existing nuclear power capacities still have strong willingness to increase the amount and share of nuclear power in their energy mix while others are actively preparing for the adoption of nuclear power despite the setback brought about by the Fukushima accident. Nuclear safety networks and international cooperation/mechanisms in nuclear information exchange, experience sharing, and technology diffusion should be established. Seventh, domestic energy market reforms and other measures to manage energy demand and energy efficiency should also be emphasized, as there is substantial room for energy conservation in most Asian economies. Last but not least, concerns on the environmental impacts of non-renewable energy production and consumption have been rising but no internationally binding mechanisms are at work in the region to contain GHG emissions and other environmental problems. In other words, the production and consumption of non-renewable energy cannot be said to be properly priced without including and taking account of negative externalities on the environment. International cooperation is also needed in this regard.

In sum, while progress in energy production and consumption technologies, including backstop energy technologies, is expected to relieve the energy sustainability and security concerns in the long term, in the short term, policies still have a lot to do to improve energy efficiency, reform the energy sector, ensure adequate investment in energy infrastructure, and drive for regional cooperation in energy market integration, infrastructure investment, and infrastructure connectivity.

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ENDNOTES

[1] Yao and Chang (2014) have applied the 4As framework to examine energy security in China.

[2] If the marginal cost of extraction is independent of the rate of extraction and invariant over time, then resource price will grow at a rate that tends toward the rate of interest as the share of cost in resource price gets smaller and smaller over time.

[3] At the Fukushima nuclear power plant, 10 GW of nuclear generating capacity or more than 20 percent of present nuclear generating capacity (about 49 GW) is offline. In addition, with 42 of Japan's 54 reactors offline for maintenance, disaster repairs or safety problems, another 60 percent of nuclear generating capacity is currently down (Moe, 2012).

[4] The study applies a Material Flow Accounting (MFA) method, using domestic extraction data only.

[5] Membership of the EAS comprises the ten ASEAN countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Vietnam), Australia, China, India, Japan, New Zealand, the Republic of Korea, the United States and Russia.

[6] According to the Wall Street Journal, 15 October 2013.

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