Japan after Fukushima: Role of Renewable Energy

Analysis using Hybrid GIS-TIMES Technology Model

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- Think Tank established by 80 Japanese Companies

- Research Areas
  1. International Affairs and Diplomacy Issues
  2. Environmental and Energy Issues
  3. Structural Reform Issues
  4. Recovery from the East Japan Earthquake

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I. Introductions & Motivations

- **Nuclear** power generated more than a quarter of Japan’s electricity over the past few decades.

- The Fukushima disaster eroded people’s confidence in nuclear to the extent that **all nuclear plants (54)** were forced to be shut down now and only two nuclear plants are operating to meet summer demand peak.

- Maintaining a steady electricity supply at reasonable prices without nuclear is the primary challenge the country faces today.

- This study aims to illustrate the Japanese electricity supply system after the earthquake with consideration of Japanese uniqueness including its **10 separate grids with weak connections between them and the geographical gap between renewable potential and electricity consumptions** using GIS data for a TIMES model.

- This study tries to discuss about the **design of FIT** to popularise renewables **at the least costs**.

Three Pillars
1. Realisation of no-nuclear society
2. Realisation of green revolution
3. Realisation of stable energy supply

Three Principles towards Denuclearisation
1. 40 years life-time
2. Only nuclear power station approved by new safety standards will be re-started
3. No more new construction and additional nuclear power stations

...however, the strategy was “not” approved in a Cabinet meeting due to the oppositions from Japanese business sector. It is now more like a reference material.
II. HYBRID GIS-TIMES TECHNOLOGY MODEL
JMRT (JAPAN MULTI-REGIONAL TRANSMISSION MODEL)
JMRT is…

- Detailed **disaggregate Japanese electricity generation system model** based on TIMES.
- **10 electricity grids with weak connections** between grids.
- **Two different electricity frequencies**, 50Hz and 60Hz, with frequency converters to convert one frequency to another.
- **Energy Demands** at Prefecture Level (**47 Prefectures** in Japan)
- **12 Time Slices** (4 Seasons & 3 Times)
- Existing PowerStation Data & Planned PowerStation Data
- Life-time Extension of Existing PowerStation
- Capacity of LNG and Coal Port
- Limits to the capacity share of Wind in each grid (30%)
10 Grids and Grid Connections

- 50 MHz
- 60 MHz
- Frequency converter

Grid Connections:
- Chugoku: 16.66 GW
- Kansai: 2.4 GW
- Kyushu: 5.57 GW
- Shikoku: 1.4 GW
- Chubu: 5.57 GW
- Tohoku: 6 GW
- Hokkaido: 0.6 GW
- Okinawa: 0.9 GW
12 Time Slices

- **3 Time Periods**
  - Day (8～13, 16～23)
  - Peak (14～15)
  - Night (0～7)

- **4 Seasons**
  - Spring (3～6)
  - Summer (7～9)
  - Autumn (10～12)
  - Winter (1～2)

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Load Curve in Most Electricity Consumed day

Peak Demand in each Year
Existing PowerStation Data include

- Type of PowerStation
- Latitude, Longitude
- Prefecture
- Start Year
- Life Time
- Electricity Generation Capacity
- Availability Factor (AF)
Location is important (e.g. Wind Turbine)

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>AF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>15.8%</td>
</tr>
<tr>
<td>6</td>
<td>19.7%</td>
</tr>
<tr>
<td>6.5</td>
<td>23.5%</td>
</tr>
<tr>
<td>7</td>
<td>27.3%</td>
</tr>
<tr>
<td>7.5</td>
<td>31.0%</td>
</tr>
<tr>
<td>8</td>
<td>34.5%</td>
</tr>
<tr>
<td>8.5</td>
<td>37.9%</td>
</tr>
</tbody>
</table>

Sea Depth (Offshore)

Distance from grid

Distance from road

Initial Cost
### Data of Renewable Potential

<table>
<thead>
<tr>
<th>No.</th>
<th>Prefecture Code</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Wind Speed</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td></td>
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</tr>
</tbody>
</table>

GIS Data is from MOE Potential Survey

- **Huge Renewable Potential in Hokkaido Area.**
- **Huge Electricity Consumption in Kanto Area including Tokyo.**

**Legend:**
- Red: Geothermal
- Purple: Offshore Wind
- Blue: Onshore Wind

1 km mesh
## New Data Sets (Off-shore Wind)

<table>
<thead>
<tr>
<th>No.</th>
<th>MOE GIS Data</th>
<th>GIS Calculations</th>
<th>New Data</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Prefecture Code</td>
<td>Distance from Road</td>
<td>Capacity</td>
</tr>
<tr>
<td></td>
<td>Latitude</td>
<td>Distance from Grid</td>
<td>Investment</td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
<td>Sea Depth</td>
<td>Availability Factor (AF)</td>
</tr>
<tr>
<td></td>
<td>Wind Speed</td>
<td></td>
<td>O&amp;M</td>
</tr>
</tbody>
</table>

1. | | + | |
2. | | + | |
3. | | + | |
GIS to TIMES (Aggregation)

GIS

<table>
<thead>
<tr>
<th>No.</th>
<th>Prefecture Code</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Wind Speed</th>
<th>Distance from Road</th>
<th>Distance from Grid</th>
<th>Capacity</th>
<th>Investment cost</th>
<th>Availability Factor (AF)</th>
<th>O&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

TIMES

<table>
<thead>
<tr>
<th>Cost</th>
<th>AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost 0</td>
<td>AF 0</td>
</tr>
<tr>
<td>Cost 0</td>
<td>AF 1</td>
</tr>
<tr>
<td>Cost 1</td>
<td>AF 0</td>
</tr>
<tr>
<td>Cost 1</td>
<td>AF 1</td>
</tr>
</tbody>
</table>

Upper limits of Capacity in each cluster

Onshore Wind 3,290 Tech.

Onshore Wind 373,356 Tech.
Simulation Flow

Potential (e.g. Wind)

Policy & Targets
- FIT
- Nuclear AF
- CO2

Expected (e.g. Wind)

- Electricity Generation Structure
- Fossil Fuel Imports
- Marginal Cost in each Time Slices
- Carbon Dioxide
- System Costs
Overview of JMRT

- Existing PowerStation
  - USC
  - IGCC
  - GTCC
  - Nuclear
  - Biomass
  - Wind
  - PV
  - Geothermal
  - Small Hydro

- Existing Pumped-Storage
- Electricity
  - Industry
    - Manufacturing
    - Non-manufacturing
  - Domestic
    - Household
    - Office
  - Transport

USC: Ultra-super Critical
IGCC: Integrated Gasification Combined Cycle
GTCC: Gas Turbine Combined Cycle
# Data Sources

<table>
<thead>
<tr>
<th>Categories</th>
<th>Description</th>
<th>Sources</th>
</tr>
</thead>
</table>
| **Existing Power Stations**   | Capacity, Generation      | Agency for Natural Resources and Energy, Overview of Electricity Demand and Supply 2009  
                                  |                                                                          | Federation of Electric Power Companies of Japan, Handbook of Electricity Business 2010 |
| **Power Stations Under Construction** | Capacity                | Agency for Natural Resources and Energy, Prefecture Energy Consumption Statistics, Institute of Energy Economics |
| **LNG Port**                  | Capacity                  | Tex Report, Gas Annual Report 2010                                      |
| **Biomass**                   | Potential                 | New Energy and Industrial Technology Development Organization (NEDO), Biomass Potential and Available Biomass Estimation |
|                               | Cost                      | International Energy Agency (IEA), World Energy Outlook                  |
| **Conventional Power Generation** | Cost                      | International Energy Agency (IEA), World Energy Outlook                  |
| **Electricity Consumption**   | Electricity Consumption by Prefecture | Agency for Natural Resources and Energy, Prefecture Energy Consumption Statistics |
| **Electricity Load Curve**    |                           | Federation of Electric Power Companies of Japan, Nuclear and Energy Drawings |
Preliminary Results

III. FEED-IN-TARIFF (FIT) SIMULATIONS UNDER BUDGE CONSTRAINTS
Simulation Assumptions

- We have tried to identify the relationship between FIT price and the quantity of electricity generated by renewables under FIT budget constraints.
- Proposed FIT Price: 40 cents/kWh for PV and 20 cents/kWh for non-PV in 2012.
- 4 Nuclear Reactors at Fukushima Dai-ichi are assumed to be decommissioned in 2012.
- The life-time of nuclear PowerStation is 40 yrs and no new nuclear PowerStation will be built.

Before the earthquake, nuclear was expected to play a major role in achieving energy self-sufficiency and carbon mitigation targets by increasing the availability factor to about 90% and building 14 new nuclear power stations by 2030.
RE and FIT Under 3 Budget Constraints
Grid Expansions (10 Grids to 1 Grid)
Benefits of Grid Expansion
Comparisons between with and without GE

<table>
<thead>
<tr>
<th></th>
<th>Electricity Generation in 2020 (TWh)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>With GE</td>
</tr>
<tr>
<td>Biomass</td>
<td>24.9</td>
</tr>
<tr>
<td>Geothermal</td>
<td>10.4</td>
</tr>
<tr>
<td>Small Hydro</td>
<td>30.9</td>
</tr>
<tr>
<td>PV</td>
<td>0.0</td>
</tr>
<tr>
<td>Offshore Wind</td>
<td>27.7</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>117.8</td>
</tr>
</tbody>
</table>

Onshore-Wind Electricity Generation by Prefecture (2020) (TWh)

GE make possible to cheap renewable potentials.
IV. Conclusions

The research has challenged

- a modelling approach where the electricity system of the entire country is represented with extremely disaggregated information on existing stock and future potentials.

- Identifying a mix of new capacity additions, life extensions, along with their locations to tide Japan over during the possible stoppage of nuclear power production in 2013.

High FIT prices make the huge potential of renewables commercially viable, but at the same time, they limit the maximum introduction of renewables under budgets constraints.

Exploring and quantifying the benefits of grid expansion in the medium and long term to meet policy targets related to climate and energy security. The GIS-TIMES hybrid model is one idea for simulating the uniqueness of both Japan’s electricity market and renewable energy.
shaping tomorrow with you
## Japan Feed-in-Tariff

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Solar PV</th>
<th>Wind power</th>
<th>Geothermal power</th>
<th>Small- and medium-scale hydraulic power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Procurement category</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 kW or more</td>
<td>Less than 10 kW (purchase of excess electricity)</td>
<td>20 kW or more</td>
<td>15MW or more</td>
</tr>
<tr>
<td>Installation cost</td>
<td>325,000 yen/kW</td>
<td>466,000 yen/kW</td>
<td>300,000 yen/kW</td>
<td>1,250,000 yen/kW</td>
</tr>
<tr>
<td>Operating and</td>
<td>10,000 yen/kW</td>
<td>4,700 yen/kW</td>
<td>6,000 yen/kW</td>
<td>---</td>
</tr>
<tr>
<td>maintenance costs</td>
<td>(per year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-tax IRR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Internal Rate of</td>
<td>6%</td>
<td>3.2%*(1)</td>
<td>8%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Return)</td>
<td></td>
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<tr>
<td>Tax inclusive</td>
<td>42.00 yen</td>
<td>42 yen</td>
<td>23.10 yen</td>
<td>57.75 yen</td>
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<td>(per kWh)</td>
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<td>*(1)</td>
<td>*(1)</td>
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<tr>
<td>Tax exclusive</td>
<td>40 yen</td>
<td>42 yen</td>
<td>22 yen</td>
<td>55 yen</td>
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<tr>
<td>Duration</td>
<td>20 years</td>
<td>10 years</td>
<td>20 years</td>
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