Present Status of Japan's Energy

Yasunori Kikuchi, Seiichiro Kimura, and Michihisa Koyama

Abstract Japan is at a momentous turning point in world history and faces a wide range of social issues that call for proactive solutions, such as the control of environmental loads, countermeasures against rapid population aging and stagnant birthrates, and the construction of sustainable energy systems. These issues have resulted from its mature society, which means that all other countries may confront the same or similar issues in the future. Japan has an opportunity to become the first country to solve them and share its methods.

Realizing sustainable energy use has been an important target. Toward an ideal or favorable future for Japan's energy, understanding the present status and future available energy options is an initial step, followed by a discussion of issues related to each option. The aim of this chapter is to concisely review the current state of Japan and its energy through a statistical investigation. Japan has a fixed estimate of decreasing population in the future. Most of the primary energy in the country has been imported from specific countries, with an associated cost increase for that energy.

With its cutting-edge technologies and cultural creativity, Japan is expected to create new demand and revitalize its socioeconomic affluence, and have a leading role in showcasing solutions to common problems in the world.

Keywords Energy statistics • GDP • Energy per capita • Resource import

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1 Status of Japan: Confronting Issues Resulting from a Mature Society

Japan is at a momentous turning point in world history and faces a wide range of social issues that call for proactive solutions, such as the control of environmental loads, countermeasures against rapid population aging and stagnant birthrates, and construction of sustainable energy systems (Fig. 1). These issues have resulted from its mature society, which indicates that other countries may confront the same issues. Each issue shown in Fig. 1 has interconnections. For example, the consumption of fossil resources decreases the self-sufficiency ratio of primary energy and increases greenhouse gas (GHG) emission. The stagnant birthrate is one of the major causes of the increase in the ratio of elderly within the population. Japan has an opportunity to become the first country to solve them and share its methods [1].

Key features of the world in the twenty-first century, which may be regarded as a mature society, can be categorized into four essential trends [1]:

1. Remarkable growth of wealth
2. Longevity resulting from the growth of wealth
3. Saturation of products or amenities they provide
4. Shifts from fossil to renewable primary energy resources

The first feature, the growth of wealth, first occurred in developed countries. In Fig. 2, GDP per capita is shown from the years 1000 to 2008. This demonstrates that GDP per capita increased substantially after the advent of the Industrial Revolution,

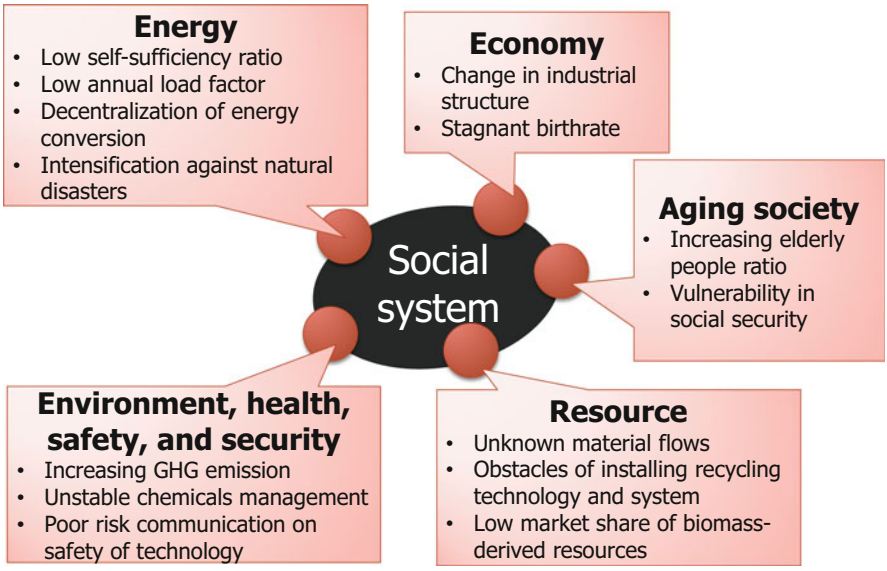

Fig. 1 Example of social issues in Japan

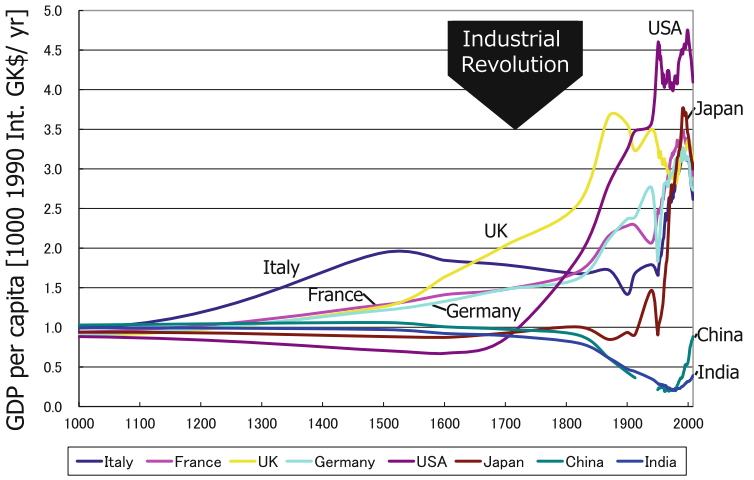

Fig. 2 GDP per capita of selected countries extracted from the literature [1] (Data from Angus Maddison [2] and The Conference Board Total Economy Database [3])

where first the United Kingdom and then the United States, France, Germany, Italy, and Japan had nearly exponential growth in wealth per capita. After fluctuations caused by depressions and wars, the developed countries reached a plateau of GDP per capita in recent years. Meanwhile, developing countries such as China and India have had increasing curves in recent years. They can be expected to reach the status of developed countries soon. In developed countries, people have adequate mobility and access to food, clothing, housing, and information.

The second feature of a mature society is longevity resulting from the growth in wealth. The 1999 life expectancy for OECD countries and the world average exceeded 70 or 65 years old, respectively [1]. Elderly people should be able to find satisfaction and motivation in life within a mature society. Figure 3 shows a population estimation for Japan [4]. That population is now decreasing and will drop to less than 100 million by 2050. The ratio of people over 65 years of age is currently increasing and will reach ~40 % by that year. This is because of a stagnant birthrate in the country and a small number of immigrants. Longevity is definitely desirable, but it should be carefully addressed given the stagnant birthrate.

The third feature is the saturation of products or the saturation of amenities provided by those products. As discussed in the literature, cement production in developed countries has already reached saturation [1]. According to Japanese statistics, the penetration of home electronic appliances such as air conditioners, television sets, refrigerators, personal computers, and mobile phones has reached near 100 % [5]. Electricity consumption per family unit has become saturated [6]. In lieu of products, services have become important in developed countries, which is manifested by decoupling of economic development and energy

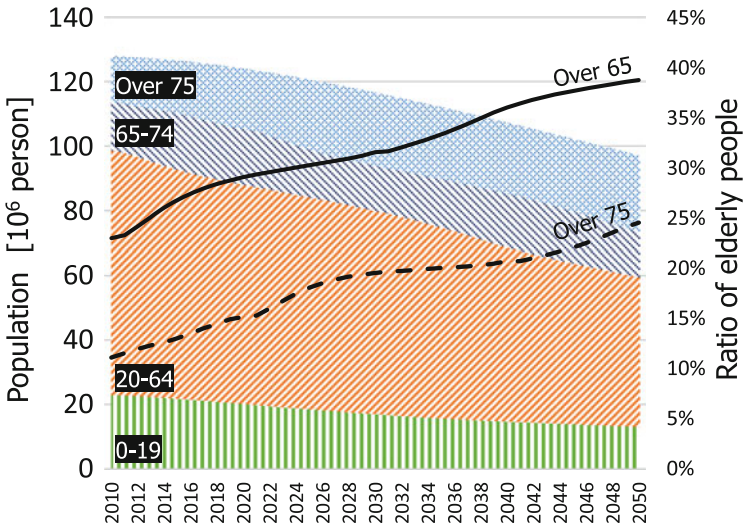

Fig. 3 Estimation of population by age bracket in Japan (*colored hatching*) with the ratio of elderly to total population (*dashed* and *solid black curves*) [4]

consumption. Industrial structures are now shifting from product-based to service-based activities.

The fourth feature is a shift from fossil to renewable resources. Fossil resources were increasingly used from the eighteenth century, when the Industrial Revolution began. Coal, petroleum, and natural gas became indispensable resources all over the world. In recent decades, the impacts on the environment of these resources have constrained human activities, and their use may be limited in the near future. In the twenty-first century, means for shifting from fossil to renewable resources have been explored for constructing sustainable energy systems. Because a rapid shift to such systems is infeasible, the transition should be managed by combining all potential technology options.

As mentioned above, the four features of a mature society are emerging in developing countries or will do so in the near future. In those countries, resource and energy issues may be critical for implementing countermeasures against other issues. A combination of technology options should be deployed in a prompt but appropriate manner to overcome the difficult obstacles toward a sustainable future.

2 Japan's Energy Situation

2.1 GDP vs. Energy Consumption

Figure 4 shows energy ladders for Japan, the USA, and other regions. The plots indicate the primary energy consumption per capita to GDP per capita in 1990, 2000, 2005, 2010, 2011, and 2012, which are arranged from left to right for all countries and regions. The dotted line shows an extrapolation of world average plots. As shown in the plots for the EU (OECD), USA, and Japan, the slopes are negative for 2010, 2011, and 2012. Although the bankruptcy of Lehman Brothers may have caused the decrease of energy consumption from 2005 to 2010, the decrease in 2011 and 2012 may mean that energy efficiency for GDP has increased in the EU (OECD) and USA. The Great East Japan Earthquake on 11 March 2011 had a greater impact on energy consumption in Japan than the aforementioned bankruptcy. It is not easy to distinguish the contributions of various influences on the increase in efficiency of energy consumption per GDP, but the severe power supply deficiency caused by the earthquake may have affected the energy-use attitudes and stimulated the implementation of more efficient systems. One sees that Oceania is in a plateau state, whereas an increase in GDP is associated with increased energy consumption in countries in the other regions. These differences can be recognized as a transition to the decoupling of economic development and energy consumption [8]. In the mature society, the decoupling of the economy and environment has occurred, e.g., in the EU (OECD), USA, and Japan.

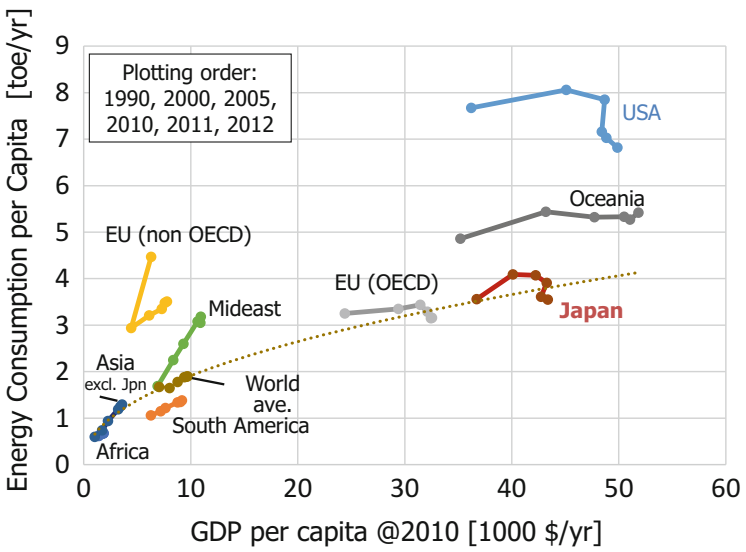

Fig. 4 GDP per capita and energy consumption [7]

2.2 *Energy Demand and Flows*

Figure 5 shows Japan's energy flow in fiscal year (FY) 2013. It is based on an analysis of data in *Comprehensive Energy Statistics* for FY 2013, referring to the energy flowchart released each year by Lawrence Livermore National Laboratory (LLNL) in the USA [9]. Primary energy resources on the left are converted to electricity in part and then used in residential, commercial, industrial, and transportation sectors. Units in this chart are exajoules (EJ or 10^{18} J), and each number has an error range of approximately ± 1 %. In terms of energy efficiency, actual values were used for thermal power generation. For residential and commercial sectors, 65 % efficiency is used, equivalent to the assumption in the LLNL chart, with 80 % for the industrial sector and 21 % for transportation as assumed values. Energy efficiency of 100 % is used for power generation, except thermal power. The results show that Japanese energy consumption is ~21 EJ, 40 % of which is supplied from petroleum and 30 % each from coal and natural gas. It is also revealed that 45 % of the supplied primary energy is used for power generation. The electrification rate in energy consumption of the residential and commercial sectors is ~50 %, whereas it is ~20 % in the industrial sector and only 2 % in transportation.

The same analysis was conducted for each year after 1990 to distinguish the primary energy supply. Primary energy procurement cost for imports was also analyzed using foreign trade statistics. The results are shown in Fig. 6.

After the Fukushima Daiichi Nuclear Power Plant accident in 2011, Japan made strict regulations on the restart of nuclear power plants. Natural gas, coal, and

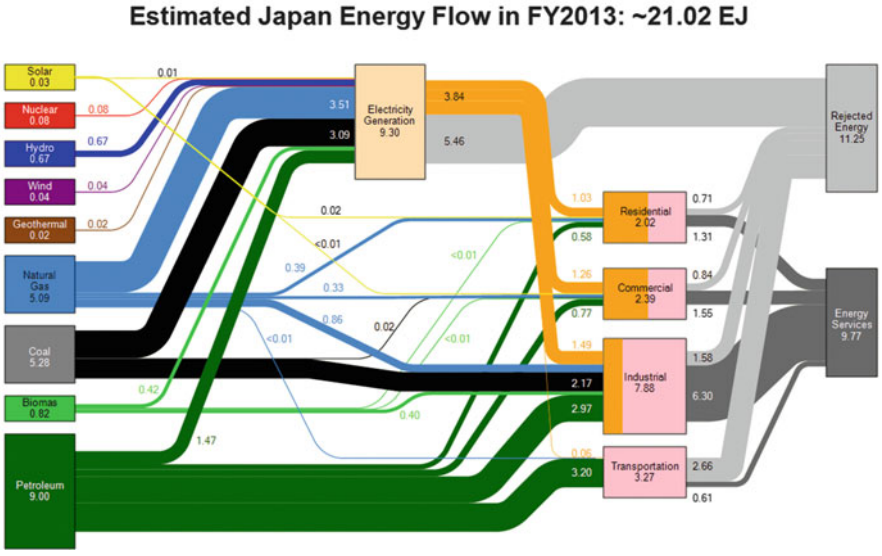

Fig. 5 Estimated Japan energy flow in FY2013

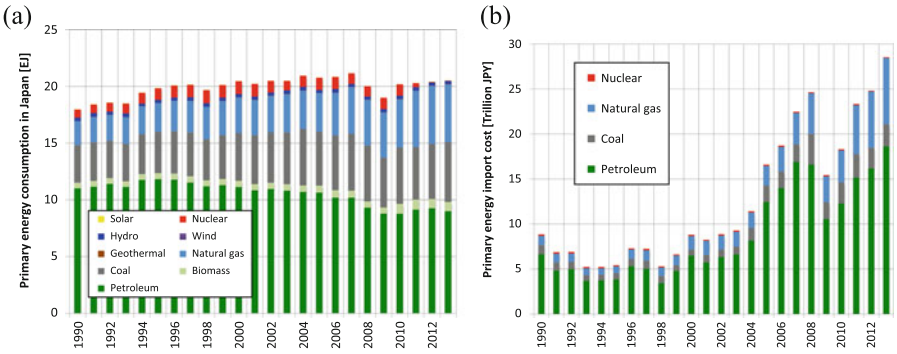

Fig. 6 Primary energy resource consumption in Japan. (**a**) Primary energy consumption in Japan, FY 1990–2013 (HHV: higher heating value base) [10]. (**b**) Energy import cost of Japan, FY 1990–2013 [11]

petroleum have made up for the shortage of electricity supply caused by the shutdown of those plants. Therefore, the nuclear energy supply has decreased since 2011, and, on 16 September 2013, the country was completely without nuclear-produced electrical power. Nuclear energy constituted ~5 % of primary energy sources in Japan, which was ~30 % of the total electric power supply. The thermal power reserve margin was effective because the country has not had a serious power shortage, because the national energy supply structure has been changing since 2000 from petroleum to coal and liquefied natural gas (LNG) (Fig. 6a). That is, Japan established more coal and LNG power plants without operating oil-fired power plants but maintaining their facilities, which helped maintain the power supply when it was confronted with the power shortage. Nevertheless, the energy transition from petroleum to the other energy resources was interrupted after the accident.

The situation regarding energy procurement costs changed in 2004 (Fig. 6b). These costs did not exceed 10 trillion JPY before then, but they increased because of a rise in petroleum prices beginning that year, approaching 25 trillion JPY in FY 2007. Later, procurement cost was reduced by global economic stagnation because of the collapse of Lehman Brothers, but increased again after the Fukushima accident to obtain natural gas for power generation. Therefore, purchasing cost has reached 28 trillion JPY. This is approximately one third of total import cost in a year, and energy procurement is the biggest deficit factor in Japan's trade balance.

Figure 7 shows import partner countries for coal, petroleum, and LNG. As seen from the self-sufficiency ratio for these three fossil resources, Japan is strongly dependent on imports from other countries for fossil fuel. Among the import partners, the dependency of petroleum on the Middle East is as high as 84 %. Strong dependence on certain regions or countries reduces the energy security of the country [12]. Thus, the diversification of import partner countries and of fuel type and an increase of domestic primary energy including renewable resources are important.

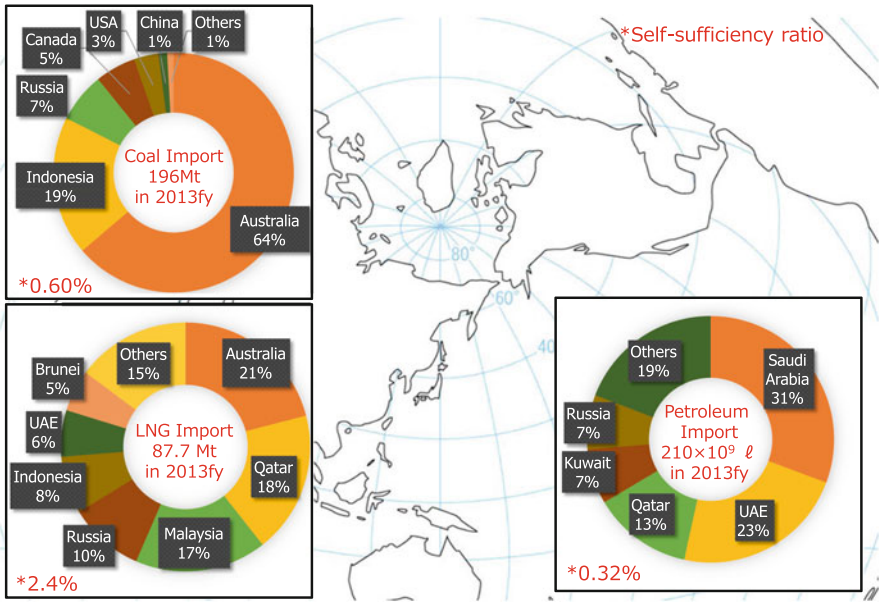

Fig. 7 Import partner countries for coal, petroleum, and liquefied natural gas (LNG) [7]

Figure 8 gives an overview of Japan's energy consumption, in which the contributions in divisions and subdivisions of the energy demand sectors are shown. The largest demand sector is primary and secondary industries, in which the contribution of chemical products and iron and steel production to total energy demand is much larger than the other subdivisions of the primary and secondary industrial sectors. The second largest demand sector is the commercial sector including tertiary industry, in which wholesale and retail trade use the greatest amount of energy. The loss of energy from centralized power generation in the commercial sector is larger than that of the primary and secondary industrial sectors. This is because of greater electricity demand in the commercial sector. In the primary and secondary industrial sectors, many decentralized combined heating and power systems have been implemented, which partly explains the smaller energy loss in those two sectors. The residential sector shows a tendency similar to the commercial sector, because substantial electricity is also used in the former sector. Almost all primary energy in the transportation sector is derived from petroleum oil. Although little loss is shown in the bar graph of that sector, much energy loss occurs during transport. The efficiency of automobiles or other types of fleets should be considered in this sector. As a nonenergy use of fossil resources, petroleum converted to chemicals and coal used as reductants of ferric oxide are in the majority.

We have briefly summarized Japan's energy situation; a detailed energy review may be found in the literature [13].

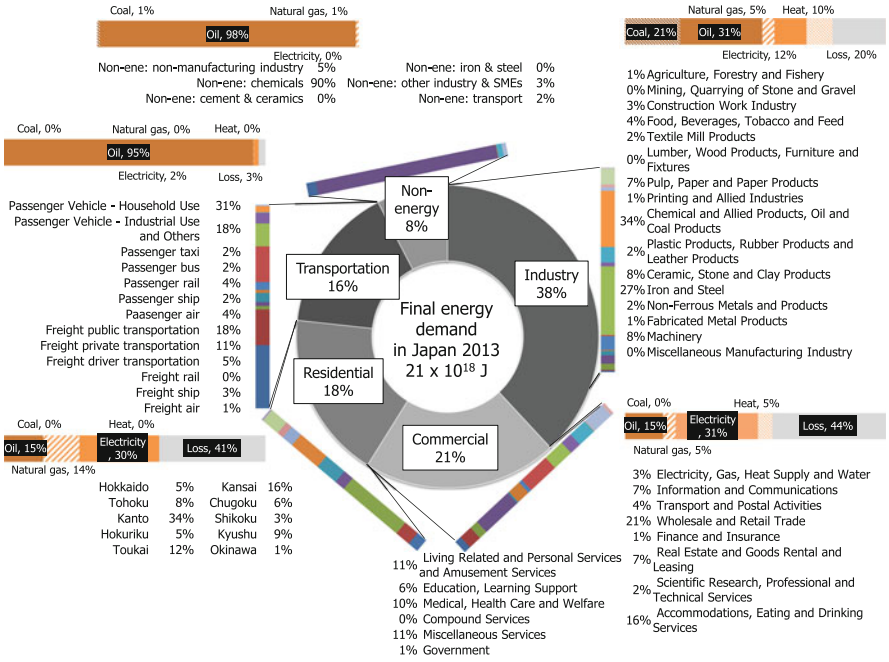

Fig. 8 Overview of energy demand in Japan [10]

3 Challenge for Designing Future Energy Systems

An important task in Japan is the successful redesign of energy systems with feasible technology options. Solutions must be harmonized not only with constraints on energy systems such as safety and energy security but also with social aspects stemming from a mature society. Part of such socioeconomic performance or other aspects can be quantified using existing methods or assessments. Life cycle assessment (LCA) of environmental impacts [14], life cycle costing or social LCA [15] for socioeconomic efficiency [16], risk assessment or process safety analysis for safety [17], and indicators developed for energy security [12] are examples of available quantification approaches. Based on such scientific analyses, technology options can be examined toward a sustainable society. With its cutting-edge technologies and cultural creativity, Japan is expected to create new demand and revitalize its socioeconomic affluence and has a leading role in showcasing solutions to common problems around the world.

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