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Green Innovation and Green Growth for Realizing an Affluent Low-Carbon Society

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Abstract

After the Liberal Democratic Party won the election in 2012, Prime Minister Abe stated that the government would strive to implement aggressive abatement measures against global warming. Here, we define five types of green innovation and three types of green growth with the aim to clarify the necessary abatement measures against global warming. Next, for promoting green growth we propose a novel organization, which is referred to as the Green Power Moderator (GPM). Furthermore, we estimate the economic impact of the measures on the national economy and households in 2030, assuming that GPM successfully promotes green growth. For this purpose, we develop an energy and economy model, in which the bounded rationality of consumers is taken into consideration. Finally, we identify significant factors in establishing an affluent low-carbon society based on the results of our model simulation.

Keywords

Green Innovation, Green Growth, Green Power Moderator, Bounded Rationality, Energy and Economy Model, Affluent Low-Carbon Society

1. Introduction

The basic goal of a sound energy policy is to support a secure, affluent and environmentally sustainable society. In the Basic Energy Plan authorized by the Japanese Cabinet in 2010, nuclear energy was expected to play a significant role in ensuring a stable supply of energy and reducing CO_2 emissions in Japan. The Plan calls for building 14 new nuclear power plants and increasing the average operating rates of all domestic nuclear power plants to 90% by 2030. However, on March 11, 2011, the Great East Japan Earthquake devastated the eastern region of Japan. The earthquake and the subsequent tsunami cut off all power, including emergency backup

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power, and the Fukushima Dai-ichi Nuclear Power Plant operated by the Tokyo Electric Power Company, causing a major nuclear accident. The situation remains uncertain, and we can only hope for a speedy resolution and recovery. This nuclear accident, the most serious in Japan's history, will inevitably affect the country's future plans for nuclear energy, and the government will revise the Basic Energy Plan.

Under these circumstances, the Energy and Environment Council in the National Policy Unit published three potential scenarios for the national economy and energy policy until 2030 [1]. These scenarios have different power structures in which nuclear power accounts for 0%, 15% or 20% - 25%. For comparison, the Council presented figures for the amount of greenhouse gas emissions, household expenditure for electricity, the real gross domestic product (GDP) and other economic indicators in each scenario. An overview of the published results is shown in **Table 1**.

According to the economic indicators considered by the Council, implementing measures for decreasing greenhouse gas emissions are not advantageous to households compared with the case where no such measures are adopted. We have investigated these results and pointed out problems with the assessment [2].

The Liberal Democratic Party won the election in 2012, and the Abe administration came into power. Prime Minister Abe stated the government's intention to revise the scenarios for the economy and energy policy presented by the former government. He also promised to implement aggressive abatement measures against global warming. Such abatement measures are expected to have positive effects on households. For this purpose, we need to promote green innovation in order to realize green economic growth.

2. Green Innovation and Green Growth

The categories of green innovation necessary to mitigate climate change are generally classified as shown in **Table 2**.

Here, we present the Green Deal in the UK as an example of innovation in institutions and organizations. The UK government initiated the Green Deal on October 1, 2012 [3], which allowed millions of households and companies to adopt energy-saving appliances without any initial investment. This framework, which is open to anyone, encompasses 45 technologies, such as thermal insulations in walls, roofs and floors, high-efficiency boilers, double glazing, photovoltaic systems, solar water heaters, high-efficiency heat pumps and wind turbines. Green Deal providers can offer financing of up to 10,000 pounds per customer, where the repayment period can be 25 years or longer, and an appropriate repayment amount is added to the monthly electricity bill [3].

Table 1. Estimation results published by the energy and environment council [1].

Item	Year 2010	0% Scenario	15% scenario	20% - 25% scenario
Real GDP (trillion yen)	511	564 - 628	579 - 634	581 - 634
Change in CO_2 emissions relative to energy consumption in 1990	+6.1%	-23%	−23%	−25%
Total electricity consumption (trillion kWh)	1.1	1.0	1.0	1.0
Monthly household expenditure for electricity (yen/month)	10,000	14,000 - 21,000	14,000 - 18,000	14,000 - 18,000

Table 2. Green innovation categories necessary to mitigate climate change.

Product innovation	Strong potential for application in end-use products such as electric vehicles, photovoltaic systems, energy-saving electric appliances and batteries
Process innovation	Concerns mainly energy-intensive industries, such as iron and steel manufacturing. Since energy saving in these industries has been promoted since the first oil crisis in 1973, the residual potential for process innovation in Japan is small.
Market innovation	Includes a feed-in tariff for renewable energy technologies as well as emissions trading systems
Innovation in supply chains	Includes smart grid and smart community systems
Innovation in institutions and organizations	Activates new business models through new legislative regulation or deregulation, such as the top-runner standards

To realize green growth by implementing such green innovation, we first need to define the concept of green growth based on its differences from green innovation. Here, green growth is defined as sustained economic growth with decreasing CO_2/GDP ratio. We propose three types of green growth, which are outlined in **Table 3**.

In particular, type 1 green growth is significant from the point of view that it generally improves the welfare of households, and the reason for this can be schematically explained as shown in **Figure 1**.

There are various energy-saving measures for households which reduce life cycle cost. Adopting such measures leads to a reduction in CO_2 emissions while improving consumer utility. However, measures which reduce life cycle cost are not necessarily adopted by all households for the following reasons.

Research on bounded rationality has indicated that humans are prone to postponing pending work and do not behave as "rational economic man". Therefore, it is not necessarily true that users will always purchase goods to reduce life cycle cost. From this viewpoint, a feed-in tariff for renewable energy technology may not be a useful measure. Although investors make certain repayment periods reliable by long-term stable electricity sales in the feed-in tariff scheme, the burden of initial investment is too heavy for households. Rather, a green deal system with zero investment cost would be desired, where consumers can cover the repayment cost by saving on their electricity bills.

Taking the above point into consideration, here we propose the Green Power Moderator (GPM) as an organization to promote type 1 green growth.

1) GPM is an organization designed to take action under the necessary legislation after liberalization of the retail electricity market for households as shown in **Figure 2**.
2) GPM supplies energy-saving electric appliances or photovoltaic systems to more than 1000 households through its own investment (no initial cost to households) and takes the amount saved by households on their electricity bills as revenue. Thus, GPM contributes toward energy saving and the realization of a low-carbon society.
3) GPM can manage revenue risk through a portfolio including many households. At the same time, GPM appropriately combines the fluctuation in photovoltaic system outputs with the variation in the saved electricity in order to smooth the total fluctuation over a few minutes. Thus, GPM mitigates the constraints of load frequency control and solves the problems associated with mass introduction of renewable energy sources.

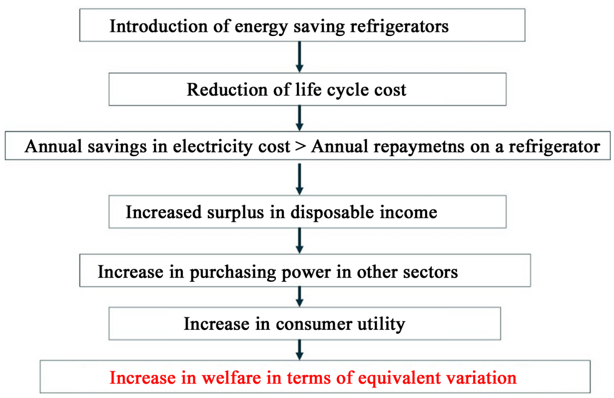

Figure 1. Type one green growth and welfare value of households.

Table 3. Three types of green growth.

Type 1 green growth	Decreases the CO_2/GDP ratio in the residential sector while contributing to economic growths by disseminating product innovation, such as energy-saving electric appliances and photovoltaic systems, through market innovation.
Type 2 green growth	Decreases the CO_2/GDP ratio in the industrial sector while contributing to economic growth by combining process innovation in energy-intensive industries with innovation in institutions.
Type 3 green growth	Decreases the CO_2/GDP ratio in the industrial sector while contributing to economic growth by combining various types of innovation in the information and communication technology (ICT) sector, service sector, medical and social welfare sector, education sector, culture sector and sport sector, which all have low CO_2 emissions per value added, in order to increase their shares. This involves structural changes in the national economy.

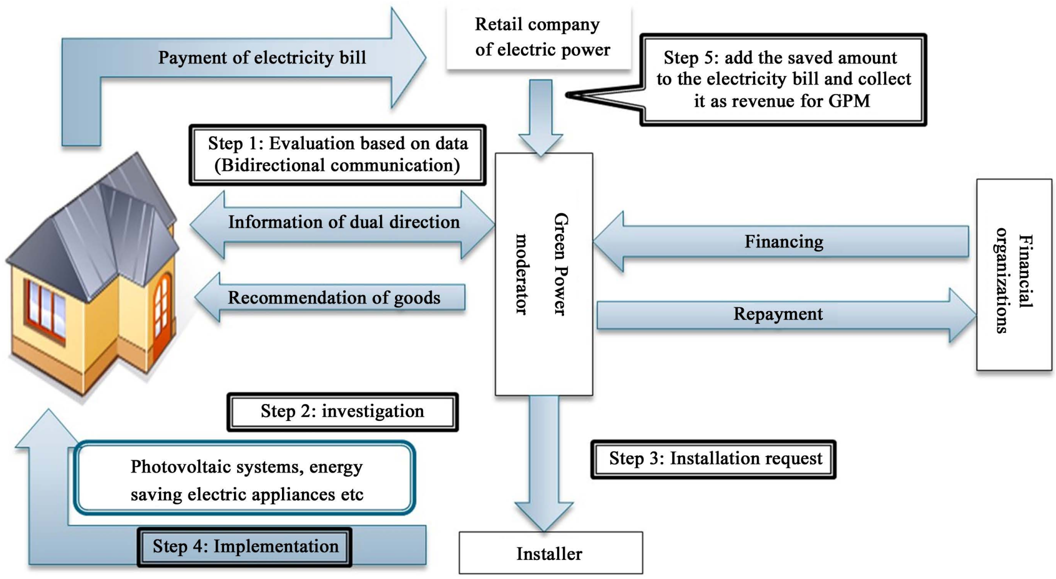

Figure 2. Concept of GPM.

4) GPM forecasts the daily electricity demand and issues warnings to call for power saving to the households when electricity supply cannot keep up with demand.

The activities of GPM are expected to have the following effects.

1) The behavior of households differs by income, family constitution, cultural background and other characteristics. GPM proposes appropriate measures for each household, based on information from an ICT network. Household utility generally increases after introducing GPM.
2) Electric power companies also benefit, because the constraints on the mass introduction of renewable energy are mitigated. Now that the future of nuclear power plants is uncertain, investments in fossil-fired power plants lead to high risk in terms of revenue. Under these circumstances, GPM could help decrease the investment risk through electricity savings.

We need to design this novel institution in a way that ensures a win-win-win relationship among households, electric power companies and GPM. In the next section, we estimate the potential effects of GPM in realizing an affluent low-carbon society.

3. Analysis Framework

3.1. General Framework

The overall framework of our analysis is as follows. We developed a novel energy and economy model for Japan and a final energy demand model envisioning the possible energy market scenarios in 2030. The results estimated by the final energy demand model were input to the energy and economy model to obtain the overall impact on the national economy. The details of each model are provided below.

3.2. Model Simulating Economic Activities

We revised the model which we developed to simulate economic activities for Japan [4]. Then we used it to estimate the effects of GPM activities on the national economy. In this model, the goods and services currently available for consumption are grouped into 19 categories, as shown in the article [4]. The utility of consuming these 19 types of goods and services is expressed by using the logit function given in Equation (1).

$$U_{ij} = \log P_j^{\alpha_{ij}} + \beta_{ij} + \varepsilon \,. \quad (1)$$

Here,

U_{ij} : Utility of consumption of the *j*th goods or services by households in the *i*th income bracket;

β_{ij} : Constant of preference of the *j*th goods or services by households in the *i*th income bracket;

α_{ij} : Sensitivity of U_{ij} to P_j .

The deterministic portion of Equation (1) is expressed as $V_{ij} = \log P_j^{\alpha_{ij}} + \beta_{ij}$, so that $\exp(V_{ij}) = \exp(\log P_j^{\alpha_{ij}} + \beta_{ij}) = B_{ij} P_{ij}^{\alpha_{ij}}$. Then, the share of *k*th goods or services in the households in the *i*th income bracket is expressed as in Equation (2).

$$S_{ik} = \frac{B_{ik} P_k^{\alpha_{ik}}}{\sum_j B_{ij} P_j^{\alpha_{ij}}} . \quad (2)$$

Here,

S_{ik} : Share of *k*th goods or services consumed by households in the *i*th income bracket;

B_{ik} : $\exp(\beta_{ij})$.

In this case, the composite utility of consuming all 19 types of goods and services is expressed using the log-sum function, as shown in Equation (3).

$$U_{i,psum} = \log\left\{\sum_j \exp(V_{ij})\right\} = \log\left\{\sum_j \left(B_{ij} P_j^{\alpha_{ij}}\right)\right\} . \quad (3)$$

Here,

$U_{i,psum}$: Composite utility of consumption of all 19 types of goods and services in the *i*th income bracket.

In the same way, the present utility $U_{i,psum}$ and the utility of future consumption $U_{i,future}$ are integrated as in Equation (4).

$$U_{i,sum} = \log\left\{\exp(U_{i,psum}) + \exp(U_{i,future})\right\}. \; . \quad (4)$$

Here,

$U_{i,sum}$: Utility of households in the *i*th income bracket;

$U_{i,future}$: Utility of future consumption by households in the *i*th income bracket.

3.3. Final Energy Demand Model

We assume that the GPM will promote type 1 green growth, and estimate the market penetration of significant energy-saving technologies by the following procedure. We have to take bounded rationality into consideration, as far as the implementation of energy-saving technologies is concerned. Here, we introduce the following model of bounded rationality. First, we express the parabolic discount [5] as in Equation (7). Consequently, the net present value of return due to energy-saving technologies is expressed as in Equation (8), where the simple repayment time for implementation of technology *l* is T_l.

$$\text{Parabolic discount} = (1+at)^{-b/a} . \quad (7)$$

Here,

a, *b*: Parameters expressing parabolic discount rates estimated in [5].

$$\text{Cash flow}_P = \frac{\sum_{t=1}^{N} (1+at)^{-b/a} \times I_l}{T_l} = \frac{N_P I_l}{T_l} . \quad (8)$$

Here,

N_P : $\sum_{t=1}^{N} (1+at)^{-b/a}$;

T_l : Simple repayment period for implementation of technology *l*;

I_l : Initial investment cost of implementation of technology *l*.

Then, the utility of consumers who adopt energy-saving technologies is expressed as in Equation (9). Even if the initial investment cost of technology *l* is I_l, consumers consider it to be *AI* (*A* > 1) from the perspective of avoiding monetary loss. This is another aspect of bounded rationality.

$$U_{il} = \frac{N_P I_l}{T_l} - A_i I_l + \varepsilon . \tag{9}$$

Here,

A_i : Parameter determining the magnitude of the effect of avoiding monetary loss of households in the *i*th income bracket;

ε : Random parameter varying according to the Gumbel distribution.

Again, we denote the deterministic term in the random utility as $V_{il} = \frac{N_P I_l}{T_l} - A_i I_l$. Thus, we can estimate the market penetration rate of technology *l* without GPMas in Equation (10).

$$S_{il} = \frac{\exp(V_{il})}{1+\exp(V_{il})} . \tag{10}$$

Here,

S_{il} : Share of *l*th technology for households in the *i*th income bracket.

Next, we estimate the market penetration rate of technology *l* with GPM. Consumers do not have to bear the initial investment cost, and an appropriate repayment amount for the green deal financing is added to the monthly electricity bill. Therefore, consumer utility is expressed as follows.

$$U_{il}^{GD} = \frac{N'_P I_l}{T_l} + \varepsilon . \tag{11}$$

Here,

$$N'_p = \sum_{t=T_{loan}+1}^{N} (1+at)^{-b/a}$$

T_{loan} : Total repayment period.

Thus, the market penetration of various technologies when the green deal is applied is estimated by using Equation (12).

$$S_{il}^{GD} = \frac{\exp(V_{il}^{GD})}{1+\exp(V_{il}^{GD})} . \tag{12}$$

The results obtained based on Equation (12) can be summarized as follows:

1) We set the demand for electricity, gas, fuel oil, gasoline and other commodities in 18 income brackets on the basis of statistical data on household consumption.
2) The percentage of next-generation energy-efficient houses (1999 standard) as a stock base is assumed to be 48% in 2030, in accordance with the National Institute of Construction.
3) We assume a continuation of the top runner standards regarding home electric appliances, passenger cars and so on.
4) The percentage of next-generation passenger cars as a stock base is assumed to be 51% in 2030. Next-generation passenger cars are hybrid, plug-in hybrid, electric, fuel cell and other similar vehicles.
5) We assume efficiency improvement of lighting by introducing LEDs.
6) We assume that solar power generation systems are adopted by 16 million households.
7) We assume that fuel cells are adopted by 7.2 million households.
8) We assume that heat pumps for hot water are adopted by 5.3 million households.

3.4. Scenarios for Energy Supply, CO_2 Emissions and Their Impact on Households in 2030

Under the following assumptions, we estimate the impact of type 1 green growth due to the introduction of GPM on households and the national economy in 2030. First, GDP is assumed to grow at an annual rate of 1.3% between 2005 and 2020, and more slowly at 0.5% between 2020 and 2030 in view of the declining population and increasing maturity of the economy in the nominal case.

According to the National Policy Unit, the cost of different types of fuel for power generation is assumed as shown in **Table 4** [6]. These figures are expressed in terms of primary fuel, except for nuclear in which case the value directly represents the fuel cost for power generation.

The Energy and Environment Council to the National Policy Unit published three scenarios concerning the share of nuclear power in the total electricity production, in which nuclear power accounts for 0%, 15% or 20% - 25%. In this paper, we assume the share of nuclear power to be 15%.

For solar power generation systems, we assume that their cost will be reduced as estimated by Yamada *et al.* [7], as shown in **Table 5**. A methodology for estimating the cost of future solar power generation systems was reported and published in the proceedings of the 2011 World Engineers' Convention.

The following assumptions for improved energy efficiency and reduced CO_2 emissions in the industrial and transportation sectors are also used in this analysis.

1) Natural gas is assumed to replace 80% of petroleum products and fuel (relative to 2005 levels), including heavy oil, used in all manufacturing sectors (except the petrochemical industry).
2) Promoting modal shift: Based on an input-output analysis of distribution, CO_2 emissions in the transportation sector are assumed to be reduced by up to 44% [8].
3) Promoting energy saving in industrial sectors: In accordance with the law promoting energy conservation, the annual improvement in energy intensity in each industry is assumed to be 1%.
4) After the Great East Japan Earthquake, we observed a trend toward saving electricity not only in eastern Japan, but also in western Japan [2]. Taking this into account, we assume that electricity demand was reduced by 5% due to the changes in demand structure after the earthquake.

4. Results and Discussions

First, we present the results of our energy and economy model used to estimate the reduction in CO_2 emissions from energy consumption compared with the 1990 emissions level. **Table 6** shows the estimation results for 2030.We estimate the increase in equivalent income of all households compared to the case where energy saving is not promoted through the introduction of GPM.

Figure 3 shows the changes in household welfare value in 2030 as a difference in that for each income bracket. Changes in welfare are translated from changes in utility by using the concept of equivalent variation. Spe-

Table 4. Assumed cost of fuel for power generation [6] Yen/kWh.

	2010	2015	2020	2025	2030
Coal	1.81	1.83	1.85	1.86	1.87
Gas	4.18	4.32	4.46	4.55	4.65
Oil	6.47	6.73	6.99	7.14	7.29
Nuclear	1.40	1.40	1.40	1.40	1.40
Biomass	3.52	3.52	3.52	3.52	3.52

Table 5. Estimate of the future cost of solar power generation systems [7] (Yen/W).

Year	2012	2020	2030
Photovoltaic panels (yen/W)	100	75	50
BOS* (yen/W)	150	100	70
Photovoltaic systems (yen/W)	250	175	120
Efficiency (%)	15	20	30

*BOS: "balance of the system", denotes peripheral equipment associated with photovoltaic systems to supply electricity.

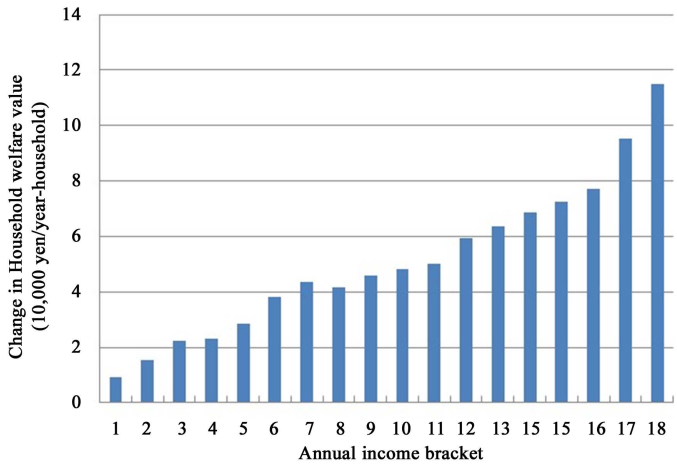

Figure 3. Changes of household welfare value in individual annual income brackets.

Table 6. GDP, household welfare value and reduction in CO_2 emissions in 2030.

CO_2 emissions from energy consumption (compared with 1060 million tons of CO_2 in 1990)	▲27.0%
Real GDP (506 trillion yen in 2005)	617 trillion yen
Increase in aggregate household welfare value[1*]	2.61 trillion yen

cifically, changes in welfare indicate changes in utility, based on the concept of equivalent variation, in which changes in utility are expressed in terms of the price of goods and services before the change. We cannot express changes in household welfare in terms of only disposable income with sufficient reliability since the prices of goods and services are different in each scenario. Hence, we use household welfare in terms of equivalent variation. Bars represent the differences from the scenario without a setup similar to the Green Deal.

All bars in **Figure 3** show positive changes from the nominal scenario. This indicates that the household utility could be improved by energy-saving technologies, such as high-efficiency electrical appliances and automobiles, spread by GPM. Thus, GPM could play a significant role in promoting the adoption of such products. In summary, the most important factor for establishing a low-carbon society is the promotion of energy conservation.

5. Conclusions

In this article, we first defined five types of green innovation and three types of green growth. Type 1 green growth decreases the CO_2/GDP ratio in the residential sector by promoting the adoption of energy-saving electric appliances, photovoltaic systems and so on. Type 2 green growth decreases the CO_2/GDP ratio in industrial sectors by promoting process innovation in energy-intensive industries. Finally, type 3 green growth decreases CO_2/GDP by promoting the ICT sector, service sector, medical and social welfare sector, education sector, culture sector and sports sectors, which all have low CO_2 emissions per value added, in order to increase their shares. These three types of green growth must be implemented by combining various types of innovation.

Next, we proposed the concept of GPM as an institution promoting type 1 green growth, and we explained its functions. Some new concepts, including a setup similar to the Green Deal in the UK, must be implemented first in order to launch GPM.

We also conducted quantitative estimation of type 1 green growth using our energy and economy model. The results indicated that type 1 green growth would be effective for households as it could increase household welfare. In future work, we plan to conduct quantitative estimation including type 2 and type 3 green growth, as well as to prepare an institutional design for realizing all three types of growth.

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