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World trend in energy: an extension to DEA applied to energy and environment

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Abstract

This study proposes a use of data envelopment analysis (DEA) to assess the performance of energy industries. The DEA is a nonparametric approach that does not assume any functional form for performance assessment. The purpose of this study is to discuss how DEA can examine the current energy industries and their trends in the world. The energy is separated into primary and secondary categories. The primary energy is classified into fossil and non-fossil fuels. The fossil fuels include oil, natural gas and coal, while the non-fossil ones include nuclear and renewable energies (e.g., solar, wind, biomass, water and others). Energy consumption is essential for developing economic prosperity in all nations. However, a use of various energy resources usually produces many different types of pollutions (e.g., air, soil and water pollutions), leading to a huge damage on our society and human health. Thus, it is important for us to understand a general trend of world energy when we consider various environmental issues. This study discusses electricity as a representative of secondary energy. It is not easy to maintain a high level of social balance, so-called sustainability between economic development and environmental protection. As the initial step for sustainability development, this study summarizes a general trend of energy whose consumption has been increasing along with an economic development and a population increase in the world. Along with discussing the trend of world energy, this study describes why DEA is useful as one of the methodologies to assess a social balance between economic success and environmental protection by identifying a level of efficiency, later referred to as "unified (operational and environmental) efficiency." Thus, this study conveys the research necessity of DEA environmental assessment on energy and sustainability from a perspective of supply and demand on energy resources in the world.

Keywords: DEA, Primary energy, Secondary energy, World energy, Environment

1 Background

This study describes how to use Data Envelopment Analysis (DEA) for assessing the performance of energy firms. The methodology has been widely used for performance assessment on various organizations in public and private sectors because of its computational practicality (i.e., solving by linear programming) and less assumption (e.g., nonparametric) on production relationship between inputs and outputs. It is indeed true that it has a high level of practicality. However, the conventional uses of DEA were often misguiding many applications, in particular, in guiding energy industries. See the recent book and article prepared by Sueyoshi and Goto (2017) and Sueyoshi et al. (2017), both of which have contained 693 articles published in energy-related SCI or SSCI-listed journals in the past four decades, where SCI and SSCI indicate Science Citation Index and Social Science Citation Index. They have claimed that the use of DEA in energy sectors has long been misguided for a long period. Of course, this study clearly acknowledges their academic contributions of the previous DEA studies in the area of DEA applied to energy and environment.

The purpose of this study is to document how to use DEA for the performance assessment of energy sectors. To attain the research objective, we will review a recent energy trend in the world and then discuss a use of DEA from energy sectors.

The energy is separated into primary and secondary categories. The primary energy is further classified into fossil fuels and non-fossil fuels. The fossil fuels include oil, natural gas, and coal, while the non-fossil ones include nuclear and renewable energies (e.g., solar, water, wind, biomass and other energy resources). Energy consumption is essential for developing economic prosperity in all nations. We consider electricity as a representative of secondary energy because it is produced through a use of primary energy sources.

As the initial step for understanding energy and its trend, this study summarizes a general trend of energy whose consumption has been increasing along with an economic development and a population increase in the world and then extends the general trend to a use of DEA applied to energy and environment.

The remainder of this article is organized as follows: Section 2 describes a world energy trend. Section 3 describes primary energy. Section 4 discusses secondary energy. Section 5 discusses how to apply DEA for the energy sectors. Section 6 concludes this research along with future extensions.

2 General trend

World primary energy consumption continues to increase along with an economic growth during past decades. It has increased from 3.8 to 12.7 billion tons of oil equivalent, indicating an average annual growth rate by 2.6% from 1965 to 2013. The growth of energy consumption varies, depending on a region and its industrialization. For example, industrial countries such as OECD nations, where OECD stands for Organization for Economic Co-operation and Development, had lower growth rates. In contrast, developing countries (e.g., non-OECD countries) had higher growth rates than such industrial nations. A rationale is because these counties have already attained a high level of industrial infrastructures so that they are sufficient in maintaining moderate growth rates in their economies and populations. Furthermore, they have improved an efficiency level of energy consumption equipment over the past by technology development. See Sueyoshi and Goto (2017). In contrast, energy consumption has been still steadily increasing in developing countries. In particular, a significant increase in the world energy consumption can be found in the Asia-Pacific region. Under such an energy consumption trend, the share of OECD countries in energy consumption has decreased from 70.0% in 1965 to 43.0% in 2013, as depicted in Fig. 1, where the left vertical axis indicates an amount of energy consumption, measured by million tons of oil equivalent, and the right vertical

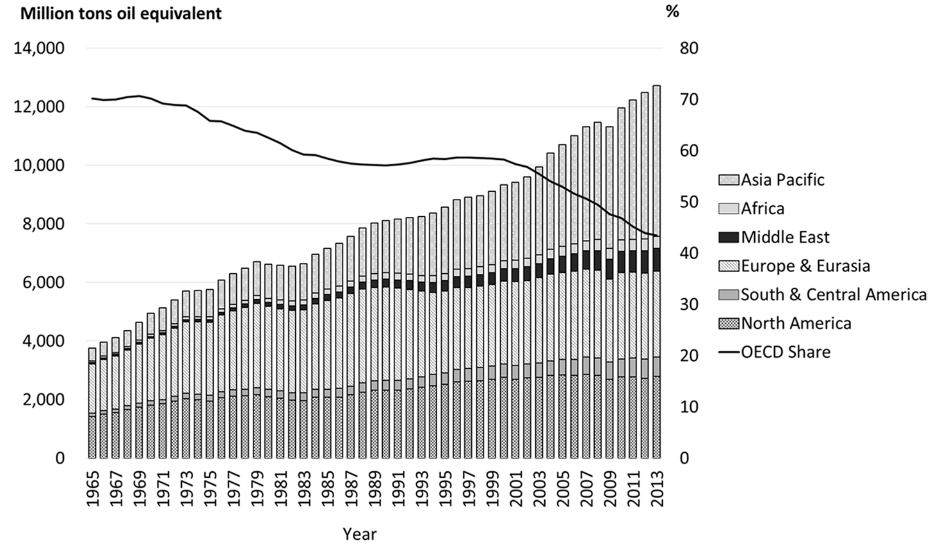

Fig. 1 Trend of World primary energy consumption. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). A large increase in energy consumption can be found in the Asia-Pacific region during the observed decades. An increase can be found in Europe and Eurasia, as well. A rapid economic development has been accomplished in the two regions. *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html)

axis indicates a percentage of the OECD share, along with an annual period on the horizontal axis.

Figure 2 visually describes the world primary energy consumption by each energy source. In the figure, the vertical axis indicates an amount of energy consumption by each energy source, and the horizontal axis indicates an annual period. Oil has been a major source of primary energy consumption, which accounted for the largest share of total energy consumption with 31.53% as of 2012, particularly supported by a steady increase in a usage of a transport sector. The average annual growth rate was 1.2% over the period from 1971 to 2012. See Sueyoshi and Goto (2017) along with Fig. 2.

The consumption of coal and natural gas has grown faster than oil over the observed annual periods. The coal consumption has increased for electricity generation, particularly in Asian counties such as China, where the coal is very popular as inexpensive generation fuel. The natural gas consumption is found in developed countries not only for generation fuel but also for city gas demand because they are required to cope with the global warming and climate change. See Sueyoshi and Goto (2017).

The most fast-growing energy sources during the observed annual periods (1971–2012) were nuclear and renewable energies (including geothermal, solar, wind, biofuels and waste, and exclude hydro) whose annual average growth rates in consumption were 7.9 and 2.1%, respectively. Rationales for the rapid growth of nuclear and renewable energies include a necessity of diversified energy supply capabilities, so directing toward a low-carbon society. However, it is important to note that their shares in primary energy consumption in total were not high enough, with approximately 5 and 11.0%, respectively, as of 2012. Thus, it is almost impossible for most of nations to use

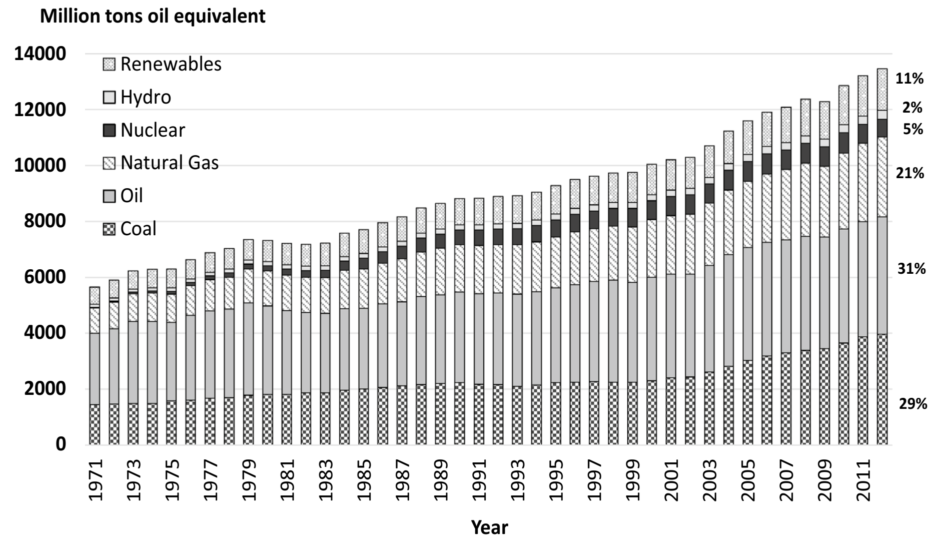

Fig. 2 World energy consumption by energy sources. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). The figure indicates that fossil-fuel components (i.e., oil, natural gas and coal) are major energy resources in the world, all of which are used for not only modern business (transport and industry sectors) and household sector but also military purposes. The fluctuation of oil price may influence the market condition of modern business because oil is the most important primary energy resource. *Source*: International Energy Agency (IEA) World Energy Statistics and Balances, OECD (Organization for Economic Co-operation and Development, Paris, France, OECDiLibrary http://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en)

the renewable generations as main energy sources even now. Of course, it is hoped that their shares will be able to increase more in the future.

Note that Sueyoshi and Goto (2017) and Sueyoshi et al. (2017) summarized previous 693 studies on DEA applied to energy and environment in the past four decades.

3 Primary energy

3.1 Fossil-fuel energy

3.1.1 Oil

An amount of proved oil reserve as of 2012 was 1 trillion and 687 billion barrels after excluding Canadian oil sands and Venezuela's Orinoco Belt, as depicted in Fig. 3, where oil reserve of each nation is expressed by a part of the pie chart. Reserve-Production (RP) ratio calculated from the numbers is 52.9 years. The RP ratio has remained almost constant during the four decades after the 1980s due to an improvement in resource recovery technology as well as newly detected and confirmed oil resources, although oil resource depletion was a serious problem after the oil shocks in 1970s. In particular, recently, the RP ratio has rather been increasing because of an increase in heavy oil reserve in Venezuela and Canada.

As of 2012, a country that has the largest proved reserves was Venezuela, although Saudi Arabia had been in the first position for a long time before it became the second since 2010. The share of the proved reserve of Venezuela was 18% with 297.6 billion barrels, followed by 16% with 265.9 billion barrels of Saudi Arabia, and 10% with 174.3 billion barrels of Canada. They were followed by Iran (9%), Iraq (9%), Kuwait (6%) and

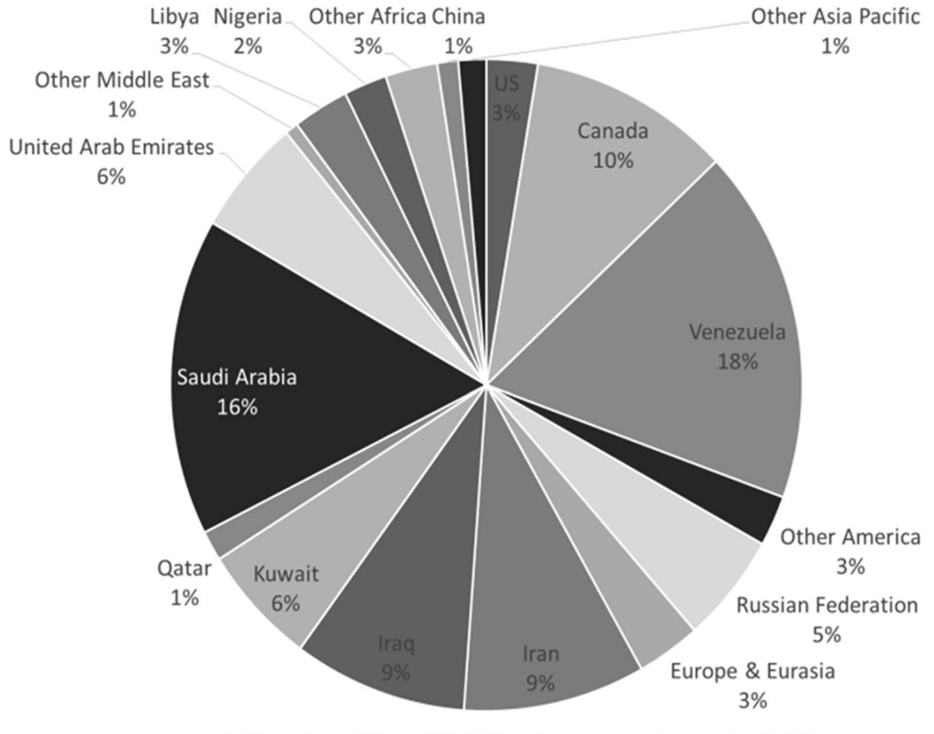

Fig. 3 World Oil Proved Reserves as of 2012. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). The figure excludes an amount of Canadian oil sands and Venezuela's Orinoco Belt. The shale oil reserve is also excluded from the figure. The largest shale oil reserve exists in China and the second is the USA. *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html)

United Arab Emirates (6%). Middle East countries accounted for approximately half of the total share of proved oil reserves in the world.

Figure 4 visually describes that world oil production, on the vertical axis, has increased from 53.66 to 86.75 million barrels per day from 1972 to 2013, so becoming approximately 1.6 times larger than the level of 1972 over the past four decades. Since 2000, European countries decreased an amount of oil production, while Asia-Pacific region, Africa and Latin America remained almost constant in their oil productions. Productions from Russia and Middle East steadily increased during the observed annual periods. As depicted in the figure, the world has a large amount of supply capability to satisfy the demand. Here, it is important to note that European nations decreased the amount of oil production, but Russia increased its production level. As a result, the total amount of European nations, including Russia, seemed almost constant as depicted in Fig. 4.

As depicted in Fig. 5, oil production in OPEC countries, on the vertical axis, decreased in the early 1980s after a large increase by the 1970s, but the amount of production gradually recovered in the late 1980s. Here, OPEC stands for Organization of the Petroleum Exporting Counties.

The decreasing oil production trend of OPEC nations in the early 1980s was because of both a production increase from non-OPEC countries, looking for high oil price, and

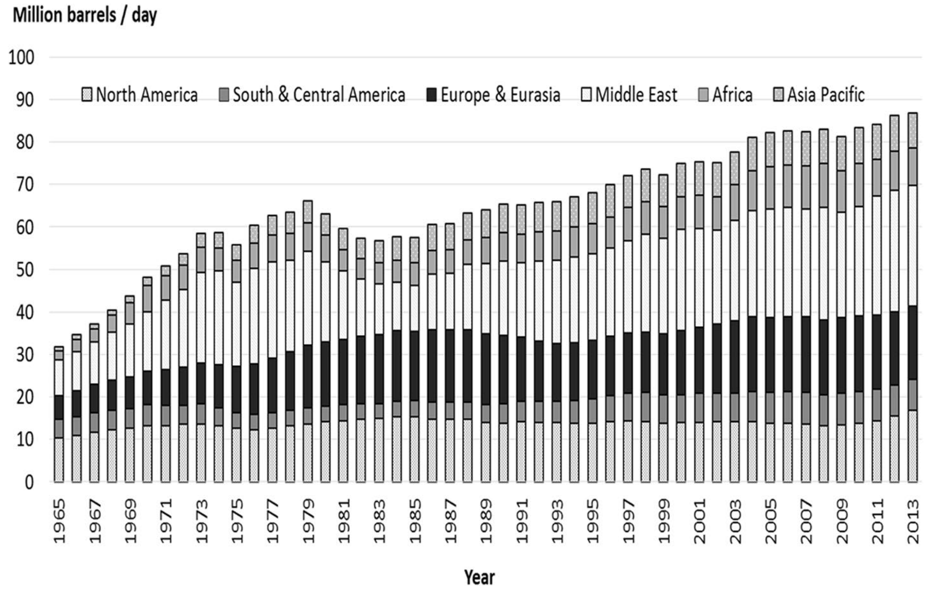

Fig. 4 Trend of World Oil Production: Regional Classification. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html)

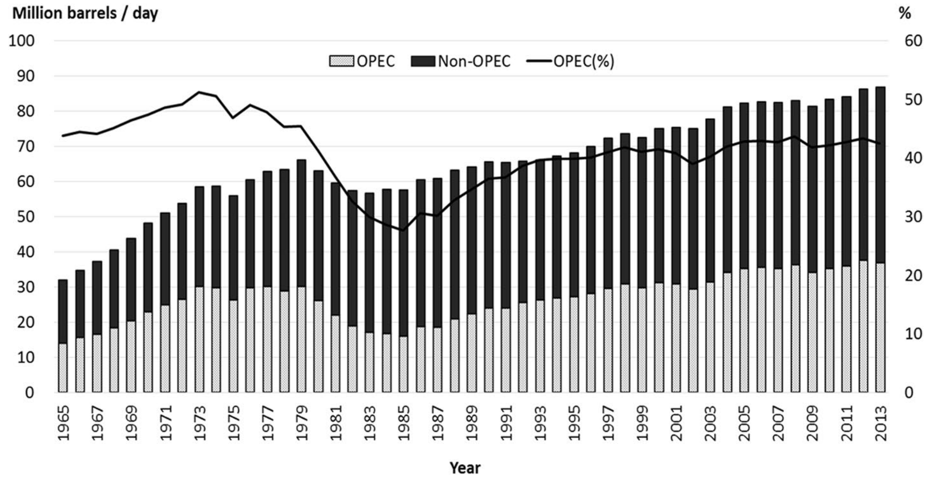

Fig. 5 Trend of World Oil Production by OPEC and Non-OPEC. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html)

lower oil consumption in the world. Consequently, the production share of OPEC countries decreased to a level of less than 30% in the middle of 1980s from more than 50% in the early 1970s. However, it increased again to the level of low 40% since the 2000s.

Oil production in non-OPEC countries, including former republics of the Soviet Union, the USA, Mexico, Canada, UK, Norway, China and Malaysia, has steadily grown from 17.88 to 49.93 million barrels per day from 1965 to 2013. In recent years, oil production in the USA has been receiving a major attention from the world, whose production has rapidly grown due to the "shale oil and gas revolution." A problem of the shale oil production is that the production cost is high (e.g., \$50 per barrel) due to technical difficulty by water cracking or super critical CO_2 so that many of US oil companies, depending upon the shale oil production, may have a financial problem because of the recent low oil price. See Sueyoshi and Goto (2017).

Figure 6 depicts that world oil consumption, on the vertical axis, has grown from 55.56 to 91.33 million barrels per day from 1973 to 2013. The annual average growth rate was 1.3%. In OECD countries, oil consumption increased during the late 1970s, from 41.32 million barrels per day in 1973, and then decreased in the beginning of 1980s because an economic recession occurred after the two oil shocks. Energy sources, such as nuclear and natural gas, were proposed as an alternative to oil, as well. Along with an expansion of economy after the late 1980s, the oil consumption slowly increased, but it stagnated since 2005, because of improved fuel efficiency of vehicles and rising oil price.

In contrast, non-OECD countries have exhibited a large amount of oil consumption in recent years. The increase was supported by their economic growths. For example, the consumption increased from 14.25 to 45.77 million barrels per day from 1973 to 2013, so indicating an increase by 3.0% as an average annual growth rate. As a result, the share of oil consumption in non-OECD counties increased from 26% in 1973 to 50% in 2013, whereas developed countries decreased their shares of consumption from 74 to 50% during the same annual periods.

World oil trading has steadily increased along with an increase in oil consumption. The volume of total oil trade has reached 55.67 million barrels per day in 2013. The 50% of the total volume of oil imports was occupied by the three large markets, including

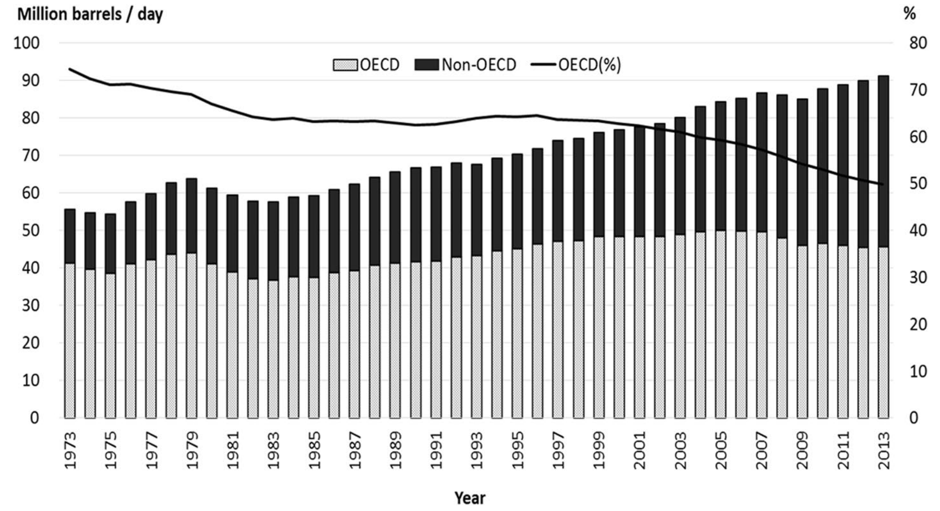

Fig. 6 Trend of World Oil Consumption by OECD and Non-OECD. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). There was no major increase in OECD nations, but there was an increasing trend in the non-OECD nations. The result indicates that industrial nations in OECD have attained the almost maximum limit on oil consumption. In contrast, non-OECD nations have increased the consumption for their industrial developments along with a population increase in these nations. *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html.)

Japan, the USA, and European nations. Meanwhile, the Middle East occupied the largest share of the total volume of exports with 35% share in 2013. In addition, the 10% of the total volume of exports from Middle East (2.01 million barrels per day) was delivered to the USA, 11% (2.07 million barrels per day) to Europe and 76% (14.74 million barrels per day) to Asia-Pacific region. The evidence confirms that the Asia-Pacific region is the largest sales channel of oil from the Middle East. The regional oil dependency to Middle East has remained higher in Asian countries than that of Europe and the USA over the 1990s in order to support their rapid economic growths, in particular China and Japan. See Sueyoshi and Goto (2017).

Note that DEA applications in the oil industry and related areas include Azadeh et al. (2012, 2015), Barros and Assaf (2009) and Barros and Managi (2009).

3.1.2 Natural gas

As visually summarized in Fig. 7, the world gas reserve was 185.7 trillion m^3 as of at the end of 2013. Middle East occupied the largest share of gas reserve with 43%, followed by Europe, Russia and the former republics of Soviet Union with 31% of the total share. Different from a high level of regional concentration of oil reserve in Middle East, natural gas has low regional concentration. Natural gas production was 3.4 trillion m^3 in 2013. The average annual growth rate was 2.5% between 2003 and 2013, which was higher than the growth rate (1.1%) of oil during the same annual periods. Two large regions in natural gas production were North America with 27% share and Europe, Russia and the former republics of Soviet Union with 31% share in 2013.

Although the amount of natural gas reserve in Middle East was 43%, the production share was only 17%. This gap between reserve and production occurred because of two business rationales. One of the two rationales was that a very large amount of investment

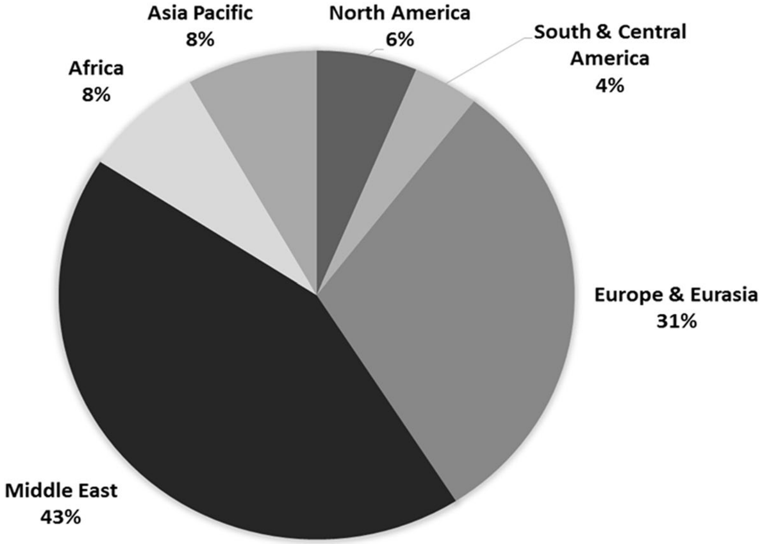

Fig. 7 World Natural Gas: Proved Reserves as of 2013. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *Source*: BP Statistical Review of World Energy (2014) (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html)

was necessary to transport natural gas through a huge pipeline network. The other rationale was that investment for natural gas production was relatively small because gas was usually produced with oil production. Oil price (per unit) was much higher than gas price. Thus, the gas pipeline network was not constructed from Middle East to large consumption areas in the world. The situation was different between Russia and Western Europe where a gas pipeline network has already existed between them. Most of natural gas produced in Middle East countries were consumed by themselves, and the remaining was liquefied and exported as Liquefied Natrual Gas (LNG).

Responding to increasing natural gas consumption in the world, major oil companies in Europe and the USA developed large natural gas plants. In particular, new LNG projects have been planned and prepared to increase an amount of LNG. In addition, new technologies such as Gas to Liquids (GTL) and Dimethyl Ether (DME) have been applied to natural gas production. Part of them has been already commercialized for gas production.

About 60% of the world natural gas consumption arises from North America, Europe, Russia and the former republics of the Soviet Union. There are two rationales for the large share in those regions. One of the two rationales is that they produce an abundant amount of natural gas and has promoted a usage of natural gas. The other rationale is that these areas have already well-developed pipeline infrastructures. A large amount of natural gas can be easily transported through their established huge infrastructure systems. See Sueyoshi and Goto (2017).

From 2003 to 2013, the world natural gas consumption increased by 2.6% as an average annual growth rate. A business rationale for the recent growth of natural gas consumption was because of a demand increase for electricity generation. The natural gas has lower environmental impacts than other fossil fuels. In addition, an economic advantage of natural gas for electricity generation has increased through a technological progress by gas turbine combined cycle generation. As of 2013, the natural gas accounted for 30, 32 and 22% in total primary energy consumption in the USA, OECD nations in Europe, and Japan, respectively. See Sueyoshi and Goto (2017).

Pricing system of natural gas varies from a region to another region. For example, the price of natural gas (i.e., LNG) exported to Japan is linked to Japan Crude Cocktail (JCC), which makes an average crude oil price imported by Japan. The pricing formula is designed to reduce a degree of variation in natural gas price. Meanwhile, the gas price in the USA and North-West Europe such as UK is determined by relationship between demand and supply in each gas market. In the other countries in continental Europe, natural gas price is linked to those of alternative fuels such as petroleum products or crude oil.

3.1.3 Coal

Confirmed coal resources were 891.5 billion tons at the end of 2013, most of which were reserved in the USA (26.6%), Russia (17.6%) and China (12.8%), respectively. Bituminous coal amounted to 403.2 billion tons. Subbituminous coal amounted to 488.3 billion tons. The advantage of coal is lesser regional concentration than oil and natural gas. Coal reserve is widely distributed over the world. Besides, according to the BP statistics in 2014, the RP ratio was 113 years, thus being considerably longer than the other energy resources such as oil.

World coal production in 2013 was estimated as 7.896 billion tons. Among the total coal production in 2013, the sum of China (47%) with the USA (13%) indicated more than half of the total sum, followed by Australia, Indonesia, India, and Russia, whose production sum became 84% of the total coal production.

China has been increasing coal production since 2001 in order to cope with rapidly expanding domestic energy consumption that is mainly used for electricity generation. In the USA, coal has long been positioned as an important energy resource, followed by oil. The coal-fired power generation had more than 50% share of electricity generation until early 2000s. However, because of increased social consciousness on various air pollution problems and increased natural gas generation, the number of coal-fired power plants has gradually decreased so that the share of electricity generation became approximately 43% by 2013 in the USA. Another rationale for explaining the share decrease was because of a large price decrease in natural gas, caused by the recent development of shale gas. The decrease in coal-fired power generation reduced the consumption and production of coal.

The total coal consumption in the world was estimated at 7.697 billion tons in 2012, implying a growth by 2.3% from the previous year. Two largest coal consumption countries were China (48%) and the USA (11%), whose sum accounted for approximately 60% of the world consumption in 2012.

The total coal export in the world was estimated at 1.255 billion tons in 2012. The largest exporter of coal was Indonesia that occupied 30.5% of the world total. The second was Australia with a share of 24.0%, followed by Russia (10.7%). China was the second largest exporter of coal in 2003. However, the amount of Chinese export drastically decreased since 2004 because of its rapid expansion in domestic coal consumption. In recent years, Asian countries such as China and India increased coal consumption for electricity generation at many coal-fired power plants to satisfy an increase in electricity consumption. In 2012, the total sum of coal imports by Asian countries, including Japan, China, Korea, India and Taiwan, was estimated to be 0.822 billion tons, or 64.4% of the world total coal import. In particular, China's import of coal exceeded 0.1 billion tons in 2009 and became a pure importer of coal as a result of a drastic increase in coal consumption.

Note that DEA applications in this area include Budeba et al. (2015), Byrnes et al. (1988), Fang et al. (2009) and Kulshreshtha and Parikh (2002).

3.1.4 Non-fossil energy

3.1.4.1 Nuclear After the world's first nuclear power generation began its operation in 1951 in the USA, many other countries have actively promoted the development of nuclear power generation. However, from the late 1980s, the growth of a nuclear power generation capacity became steady over the world, as visually summarized in Fig. 8. The figure depicts the nuclear generation capacity in the three groups (i.e., Europe, Asia and America) of OECD nations.

Many nations have paid serious attention to the nuclear power generation both to alleviate global competition for fossil-fuel energy resources and to tackle the global warming and climate change. As a result, a total nuclear power generation capacity may have increased before 2004 and stayed almost same after the period, as depicted on the vertical axis of Fig. 8.

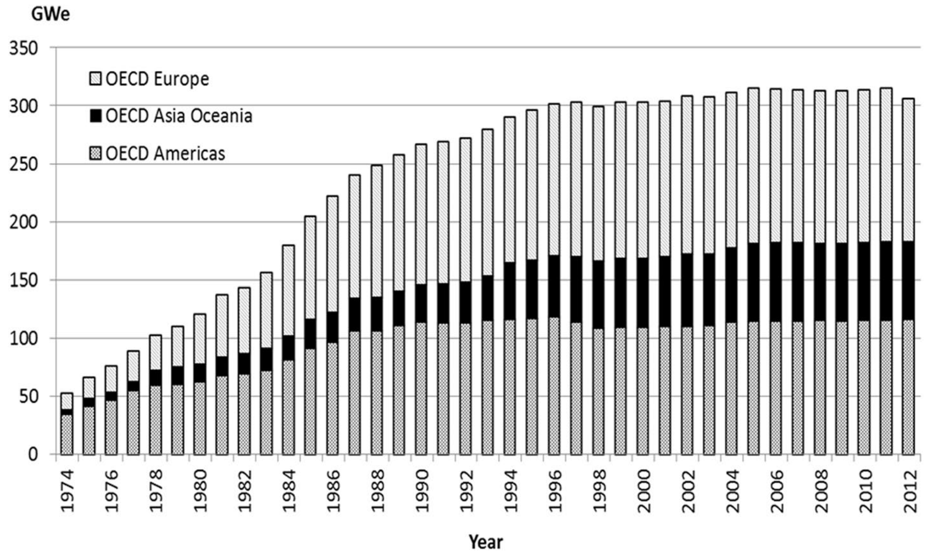

Fig. 8 Nuclear Generation Capacity in Three Groups of OECD Nations. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *GWe* Gigawatt-electrical. *Source*: International Energy Agency (IEA) Electricity Information Statistics (Organization for Economic Co-operation and Development, Paris, France, OECDiLibrary http://www.oecd-ilibrary.org/energy/data/iea-electricity-information-statistics_elect-data-en)

Figure 9 visually describes the amount of nuclear power generation in the three groups of OECD nations. The USA and Europe have constructed only a limited number of new nuclear power plants. However, during the observed annual periods, the amount of nuclear power generation indicated an increasing trend because of its enhanced generation capacity and improved utilization factor. For example, the utilization factor

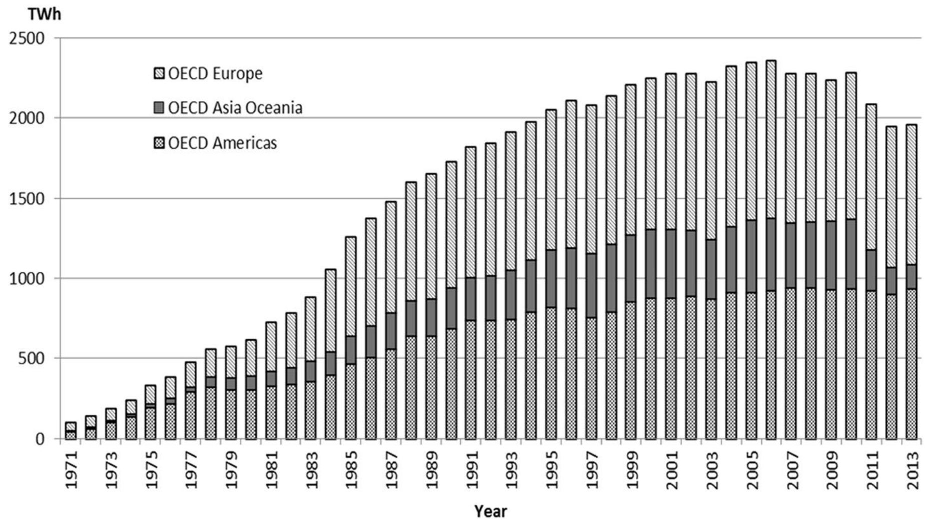

Fig. 9 Amount of Nuclear Power Generation in Three Groups of OECD Nations. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *TWh* Terawatt hour. *Source*: IEA Electricity Information Statistics (Organization for Economic Co-operation and Development, Paris, France, OECDiLibrary http://www.oecd-ilibrary.org/energy/data/iea-electricity-information-statistics_elect-data-en)

was approximately 90% in the USA as a result of efforts for high operational efficiency since the accident of Three Mile Island. Meanwhile, after the disaster of Fukushima Daiichi nuclear power plant in March 11, 2011, the amount of nuclear power generation decreased in Japan and Asian regions, but it has not largely changed in the other regions.

Uranium resource is widely distributed in the world. As of 2012, Canada, Australia and Kazakhstan ranked high in terms of an amount of uranium reserve and production. The uranium price in a spot market fluctuated with nuclear power plant constructions. The price was also influenced by other difficulties such as oil shocks and accidents of nuclear power plants. In 2007, the price once rose to \$136/lbU_3O_8 and it remained above \$60/lbU_3O_8 until March 2011 before the disaster of Fukushima Daiichi's nuclear power plant. Here, lbU_3O_8 stands for a unit mass of triuranium octoxide. After the disaster, the uranium price slightly dropped and it has remained at a relatively stable level because of a tight condition on supply and demand as well as an influence of speculation money.

Note that a DEA application in this area can be found in Sueyoshi and Goto (2015b) and Sueyoshi and Goto (2017).

3.1.4.2 Renewable energy Solar photovoltaic power generation: According to the statistics of International Energy Agency, Photovoltaic Power Systems Program (IEA PVPS: 2014), the total installed capacity of solar Photovoltaic (PV) power generation was 125 GW in 2013 over IEA countries.

Figure 10 visually describes the amount of cumulative installed PV power from 1999 to 2013. Although Japan was the largest installer of the PV capacity until 2004, the installation grew faster in Germany and Spain because the two nations adopted Feed-in-Tariff (FIT) to support expensive PV cost. See Sueyoshi and Goto (2014b) about their positive and negative concerns on the FIT.

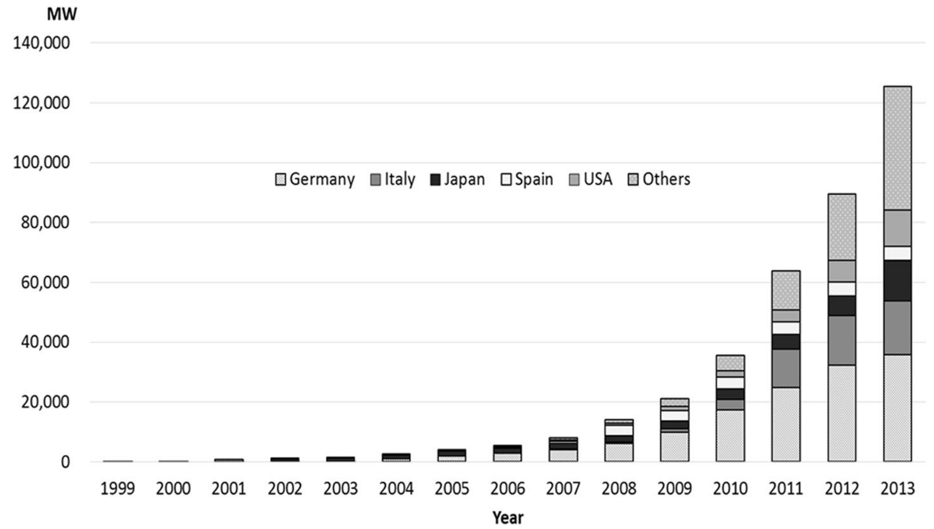

Fig. 10 Cumulative Installed Photovoltaic Power from 1999 to 2013. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *MW* Megawatt. *Source*: IEA Photovoltaic Power Systems Programme, Trends 2014 in Photovoltaic Applications (IEA-PVPS T1-25: 2014) (http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS_Trends_2014_in_PV_Applications_-_lr.pdf)

Wind power generation: The world installed capacity of wind power generation rapidly increased in recent years, reaching at a level of 369.55 GW in 2014. Figure 11 depicts the global cumulative installed wind power generation capacity between 1997 and 2014. As of 2015, the new installation of wind power generation capacity was 30,753 MW (48.5%) in China and was 8598 (13.5%) in the USA, whose accumulation became 62.0% in the world. In addition, offshore wind power generation has been rapidly expanding, recently reaching 12.1 GW in cumulative capacity by 2015. In particular, UK focuses on the offshore wind power generation, accounting for 41.8% of the accumulated installed capacity in the world in 2015.

Biomass: It supplied approximately 10% of the world's primary energy as of 2012. In particular, the biomass accounts for 4.8% of the primary energy supply in OECD countries on average, while it is 13.6% in non-OECD countries. The OECD countries, such as the USA and European nations, have been promoting the biomass generation through their energy policies in a context of countermeasure against the global warming and climate change.

To enhance the biomass usage, many countries have been developing various energy policies that attempt to reduce an amount of oil dependency in a transportation sector and an amount of GHG emissions. Meanwhile, there are social concerns on a rapid increase on the biomass usage. For example, a use of biomass seriously influences a steep rise in food prices, and it invites cutting rain forests to convert them to farm lands. Thus, to reduce such impacts originated from the biomass usage upon natural environment and food markets, international conferences are open to discuss how to construct global sustainability standards on biomass. In addition, research has been promoted to produce biofuel from non-food materials such as straw, timber and algae. International major oil companies have been recently focusing on new research and development on the next-generation biofuel.

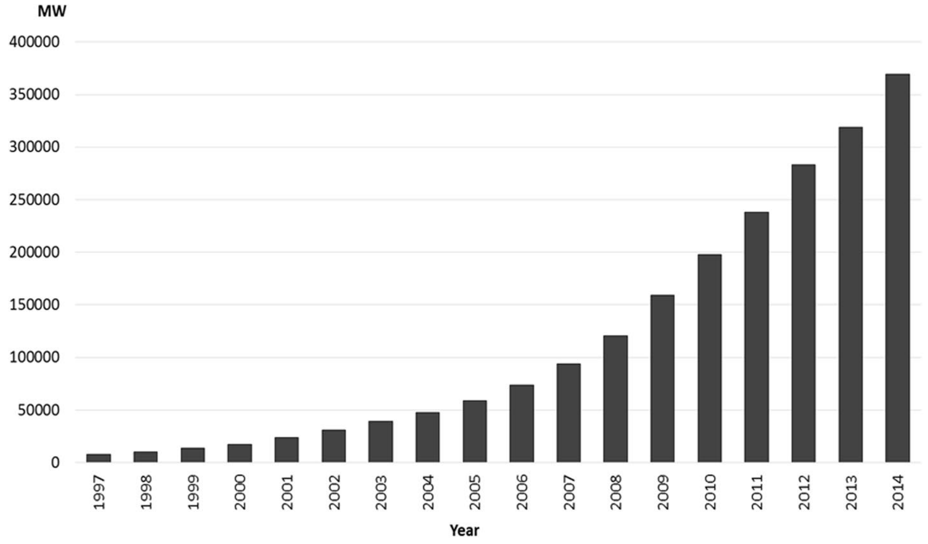

Fig. 11 Global Cumulative Installed Wind Power Generation Capacity from 1997 to 2014. We prepare the figure based upon the numbers listed in the data source. See Sueyoshi and Goto (2017). *MW* Megawatt. *Source*: Global Wind Energy Council (http://www.gwec.net/global-figures/graphs/)

Hydro: The capacity of hydro-power generation amounted to 1010 GW, which was approximately 20% of total generation capacity in the world as of 2012. Countries with large hydro-power generation capacities include China, the USA, Canada and Japan.

Geothermal: Installed capacity of geothermal power generation amounted to 11.7 GW as of 2013. Countries with large geothermal power generation included the USA, Philippine and Indonesia. They had a generation capacity of approximately 3.4, 1.9 and 1.3 GW, respectively.

Note that DEA applications in this area can be found in Lee et al. (2012, 2015), Liu et al. (2015), Longo et al. (2015), Madlener et al. (2009), Menegaki (2013), Peng and Cui (2016), Racz and Vestergaard (2016), Sueyoshi and Goto (2014b) and Wang and Sueyoshi (2017).

4 Secondary energy (electricity)

As depicted in Fig. 12, the world electricity consumption has increased constantly until today. In the 1970s, an annual growth rate remained high at 5.3% on average, although there was a temporary stagnation in the growth occurred after the oil shock. The growth rate gradually decreased to 3.6% in the 1980s and 2.5% in the 1990s, but it recovered to attain a steady growth at 3.1% in the 2000s.

The electrification rate in the world increased from 12.2% in 1980 to 18.1% in 2012, exhibiting an increase by 5.9% during the observed periods. A rationale for the increase was a rapid and widespread growth of a use of electric appliances in the world. Generation capacity in the world continuously increased and reached 5680 GW in 2012.

The average annual growth rate of a total generation capacity was 3.5% in the 1980s, which decreased to 2.2% in the 1990s, but increased to 3.9% in the 2000s. In the world, China's growth forecast will be tremendous in the future. According to the Chinese government's official announcement in the 12th version on the 5-year energy development

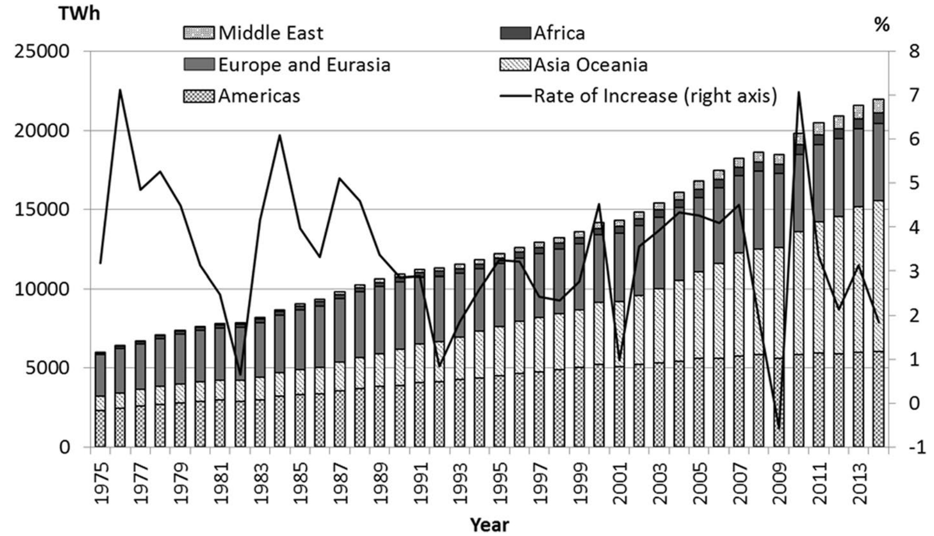

Fig. 12 Trend in World Electricity Consumption. We prepare the figure based upon the numbers listed in the data source. *TWh* Terawatt hour. *Source*: IEA World Energy Statistics and Balances (Organization for Economic Co-operation and Development, Paris, France, OECDiLibrary http://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en)

plan from 2011 to 2015, China has set a new policy goal on generation capacity to increase from 970 to 1490 GW, so indicating an increase by 9% as an average annual growth.

Considering the world's generation capacity in 2013, this study finds that steam power generations by fossil fuels were major energy sources, accounting for 64.5% share of the total generation capacity. However, since the oil shocks in the 1970s, it became necessary for many counties to develop alternative energy sources to oil. The nuclear power generation was promoted for such an industrial goal. Consequently, the nuclear power generation capacity had 9.6% on an average annual growth rate in the 1980s. However, the growth of nuclear power generation became down in developed countries. The annual growth rate stagnated at 0.5% on average in the 1990s and remained 0.8% in the 2000s. In a similar manner, the hydro-power generation capacity had a problem in identifying new sites for construction so that its growth rate was low as a result of capacity's growth in the 1990s.

The world's electricity generation continuously increased and produced 23.3 million GWh in 2013. The average annual growth rate of generation capacity was 3.5% in the 1980s and 2.2% in the 1990s, whereas the growth rate of generation amount was larger than that of generation capacity, exhibiting 3.8% in the 1980s and 2.5% in the 1990s, respectively. The average annual growth rates on capacity and generation indicated that the utilization rate of generation plants increased during the observed periods. However, the average annual growth rate of generation was 3.0% on average in the 2000s, which was lower than that of the generation capacity with 3.8%. This was because an influence of the worldwide economic recession after the financial crisis occurred in fall of 2008.

Among the fossil fuels, coal-fired power generation increased the share from 37% in 1975 to 41% in 2013, indicating that the coal-fired power generation increased faster than the total power generation. The amount of oil-fired power generation steadily increased at 5.7% on an average annual growth rate in the 1970s. However, as a result of a shift from oil to alternative energy sources because of an influence of oil shocks, the annual growth rate became constantly negative, −2.3% in the 1980s, −0.8% in the 1990s and −2.2% in the 2000s, respectively, on average. In contrast, the annual growth rate of gas-fired power generation was 4.1% on average in the 1970s and then exhibiting an increasing trend. The growth rate of gas-fired power generation was 5.4% in the 1980s, 4.4% in the 1990s and 5.4% in the 2000s, which were larger than that of the total generation. Thus, it is easily thought that the gas-fired power generation has served as an alternative energy to coal-fired and/or oil-fired ones.

Note that DEA applications in this area include Sueyoshi and Goto (2011, 2012b, c, e, 2013a, b), Sueyoshi et al. (2010), Tavassoli et al. (2015), Vaninsky (2006), von Geymueller (2009) and von Hirschhausen et al. (2006).

5 An extension to DEA environmental assessment

5.1 Implications for DEA

The world energy trend discussed in the preceding sections indicates that primary energy resources serve as inputs to produce desirable outputs (e.g., electricity) as secondary energy. In the perspective, the primary energy sources are classified into fossil and non-fossil energy categories. DEA formulations used in performance assessment for energy and environment need to be classified into the two groups. Such a group classification is based upon the fact that fossil energy sources produce Green House Gas (GHG) emissions, while non-fossil energy sources do not produce the emissions when they are used for power generation.

There are four implications for DEA development for energy and environmental assessment.

Output classification for fossil fuels First, it is necessary to separate outputs into desirable and undesirable categories. The desirable outputs include an amount of sale and an amount of electricity, while the undesirable outputs include an amount of various GHG emissions. For example, power generations by fossil fuels produce not only a desirable output (e.g., electricity) but also an undesirable output (e.g., CO_2). Thus, the outputs should be classified into the two categories: desirable and undesirable outputs.

Input classification for non-fossil fuels Second, the energy classification indicates that it is necessary for DEA to classify inputs into two categories, which could not found in a conventional use of DEA. For example, in examining the performance assessment on renewable energy sources (e.g., solar photovoltaic, wind and water power generations), inputs need to be classed into controllable variable (e.g., operational cost) and uncontrollably variables (e.g., temperature) related to weather. It is clear that solar photovoltaic power can generate any power during night and a limited amount of power during a raining season. It depends upon a weather condition, so being uncontrollable.

Direction of an input vector Third, the world population has increased, and it is expected to reach to 11.2 billion in the year 2100.[1] Along with the population increase, DEA applied to energy and environmental assessment needs to increase the direction of an input vector, or energy resources, until the increase can reach to an efficiency frontier shaped by undesirable outputs. The frontier may serve as an upper limit on the increase in an input vector. The methodological implication is inconsistent with a conventional use of DEA where an input vector should decrease or maintain a current level for efficiency enhancement.

Technology development Finally, science development and technology innovation make it possible to increase the world population. Thus, an economic growth, supported by science and technology, is essential for sustainability development in the world. Therefore, it is necessary for DEA environmental assessment to consider such technology innovation in the proposed performance assessment.

5.2 Formulations

5.2.1 Formulations for fossil energy

To describe the formulations for performance assessment related to fossil and non-fossil fuels, let us consider $X \in R_{+}^{m}$ as a controllable input vector with m components, $Y \in R_{+}^{z}$

---

[1] https://en.wikipedia.org/wiki/World_population.

as an uncontrollable input vector with z components, $G \in R_{+}^{s}$ as a desirable output vector with s components and $B \in R_{+}^{h}$ as an undesirable output vector with h components. In these column vectors, the subscript (j) is used to stand for the jth DMU, whose vector components are strictly positive.

To discuss formulations for this type of performance assessment, we need to separate outputs into desirable and undesirable categories, as mentioned previously, because this type of energy produces CO_2 and other types of GHG emissions. The importance of the fossil energy is that it can serve as a base load.

Production and pollution possibility sets are axiomatically specified as follows:

$$P_{v}^{N}(X)=\left\{(G,B):\ G\le\sum_{j=1}^{n}G_{j}\lambda_{j},\ B\ge\sum_{j=1}^{n}B_{j}\lambda_{j},\ X\ge\sum_{j=1}^{n}X_{j}\lambda_{j},\sum_{j=1}^{n}\lambda_{j}=1\ \&\ \lambda_{j}\ge0\ (j=1,\ldots,n)\right\}\text{ and}$$
$$P_{v}^{M}(X)=\left\{(G,B):\ G\le\sum_{j=1}^{n}G_{j}\lambda_{j},\ B\ge\sum_{j=1}^{n}B_{j}\lambda_{j},\ X\le\sum_{j=1}^{n}X_{j}\lambda_{j},\sum_{j=1}^{n}\lambda_{j}=1\ \&\ \lambda_{j}\ge0\ (j=1,..,n)\right\}. \tag{1}$$

$P_{v}^{N}(X)$ stands for a production and pollution possibility set under natural (N) disposability. Meanwhile, $P_{v}^{M}(X)$ is that of managerial disposability. The subscript (v) stands for "variable" RTS, where it stands for returns to scale, because the constraint ($\sum_{j=1}^{n}\lambda_{j}=1$) is incorporated into the two axiomatic expressions. See Sueyoshi and Goto (2013a) for a detailed description on RTS.

The difference between the two disposability concepts is that the production technology under natural disposability, or $P_{v}^{N}(X)$, has $X\ge\sum_{j=1}^{n}X_{j}\lambda_{j}$ in Eq. (1), implying that a DMU can attain an efficiency frontier by reducing a directional vector of inputs. Meanwhile, that of the managerial disposability, or $P_{v}^{M}(X)$, has $X\le\sum_{j=1}^{n}X_{j}\lambda_{j}$ in Eq. (1), implying that a DMU, where it stands for decision-making unit, can attain a status of an efficiency frontier by increasing a directional vector of inputs. Meanwhile, a common feature of the two disposability concepts is that both have $G\le\sum_{j=1}^{n}G_{j}\lambda_{j}$ and $B\ge\sum_{j=1}^{n}B_{j}\lambda_{j}$ in their axiomatic expressions. These conditions intuitively appeal to us because an efficiency frontier for desirable outputs should locate above or on all observations on DMUs, while that of undesirable outputs should locate below or on these observations. See Sueyoshi and Goto (2012a, d, 2014a, c, 2015a, b, 2017) on a detailed description on the two disposability concepts.

Here, it is necessary to discuss that an input vector is usually assumed to project toward a decreasing direction in the previous research efforts on DEA as discussed in Sect. 5.1. The assumption, widely believed by many authors in the previous studies, is often inconsistent with the reality related to environmental protection. For example, many governments and firms consider an increase in input resources to yield an annual "growth" of a desirable output(s). Thus, the conventional framework of DEA is not consistent with the economic concept, or "economic growth," because the previous DEA studies have implicitly assumed the minimization of total production cost. The cost concept may be acceptable for performance analysis under "economic recession" or "stagnation," but not in many cases where industrial planning and corporate strategy are based upon their economic growths. Thus, it is easily imagined that DEA applied to energy and environment, as discussed here, is conceptually and practically different from a conventional use of DEA. The cost concept for guiding public and private entities in their strategy developments is average cost (under constant RTS) or marginal cost (under variable RTS), not the total cost, anymore. Furthermore, an opportunity cost, originated from business risk due to industrial pollutions and the other types of various environmental problems (e.g., the nuclear power plant accident at Fukushima Daiichi in Japan), has a major role in modern corporate governance issues. Such cost concepts for current policy making and modern business are implicitly incorporated in formulating the two disposability concepts, in particular in managerial disposability.

The following radial model to measure the level of unified efficiency on the *k*th DMU under natural disposability (e.g., Sueyoshi and Goto 2012e) is as follows:

$$
\begin{aligned}
\text{Maximize}\quad & \xi + \varepsilon_s\left(\sum_{i=1}^{m} R_i^x d_i^{x-} + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right) \\
\text{s.t.}\quad & \sum_{j=1}^{n} x_{ij}\lambda_j + d_i^{x-} = x_{ik} \qquad (i = 1, \ldots, m), \\
& \sum_{j=1}^{n} g_{rj}\lambda_j - d_r^g - \xi g_{rk} = g_{rk} \qquad (r = 1, \ldots, s) \\
& \sum_{j=1}^{n} b_{fj}\lambda_j + d_f^b + \xi b_{fk} = b_{fk} \qquad (f = 1, \ldots, h), \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \lambda_j \geq 0\ (j = 1, \ldots, n),\ \xi:\ \text{URS},\ d_i^{x-} \geq 0\ (i = 1, \ldots, m), \\
& d_r^g \geq 0\ (r = 1, \ldots, s)\ \&\ d_f^b \geq 0\ (f = 1, \ldots, h).
\end{aligned}
\tag{2}
$$

Here, ξ stands for an inefficiency score of the specific *k*th DMU. The scalar value, listed by λ_j $(j = 1, \ldots, n)$, stands for the *j*th intensive (structural) variable. As a result of the incorporation, the surface of a production possibility set is shaped by a convex polyhedral cone under variable Returns to Scale (RTS). All slack variables are expressed by $d_i^x\ (i = 1, \ldots, m)$, $d_f^z\ (f = 1, \ldots, h)$ and $d_r^g\ (r = 1, \ldots, s)$, and ε_s is a prescribed very small number.

An important feature of Model (2) is that production factors are adjusted by these data ranges in the objective function. The data range adjustments are determined by the upper and lower bounds on inputs and those of desirable and undesirable outputs in the following manner:

(a) $R_i^x = (m+s+h)^{-1}\left(\max\left\{x_{ij} \middle| j = 1, \ldots, n\right\} - \min\left\{x_{ij} \middle| j = 1, \ldots, n\right\}\right)^{-1}$: a data range adjustment related to the *i*th input $(i = 1,.., m)$,

(b) $R_r^g = (m+s+h)^{-1}\left(\max\left\{g_{rj} \middle| j = 1, \ldots, n\right\} - \min\left\{g_{rj} \middle| j = 1, \ldots, n\right\}\right)^{-1}$: a data range adjustment related to the *r*th desirable output $(r = 1, \ldots, s)$ and

(c) $R_f^b = (m+s+h)^{-1}\left(\max\left\{b_{fj} \middle| j = 1, \ldots, n\right\} - \min\left\{b_{fj} \middle| j = 1, \ldots, n\right\}\right)^{-1}$: a data range adjustment related to the *f*th undesirable output $(f = 1, \ldots, h)$.

A unified efficiency score (UEN_v^R) of the *k*th DMU under natural disposability is measured by

$$
\text{UEN}_v^R = 1 - \left[\xi^* + \varepsilon_s\left(\sum_{i=1}^{m} R_i^x d_i^{x-*} + \sum_{r=1}^{s} R_r^g d_r^{g*} + \sum_{f=1}^{h} R_f^b d_f^{b*}\right)\right], \tag{3}
$$

where the inefficiency score and all slack variables are determined on the optimality of Model (3). Thus, the equation within the parenthesis is obtained from the optimality of Model (3).

Shifting our research interest from natural disposability to managerial disposability (M), where the first priority is environmental performance and the second priority is operational performance, this chapter utilizes the following radial model that measures the unified efficiency of the kth DMU under managerial disposability (e.g., Sueyoshi and Goto 2012e):

$$\begin{aligned}
&\text{Maximize } \xi+\varepsilon_s\left(\sum_{i=1}^{m}R_i^x d_i^{x+}+\sum_{r=1}^{s}R_r^g d_r^g+\sum_{f=1}^{h}R_f^b d_f^b\right)\\
&\text{s.t.}\quad \sum_{j=1}^{n}x_{ij}\lambda_j-d_i^{x+}=x_{ik}\qquad (i=1,\ldots,m),\\
&\qquad\ \sum_{j=1}^{n}g_{rj}\lambda_j-d_r^g-\xi g_{rk}=g_{rk}\qquad (r=1,\ldots,s)\\
&\qquad\ \sum_{j=1}^{n}b_{fj}\lambda_j+d_f^b+\xi b_{fk}=b_{fk}\qquad (f=1,\ldots,h),\\
&\qquad\ \sum_{j=1}^{n}\lambda_j=1,\\
&\qquad\ \lambda_j\geq 0\ (j=1,\ldots,n),\ \xi:\ \text{URS},\ d_i^{x+}\geq 0\ (i=1,\ldots,m),\\
&\qquad\ d_r^g\geq 0\ (r=1,\ldots,s)\ \&\ d_f^b\geq 0\ (f=1,\ldots,h).
\end{aligned}\tag{4}$$

An important feature of Model (4) is that it changes $+d_i^{x-}$ of Model (4) to $-d_i^{x+}$ in order to attain the status of managerial disposability. A unified efficiency score (UEM_v^R) on the kth DMU under managerial disposability is measured by

$$\text{UEM}_v^R=1-\left[\xi^*+\varepsilon\left(\sum_{i=1}^{m}R_i^x d_i^{x+*}+\sum_{r=1}^{s}R_r^g d_r^{g*}+\sum_{f=1}^{h}R_f^b d_f^{b*}\right)\right],\tag{5}$$

where the inefficiency score and all slacks are determined on the optimality of Model (4). Thus, the equation within the parenthesis, obtained from the optimality of Model (4), indicates the level of unified inefficiency under managerial disposability. The unified efficiency is obtained by subtracting the level of inefficiency from unity.

5.2.2 For non-fossil energy

Non-fossil energy sources do not produce GHGs for power generation. Thus, policy makers and individuals, who are interested in green energy, pay serious attention to the development of non-fossil energy sources such as solar photovoltaic and wind power stations. Except nuclear generation, the other non-fossil energy sources depend upon a time and a weather condition. The nuclear generation does not depend upon such an uncontrollable condition (e.g., weather), so being able to serve as a base load. However, it is widely known that the generation produces a nuclear waste.

The following mathematical structure under radial measurement can identify an efficiency score (θ) of the specific kth DMU (Wang and Sueyoshi 2017):

$$
\begin{aligned}
\text{Minimize}\quad & \theta - \varepsilon_s \left(\sum_{i=1}^{m} R_i^x d_i^{x-} + \sum_{p=1}^{z} R_p^y d_p^y + \sum_{f=1}^{h} R_f^b d_f^b \right) \\
\text{s.t.}\quad & -\sum_{j=1}^{n} x_{ij}\lambda_j - d_i^{x-} + \theta x_{ik} = 0 \qquad (i = 1, \ldots, m), \\
& \sum_{j=1}^{n} y_{pj}\lambda_j - d_p^y = \mathrm{y}_{pk} \qquad (p = 1, \ldots, z), \\
& \sum_{j=1}^{n} g_{rj}\lambda_j - d_r^g = g_{rk} \qquad (r = 1, \ldots, s), \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \theta : \text{URS},\ \lambda_j \geq 0 (j = 1, \ldots, n), \quad d_i^x \geq 0 (i = 1, \ldots, m), \\
& d_p^y \geq 0 (p = 1, \ldots, z) \quad \& \quad \mathrm{d}_\mathrm{r}^\mathrm{g} \geq 0(\mathrm{r} = 1, \ldots, \mathrm{s}).
\end{aligned}
\tag{6}
$$

where Model (6) incorporates the side constraint ($\sum_{j=1}^{n} \lambda_j = 1$) in the formulation. In Model (6), all slack variables are expressed by d_i^{x-} $(i = 1, \ldots, m)$, d_p^y $(p = 1, \ldots, z)$ and d_r^g $(r = 1, \ldots, s)$ in Model (6). The slacks are associated with these-related data adjustment ranges. It is important to note that undesirable outputs are excluded from Model (6). The data range for R_p^y, newly incorporated in Model (6), can be specified by its upper and lower bounds on data as discussed previously.

It is important to note that Model (6) is formulated under natural disposability, so being part of a conventional DEA framework. However, when we consider renewable energies such as solar photovoltaic generation, for example, the larger input (e.g., the degree of temperature and the number of sunshine days) produces the better performance. As a result, we should formulate it under managerial disposability. In the case, Model (6) needs to change the slacks $(-d_i^{x-})$ to $+d_i^{x-}$. and such is a necessary requirement to attain the status of managerial disposability. However, as discussed by Wang and Sueyoshi (2017), if we change such an input by the reciprocal of an original data, then Model (6) can be expressed by the natural disposability as it is. See Wang and Sueyoshi (2017) for a detailed description on the data treatment.

6 Conclusion

This study described a recent energy trend in the world so that we could discuss the research direction of DEA studies applied to energy and environment. The energy was separated into primary and secondary categories in this study. The primary energy was further classified into fossil and non-fossil fuels. The fossil fuels included oil, natural gas and coal, while the non-fossil ones included nuclear and renewable energies (e.g., solar, wind, biomass and others). This study also discussed electricity generation as a representative of the secondary energy.

It is easily imagined that energy consumption is essential for the development of economic prosperity in all nations. However, a use of various energy sources usually produces many different types of pollutions (e.g., air, soil and water pollutions) on the earth, so resulting in a huge damage on our society, economics and human health. Thus, it is essential for us to understand a general trend of world energy, as discussed in developing the research direction of DEA applied to energy and environment.

This study has discussed important methodological implications (e.g., input and output classifications) in assessing various DEA-related applications on energy and environment. One of such methodological implications is that DEA applications to energy and environmental assessment need to develop different types of formulations for fossil and non-fossil fuels. The fossil fuels produce both desirable and undesirable outputs so that DEA needs to consider how to unify the two types of outputs along with inputs. Meanwhile, the non-fossil fuels do not produce an undesirable output, but they have controllable and uncontrollable inputs, where the latter group includes weather-related inputs such as the number of sunshine days and the degree of temperature.

The other implication is that we need to pay attention to the fact that total energy consumption, along with an increase in the world population, has been increasing in most of annual periods after the World War II, except some periods under economic recession. Energy resources are usually used as inputs in DEA performance analysis. So, it is not easy for us to use a conventional framework of DEA in order to find an efficiency frontier that locates above an observed input vector. Thus, the conventional use is inconsistent with the reality on energy and environmental assessment. As discussed in this study, all the components of an input vector should decrease under input-oriented measurement as formulated in the conventional framework. Meanwhile, they should maintain the current observed values under output-oriented measurement. Thus, the conventional use of DEA is useful in conducting the performance assessment of many different organizations under an economic stability, but not under an economic growth for sustainability development. Thus, most of previous DEA studies had limited practicality in modern business and economy where environmental concerns are essential. See Sueyoshi et al. (2017) and Sueyoshi and Goto (2017).

In addition to the above methodological implication, this study needs to mention that it is not easy for us to maintain a social balance (so, sustainability) between economic development and environmental protection. The DEA may serve as a holistic methodology to identify such a balance by identifying a source(s) of efficiency and inefficiency, referred to as unified (operational and environmental) efficiency between economic success and pollution prevention. The unification process to attain a status of sustainability needs a new approach to combine desirable outputs (e.g., electricity) and undesirable outputs (e.g., GHG emission) in performance assessment. The existence of undesirable outputs was insufficiently considered in the conventional assessment by using DEA formulations. Consequently, the conventional use of DEA has a limited capability for environmental assessment. Thus, it is essential that DEA needs to develop a new research direction for sustainability development as discussed in this study. See Sueyoshi and Goto (2017) and Sueyoshi et al. (2017).

In conclusion, it is hoped that this study makes a contribution on DEA applied to energy and environment. We look forward to seeing future research developments as discussed in this study.

Authors' contributions

TS contributes 50% and MG contributes 50% of this study. The second author prepares all figures, and the first author prepares the whole manuscript, including mathematical formulations. This study documents a linkage between world energy trend and DEA formulations. No research has explored this type of research concern. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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