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# Evaluation of Green Paradox: Case Study of Japan

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Introducing renewable energy is progressing rapidly in various countries. It has long been thought that the introducing is not only extending the availability period of fossil fuels but also not directly discharging harmful substances into the atmosphere. In recent years, a concept of “Green Paradox” casts doubt on that ideas. According to the concept, the renewable energy introducing accelerates fossil fuels consumption and promotes the increase of harmful substances due to the consumption. Because the number of papers evaluating the Green Paradox is limited and evaluation method is not well established. This paper attempts to evaluate the Green Paradox in Japan following three indicators. The first is the electricity charge, the second is the introduction amount of renewable energy, and the third is the relocation amount of Japanese factories to other countries.

Keywords: Renewable energy, Green Paradox, Japan, fossil fuels hydrogen energy

## 1. Introduction

Our society has consumed fossil fuels and generated electricity to promote our economic growth. The amount of natural gas, coal/petroleum, and oil consumption known for typical fossil fuels accounted for over 80% shown in Fig.1<sup>1</sup>. The amount of consumption is estimated to keep growing up as shown in Fig 2<sup>2</sup>. When we take into account of the mining limitation, minable years as reserves-to-production (R/P) rate tends to decrease<sup>3</sup>. Although natural gas could keep supporting the demand of our society near future, the minable years will face the limitation in the long term.

Although the fossil fuels will be exhausted in the future, we could afford to keep consuming for several hundred years. However, what we have to consider is not the year when fossil fuels dried up, but when fossil fuels are mined with the largest amount. As long as we no longer increase the amount of mined fossil fuels, the economic growth will not be maintained because our society relies on the fossil fuels. Mohr *et.al.* suggest that the year when the amount of fossil fuels becomes the most so-called “production peak” of primary fossil fuels will come by 2025<sup>4</sup>. Although the estimation is significantly earlier than reality, we will not be able to avoid the production peak in the future. Our economy is relying on the fossil fuels. Before the production peak comes, we need to build society which does not rely on fossil fuels. Otherwise our social situation depending on them will be very unstable.

It seems introducing renewable energy with solar power and wind power is the promising way for our future. The

renewable energy does not directly emit harmful substance such as CO<sub>2</sub> which could lead to global warming<sup>5</sup>. Indeed, hydropower as a renewable energy could be increased to supply electricity in the future.<sup>6</sup> However, the amount will not be able to cover total energy demand for future due to the limited location for new installation sites.

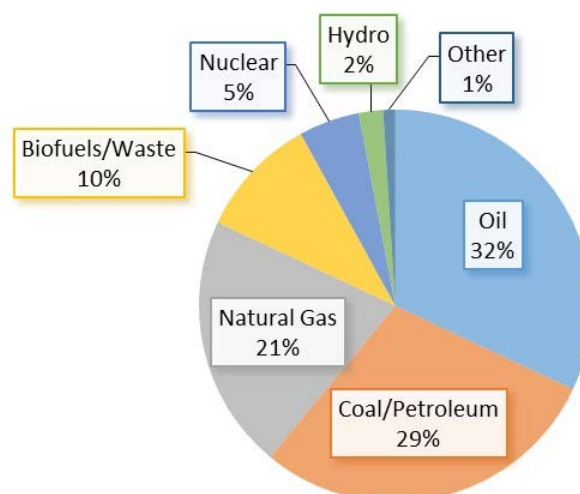
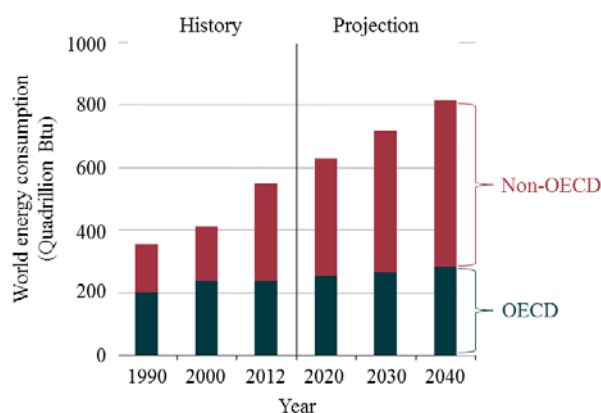


Fig. 1: World's fuel shares of total primary energy supply.<sup>1</sup>



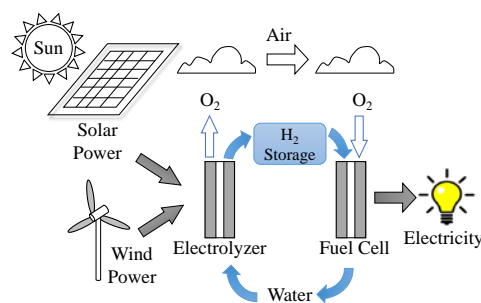
**Fig. 2:** World energy consumption from 1990 to 2040(Estimated)<sup>2</sup> Source: U.S. Energy Information Administration (May Oct 2016)

## 2. Hydrogen Society

These days, the usage of hydrogen as energy carrier has attracted attention because it is good at storing huge amount of energy. Combination of solar/wind energy and hydrogen can be a bright candidate to establish sustainable society because they can be combined as a closed energy cycle with water and hydrogen (,and oxygen in air).<sup>7</sup> Fig. 3 shows schematic system of society combined with fuel cells, water electrolyzers and renewable energy. This system is called “Hydrogen Society”, which is completely dependent on consumption of fossil fuels to obtain electricity.

However, the hydrogen itself currently has to be isolated or produced from other chemical compounds such as carbon hydride ( $C_xH_y$ ). It is because producing hydrogen with water electrolyzers is much more expensive than fuel reforming with fossil fuels.<sup>8</sup> The amount of production of fossil fuels will begin to phase out after the production peak explained in introduction part. The system in Fig. 3 to be substituted for our conventional energy supply with fossil fuels will be necessary. In fact, this system has already begun to be adopted to produce hydrogen by electrolyzing water to realize a sustainable society<sup>9,10</sup>. Recently, renewable energy markets, technologies, investment and policy frameworks have been rapidly developed. The ratio of global energy supplied by renewable energy in 2010 was 16.7%. The consumption has strongly increased year by year<sup>11</sup>. However, there are remaining issues for widespread utilization of renewable energy sources. For instance, the installation cost is expensive, and the amount of hydrogen which can be stored at a time is small. To overcome both issues, the success depends on the result of research and development. Especially, Japanese government has established the

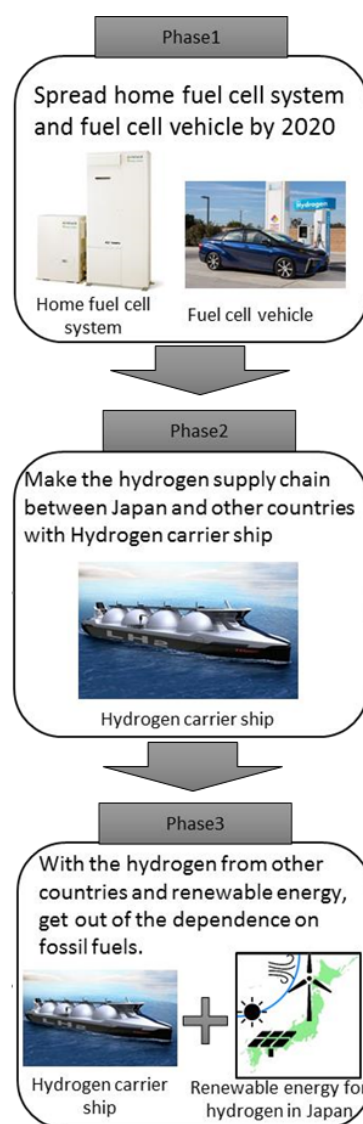
roadmap which is composed of three steps.



**Fig.1** Concept of a hydrogen renewable energy system for power generation  
(This system is independent on consumption of fossil fuel)

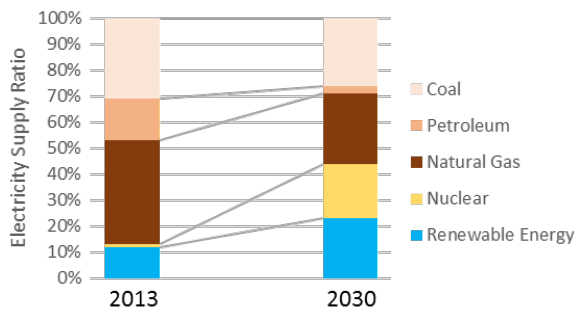
**Fig. 3:** Schematic model of hydrogen society.<sup>12,13</sup>

## 3. Roadmap for Hydrogen Society in Japan



**Fig. 4:** Three phases to get out of dependence on fossil fuels in Japan<sup>14</sup>

To get out of dependence on the fossil fuels, Japan has energy policy to build hydrogen society as shown in Fig 3. It is composed of three phases as shown in Fig 4. Firstly, it is to spread home-type fuel cell and fuel cell vehicle by 2020. Secondary, it is to make the hydrogen supply chain between Japan and other countries with unused hydrogen by 2030. Finally, with the supply chain and hydrogen from renewable energy, Japan will aim to get out of dependence on the fossil fuels by 2040<sup>14</sup>. The above plan is really challenging because Japanese government also attempts to cover around 20 % electricity of Japan by 2030 with renewable energy. In short, still Japan will provide 80 % electricity with fossil fuels until 2020. If Japan follows above plan shown in Fig. 5, Japan will be required to cover entire electricity demand by 2040 with renewable energy in 10 years from 2030. Such a rapid installation of fossil fuels, it may lead to accelerate the consumption of fossil fuels and the amount of emitted harmful substances due to the fossil fuel consumption, which is called “Green Paradox”.



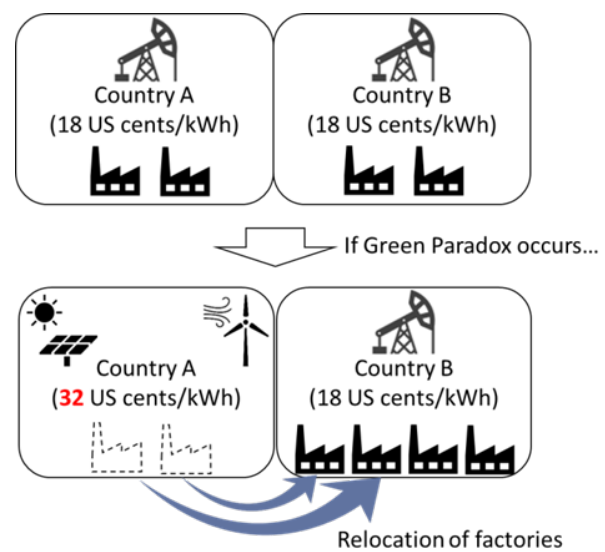
**Fig. 5:** The component ratio for electricity supply between 2013 and 2030(Target Value)<sup>15</sup>.

#### 4. Green Paradox

According to Jensen *et al.*, the green paradox refers to an outcome in which climate policies such as carbon taxes, which are aimed at reducing carbon emissions, instead have the opposite effect: emissions increase, at least for some period of time.”<sup>16</sup>. Green paradox hypothesis comes to receive attention from 2008 when Sinn *et al.* pointed out<sup>17</sup>. Sinn *et al.* suggest the mechanism that introducing renewable energy is likely to increase the amount of CO<sub>2</sub> emission as follows. As shown in Fig. 6, in case that the price of electricity in both country A and country B, companies in respective countries will not be affected by the electricity price. However, when country A actively introduces renewable energy, the price in the country A will increase. Therefore, companies in Country A will relocate factories to Country B. Thus, introducing renewable energy in specific country such as this Country A induces to have factories which used to be in country A

increase the amount of CO<sub>2</sub> emission and shortage the term for minable years of fossil fuels in the world. This is the example of Green Paradox.

Because fossil fuels are finite, as long as we continue economic activity, the fossil fuels will be exhausted at some point in the future. Although we somehow need to seek the alternative energy resources and we have kept expecting renewable energy can be a promising, the Green Paradox suggests introduction of renewable energy does not have a positive effect. In addition, there is concern that people in the country where factories relocated are confronted with employment issue. What above Green Paradox insists is that introduction of renewable energy is not the suitable solution to reduce dependence on fossil fuels.



**Fig. 6:** The result of Green Paradox between Country A and Country B.

#### 5. Literature Review

Before evaluation of the Green Paradox in Japan, this paper summarizes previous studies. As mentioned, the previous studies pointed out the cases consisting with Green Paradox hypothesis. In case of Ghana, previous research addressed the possibility that assumption of Green Paradox was realized. After refined oil subsidies finished from 2010, the import cost of oil rises. The result shows that the removal of subsidies on refined oil imports in Ghana would lead to the increase of CO<sub>2</sub> emissions in Ghana. This is an evidence of the Green Paradox.<sup>18</sup> In addition, in case of China, previous research addressed that the policy of central government prevents Green paradox, but that of local government does not prevent it. The previous research compares the emission of SO<sub>2</sub> to evaluate the amount of CO<sub>2</sub> emission<sup>19</sup>. Furthermore, another research implies that Germany also occurs because the country increased the price of electricity to

introduce renewable energy<sup>20</sup>. However, evaluation methods to clarify if Green Paradox occurs are not in common and unclear in several points. Therefore, in order to clarify Green Paradox in Japan, it is necessary to needs to establish advanced and sophisticated evaluation method.

## 6. Evaluation Method

Just a few reports related to the investigation of Green Paradox in each country have been published. Then, to examine whether Green Paradox occurs in Japan, this section explains the evaluation procedure for Green Paradox in Japan. As mentioned above, the Green Paradox refers to that introducing renewable energy eventually leads to increase the amount of harmful substances emission due to expensive electricity price and relocation of factories. This study collected following there types of data between 1996 and 2015 in Japan. The first is the amount of electricity price, the second is the renewable energy ratio in total electricity production, and the third is the trend in overseas production. All data obtained from Ministry of Economy, Trade and Industry, and Ministry of Land, Infrastructure, Transport and Tourism in Japan<sup>20,21,22</sup>.

## 7. Results and Discussion

Table.1 summarizes the data for the amounts of electricity price, renewable energy ratio in total electricity production, and the trend in overseas production. Some data are missing because of lack of original data. It is considered that renewable energy introduction leads to electricity price, whose change cause eventually to move factories in Japan to move to other countries. From this analysis when the values of all indices increase in same year, it is seemed that Green Paradox occurs in Japan.

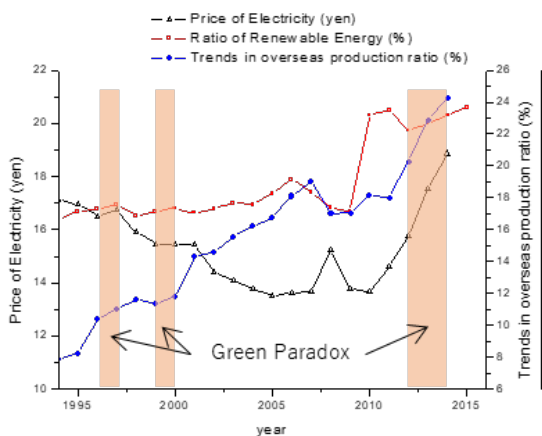
Fig. 7 shows the graphical data of summarized table1. In the three terms shown by red band (1996, 1999, and between 2012 and 2014) the price of electricity, ratio of renewable energy, and trends in overseas production ratio increased, suggesting that the Green Paradox may occur in Japan in that above three terms<sup>20,21,22</sup>.

Because renewable energy is higher cost than conventional primary energy, it is thought that the increase in the ratio of renewable energy causes a bad influence on electricity charges. In addition, some Japanese industries say that raising the electricity price can be considered as a cause of overseas relocation. Therefore, these are phenomena are matching to the green paradox. In addition to the factors mentioned above, there seems to be other factors that affect each of them, but it can be proposed as one criterion for determining the green paradox.

**Table1.** Summarized data of trends in overseas production ratio, price of electricity, and ratio of renewable energy in Japan.

year	Trends in overseas production ratio (%)	Price of Electricity (JPY)	Ratio of Renewable Energy (%)
1965			0.109
1966			0.109
1967			0.112
1968			0.123
1969			0.132
1970		4.968	0.139
1971		5.089	0.143
1972		5.115	0.147
1973		5.328	0.156
1974		9.301	0.151
1975		10.276	0.145
1976		11.753	0.157
1977		12.955	0.159
1978		12.428	0.161
1979		13.114	0.179
1980		20.829	0.176
1981		21.295	0.176
1982		21.608	0.188
1983		21.586	0.201
1984		21.562	0.215
1985		21.908	0.221
1986		19.994	0.226
1987		18.695	0.238
1988		17.719	0.248
1989		17.152	0.260
1990		17.145	0.577
1991		17.327	0.582
1992		17.548	0.574
1993		17.536	0.570
1994	7.907	17.134	0.584
1995	8.259	16.943	0.612
1996	10.403	16.503	0.622

1997	11.049	16.749	0.634
1998	11.589	15.895	0.598
1999	11.393	15.468	0.613
2000	11.781	15.443	0.623
2001	14.319	15.457	0.609
2002	14.604	14.392	0.622
2003	15.579	14.075	0.641
2004	16.219	13.754	0.637
2005	16.734	13.512	0.674
2006	18.123	13.618	0.723
2007	19.055	13.655	0.679
2008	17.004	15.215	0.626
2009	17.041	13.768	0.613
2010	18.132	13.646	0.944
2011	18.004	14.592	0.960
2012	20.290	15.727	0.891
2013	22.889	17.525	0.916
2014	24.255	18.864	0.944
2015			0.970



**Fig. 7:** Changes in electricity rates, introduction of renewable energy, overseas production ratio as function of year in Japan. Pale pink means the term that price of electricity, ratio of electricity, and trends in overseas production ratio increased simultaneously.

## 8. Conclusion

This study summarized previous paper evaluating several countries for the Green Paradox, and showed that there is no unified criteria to evaluate whether the Green Paradox occurs, or not. Then, this paper suggested novel

criteria to determine if the Green Paradox occurs in specific country. From the viewpoints of electricity rates, introduction of renewable energy, overseas production ratio, Japan is also determined that Green Paradox occurred 3 times in 1996, 1999, and between 2012 and 2014.

## Acknowledgements

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