Study on energy scenarios for realizing a secure, economical and low-carbon society

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Center for Low Carbon Society Strategy
The Goal of LCS is establishment of strategies to move present societies to sustainable and affluent low carbon societies.

LCS was established in Dec. 2009 in Japan Science and Technology Agency with the above aim.
Center for Low Carbon Society Strategy (LCS)

Established in December 2009 in Japan Science and Technology Agency (JST)

- Define a Low Carbon Society in 2020/2050 and Analyze Requirements for Shaping it
- Explore Comprehensive Strategies, Formulate Scenarios, and Establish a Model for Achieving a Low Carbon Society
- Reduction Target of 80% in 2050 from 1990 levels
- Reduction Target of 25% in 2020 from 1990 levels

Current Society in 2010

Low Carbon Society in 2020

Low Carbon Society in 2050

Establish a Low Carbon Society
CO2 Reduction Target of Japan

(Mt-CO$_2$/y)

Year

1990 (Basis) 1,261

2005 1,359 △7.7%

Kyoto Protocol

Hatoyama target 1,186 △6%

2010 △25%

2020 946

Year
Japan’s GHG emissions in 2008 fiscal year is estimated to be approximately +1.6% relative to 1990. Forest sink contribute to 3.8% reduction from this number. Using Kyoto mechanisms, Japanese government acquired approximately 95 million ton (annually 19 million ton), while Japanese industries acquired 350 million ton (annually 70 million ton). These corresponds to more than 6% of annual domestic GHG emissions in 1990. As conclusion, we estimate Japan could comply with Kyoto Protocol even with economic revival in future.
Strategic Scheme for Green Innovation by MEXT

Social System Transformation for Low Carbon Society

Mitigation Strategy
- Innovative technology contributing to Greenhouse Gases Reduction
- Advanced Low Carbon Related Technologies etc (5,809 Million Yen; 1,339 Million Yen)
- Promote R&D of Near & Long Term Energy Technology
- Utilize full results of Basic Research Strategy (JST’s CREST etc)

Field Experiment Strategy
- Field experimental research of Low Carbon Technology
  - Society system reform program toward new society corresponding to climate change
    (5 Million Yen (New))

Adaptation Strategy
- Research for adaptation of environmental change caused by global warming
  - Climate Change Adaptation Strategy Initiative etc
    (3,158 Million Yen; 2,316 Million Yen)
- Promote Climate Change Projection and Data Integration as common platform technology
- Apply full results of EO Strategy

General Strategy
- Social Scenario Research for Low Carbon Society
  (300 Million Yen (New))
- JST Low Carbon Social Strategy Center Establishment

Research Analysis
- on realization of new technology
- on possibilities of adoption and diffusion of technology considering utility to public and lifestyle change
- on influence of new technology to society

Diplomatic Strategy
- Int’l Cooperation • S&T Diplomacy
  - Contribute to UNFCCC / IPCC / GEOSS etc
  - Support to Developing Countries, Capacity Bldg

Linkage to Related Ministries, Agencies, Local Governments,

Low Carbon Society R&D Strategy Bureau
- Consulting
- Control overall strategy (Prioritize R&D Items)

Low Carbon Society R&D Strategy Promotion Committee
- Apply collective R&D efforts from Univ., Agencies, Institutes

[Diagram showing various strategies and their corresponding initiatives and budgets]
On March 11, 2011, a great earthquake devastated the East Japan region. The earthquake and subsequent tsunami also cut off all power, including emergency backups, to the Tokyo Electric Power Company's Fukushima Dai-ichi Nuclear Plant, causing a critical situation. Now we can only hope for a speedy resolution and recovery. This, the biggest nuclear accident in Japanese history, will inevitably affect the country's future energy and anti-global warming policies.
Major Policies on Global Warming Countermeasures, Dec. 28, 2010
Ministerial Committee on the Global Warming Issue

1. Reduce GHG emissions by 25% below 1990 levels by 2020, premised on the establishment of an equitable and effective international framework in which all major economies participate and agree on ambitious targets.

2. Domestically, implement the Basic Energy Plan to reduce CO2 from energy use to 30% or more below 1990 levels by 2030.

3. Flexibly and strategically reshape policies to adapt to changing domestic and international conditions, enhance environmental and energy technologies and accelerate green innovation.

4. From FY 2011, introduce a global warming tax. Increase the tax rate on oil and coal in proportion to the amount of CO2 emissions created to give a final increase in tax revenues of approximately 1.5 times (approx. 240 billion Yen).

5. During the current session of the Diet, propose laws to require power companies to purchase all energy produced from renewable sources (cost of purchases to be passed on to customers).

6. Give careful consideration to the establishment of a cap and trade emissions trading scheme.

7. The Japanese government will work with industry, agriculture, consumer and regional groups etc., to support global warming mitigation initiatives such as bilateral and domestic credits.

8. Secure financial resources and promote policies to absorb greenhouse gases through forestry, etc.
## Costs of PV system and batteries

<table>
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<tr>
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<th>YEAR</th>
<th>2012</th>
<th>2020</th>
<th>2030</th>
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<tbody>
<tr>
<td>PV system (yen/W)</td>
<td></td>
<td>250</td>
<td>175</td>
<td>120</td>
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<tr>
<td>Efficiency (%)</td>
<td></td>
<td>15</td>
<td>20</td>
<td>30</td>
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<tr>
<td>BOS (yen/W)</td>
<td></td>
<td>150</td>
<td>100</td>
<td>70</td>
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<tr>
<td>Cost (yen/kWh)</td>
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<td>25</td>
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<td>12</td>
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<tr>
<td>Li-ion batteries (yen/Wh)</td>
<td></td>
<td>19</td>
<td>10</td>
<td>8</td>
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<tr>
<td>Lifetime 5years 20h (yen/kWh)</td>
<td></td>
<td>76</td>
<td>40</td>
<td>16 (10years)</td>
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<tr>
<td>5h (yen/kWh)</td>
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<td>19</td>
<td>10</td>
<td>4 (10years)</td>
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<tr>
<td>Total (5h, yen/kWh)</td>
<td></td>
<td>44</td>
<td>28</td>
<td>16</td>
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</tbody>
</table>

Reference: LCS
Model of technology innovation for PV

Cautious R&D and a strategy for deployment are vital in achieving replacement with next-generation PV systems.
Model of market penetration for PV
-Estimation of feed in tariff-

We modeled the deployment of PV using Logit model.

Utility of purchasing PV in i prefecture

\[ U_i = \theta_1 W_i - \theta_2 I_i + \theta_3 S_i + \theta_4 \]

Rate of purchasing PV in i prefecture

\[ P_i = \frac{\exp(U_i)}{1 + \exp(U_i)} \]

\( W_i \): Potential generation (kWh/kW), \( I_i \): Initial investment (10000yen/kW), \( S_i \): Selling price of electricity in the feed in tariff (yen/kWh)
Synergy of technology and market innovation

PV System Utility

Domestic Demand for PV System + Overseas Demand for PV System

Balanced by

PV System Supply

PV System Unit Price

Feed in Tariff for PV

PV System Subsidy

Cumulative R&D costs

Synergy of technology and market innovation
1. Framework in this analysis
Overview of our analysis

Computable General Equilibrium Model

Multi-regional Power Planning Model

Final Energy Demand Model for Households
Structure of our CGE model

We compute the point, in which markets for goods and services are in equilibrium.

U (Utility)
H (Present consumption)
C (Future consumption),
X (Consumption of goods),
I (Consumption of leisure)

 Consumers are divided into 18 brackets based on annual income.
⇒ Evaluation of economic impact by introducing technologies.
⇒ Evaluation of economic impact in each income bracket.
Consumption and production sectors of our CGE models

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<td>4</td>
<td>Gas</td>
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<td>Medical &amp; Health</td>
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<td>19</td>
<td>Other consumptions</td>
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<td>Real estate</td>
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<td>Private non-profit</td>
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Decrease by energy saving

Increased cost

19 consumption goods

39 production goods
Scenarios of energy supply in 2030

Case 1: The nominal case.
The nominal case does not adopt any measures to reduce greenhouse gas emissions. GDP is assumed to grow at an annual rate of 1.3% from 2005 to 2020 and 0.5% from 2020 to 2030.

Case 2: Increasing nuclear plants.
With the same GDP growth rate as in Case 1, in Case 2 we assume that 14 new nuclear power plants will have been constructed by 2030; note that the 6 reactors at the Fukushima Dai-ichi Nuclear Power Plant are assumed to be decommissioned by 2020. We also assume that the operating ratio of all nuclear plants will have improved to between 90% by 2030. Moreover, generation from solar power systems is assumed to increase to 53 GW in 2030.

Case 3: Maintaining nuclear plants.
Assumptions are same as Case 2 except we assume that no further construction of nuclear plants will occur in future.

Case 4: Decreasing nuclear plants.
We assume that no further construction of nuclear plants will occur in the future, and that all other existing nuclear power plants will be decommissioned after 40 years of operation. Power shortages resulting from closing the nuclear plants will be compensated for mainly by coal, oil and natural gas power plants. Solar power generation is assumed to increase to 53 GW in 2030. All other assumptions are identical to Case 2.
Power capacity of existing nuclear power plants over their estimated lifetime

![Graph showing power capacity over the lifetime of nuclear plants.]
Common policies and measures adopted in this analysis for energy efficiency improvement

- The percentage of next-generation energy efficient homes (1999 standard) as a stock base is assumed to be 48% in 2030, in accordance with the National Institute of Construction.
- The percentage of next-generation passenger cars as a stock base is assumed to be 50% in 2030. Next-generation passenger cars are hybrid, plug-in-hybrid, electric, fuel cell vehicles and the like.
- The "Top runner" system is assumed to be continued for domestic electrical appliances and automobiles.
- Natural gas is assumed to replace 80% (relative to 2005 levels) of petroleum products and fuel, including heavy oil, used by all manufacturing sectors (except the petrochemical industry).
- Promoting modal shift: based on input-output analysis of distribution, CO\textsubscript{2} emissions in the transportation sector are assumed to be cut by up to 44%.
- Promoting energy savings in industrial sectors: in accordance with the law promoting energy conservation, the annual improvement of energy intensity in each industry is assumed to be 1%.
2. Overview of Power Planning model and influence by introducing huge amount of photovoltaics
Multi-regional power planning model

- Parameters and constraints -

- Parameters on fuel cost, efficiency of power generation, operation & maintenance cost and carbon tax

- Constraints on satisfying demand for power and on load frequency control due to power generated by photovoltaics

- Parameters on present and future capacities and initial cost of power plants

- Constraints on response to fluctuating demand, operational rates and power transmission

- Constraints on hydropower and pumped hydropower

Minimizing total costs as discounted present values

Optimal solutions for power generation, fuel consumption, newly built capacity and power transmission

Demand for primary ten electric utilities
Time period: year 2010～2030

Constraints: 482,761
Variables: 841,826
Electricity demand in the power planning model — Load curves of days in typical seasons —
2. Estimation of fluctuation on PV output
   -Smoothing effect estimated by the transfer hypothesis-

- Smoothing effect: PV systems are distributed in wide regions, so that output fluctuation is suppressed compared with individual fluctuations. This smoothing effect is estimated according to the transfer hypothesis. Ref. Hiroyuki Nagoya et al. A method for presuming total output fluctuation of highly penetrated photovoltaic generation considering mutual smoothing effect, IEEJ Transactions on Electronics, Information and Systems, Vol.131 No.10 pp.1688-1696

PV output is assumed to be proportional to solar radiation.

Data on solar radiation in each minute in Tokyo Meteorological Station. (2009/7/25)
2. Estimation of fluctuation on PV output
-Smoothing effect estimated by the transfer hypothesis-

\[ S_{tra}(f) = \left| \frac{S_{syn}(f) + j \cdot T_x \cdot f \cdot S_{ran}(f)}{1 + j \cdot T_x \cdot f} \right| \]

Frequency spectrum of fluctuation in solar radiation
2. Estimation of fluctuation on PV output

-Smoothing effect estimated by the transfer hypothesis-

Segregation into 10 kilometer meshes

Estimation of fluctuation rate take account of smoothing effect

Hokkaido: 0.1439
Tohoku: 0.0758
⇒ due to difference in distribution of PV
2. Estimation of fluctuation on PV output
-Smoothing effect estimated by the transfer hypothesis-
Estimation of necessary adjustments by LFC
-Based on fluctuation of power demand-

LFC power plants adjust to fluctuation of demand during several to twenty minutes.

Governor-free control

Adjustment by LFC

Power output

Several to 30 minutes
Multi-regional power planning model
-Constraints regarding LFC-

1. \[ O(t,r,g,h,d) \leq \{C(t,r,g) \cdot \text{MaxUtil}_D(g,d) - \ LFC\_C(t,r,g,h,d)\} + LFC\_C(t,r,g,h,d) \cdot (1 - lfc\_range(g) / 2) \]
   
   Output of generators under LFC operation, must be less than those under ordinary operation by the LFC adjustment width.

2. \[ \sum_g \{LFC\_C(t,r,g,h,d) \cdot lfc\_range(g)\} + ePV\_DMD(t,r,h,d) \cdot \text{remain} \geq \{ePV\_DMD(t,r,h,d) \cdot lfc\_dmd + PV\_GEN(t,r,h,d) \cdot lfc\_sun(r)\} \]

   LFC capacity added by residual adjustment in power grids must be larger than fluctuation of PV output added by fluctuation in demand.
Share of electricity generated (Energy saving case)

Scenario increasing nuclear

Scenario maintaining nuclear

Scenario decreasing nuclear
3. Is affluent low-carbon society feasible? 
-Impact of green technology-
The effect of the recent disaster on CO2 emissions will be extremely high due to the reduced operating ratio of existing nuclear plants and postponement of new construction.

This is why there are $13.7 \sim 14.8\%$ difference between scenarios increasing and decreasing nuclear power plants.

Simulation Result 1 using the CGE Model

Reductions in CO$_2$ emissions compared with 1990
The computed results imply that the utilities of households could be considerably improved by the spread of energy-saving products, such as high-efficiency electrical appliances and automobiles. Thus, measures to promote the spread of these products are crucial, regardless of the increase or decrease of nuclear power plants.
If there are no efficiency improvements in domestic appliances and automobiles (red bars in the above diagram), household welfare decrease in all income brackets. On the contrary, if there are efficiency improvements, household welfare increase in most income brackets as blue bars in the diagram.
Study on energy scenarios for realizing a secure, economical and low-carbon society

1. If we can no longer expect the planned new nuclear plant construction, this will have an extremely large effect on the amount of CO2 emissions in 2020.

2. Therefore green technologies such as photovoltaics are expected. Synergy of technology and market innovation would be effective for proliferating PV.

3. In Japan, increase photovoltaics could be supported by LFC power plants in electric power grids until 2030.

4. As regards the impact of low carbon policies to household welfare, efficiency improvement is an effective way to increase welfare as well as renewable energy.