Feasibility Study on Renewable Energy Use in the Island in the Seto Inland Sea

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Hiroshima University
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   1.2 Background
   1.3 Objective

2. Target island
   2.1 Target island
   2.2 Local characteristics and renewable energy

3. Estimation of energy demands in the island

4. Estimation of the supply potentials of renewable energy
   4.1 Woody biomass energy by forest utilization
   4.2 Woody biomass energy by pruning branches
   4.3 Solar energy
   4.4 Small hydropower generation

5. Evaluation of the renewable energy use potential

6. Renewable energy utilization recommended map

7. Conclusion
1.1 Islands In Japan

Islands in the Seto Inland Sea

- Rich natural resources: forests, mild climate, vast farmland
- Beautiful landscape
- Local culture and custom
1.1 Islands In Japan

Local decline

The population decreasing and the aging

vicious circle

- Decline of community
- Inconvenience of daily life
- Increasing of low-used land
- Decline in agriculture
1.2 Background

Effective use of local characteristics

+ 

Measure against local problems

Renewable energy use
1.2 Background

Effect of renewable energy use

Saving fossil fuel and reduce carbon dioxide

Stable energy supply

Local economical effects

Synergistic effect of regional industries

ex. Wind power generation in farmland
1.3 Objective

Estimates the energy demands and the energy supply potentials targeting an island in the Seto Inland Sea

**demand**
The heat and electric demands of the houses in the island

**supply**
The supply potential of renewable energy considering local characteristics

compare

Evaluates the feasibility of energy independence in the island
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7. Conclusion
2.1 Target island

Osakishomojima

2235 person
17.82 km²
Having 5 districts facing the sea
2.1 Target island

Seto Inland Sea Type Climate
– mild climate, low rainfall, high radiation

Having steep terrain

Cultivation of mandarin orange is active

Vast orchard (Terraced field)
2.1 Target island

Population decreasing and the aging is advancing rapidly
2.1 Target island

Local decline

Decline of community

Increasing of low-used land

Inconvenience of daily life

Decline in agriculture

Measures against local decline are required
2.2 Local characteristics and prospected renewable energy

Considering local characteristics of the target area, 4 types of renewable energies are selected as effective sources.

<table>
<thead>
<tr>
<th>Local Characteristics</th>
<th>Renewable Energy Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proximity of satoyama and living area</td>
<td>Woody biomass energy by forest utilization</td>
</tr>
<tr>
<td>Fruit cultivation is active</td>
<td>Woody biomass energy by pruning branches</td>
</tr>
<tr>
<td>Long sunshine hours</td>
<td>Solar energy</td>
</tr>
<tr>
<td>Having steep terrain</td>
<td>Small hydropower generation</td>
</tr>
</tbody>
</table>
Overview

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3. Estimation of demand in the island

Estimates the unit value of energy consumption per house

- Lighting and home electric
- Heating
- Hot water
- Cooling

**Simulation tool**

<table>
<thead>
<tr>
<th></th>
<th>SCHEDULE ver.2</th>
<th>SMASH ver.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated load</td>
<td>Lightning and home electric</td>
<td>Heating</td>
</tr>
<tr>
<td></td>
<td>Hot water</td>
<td>Cooling</td>
</tr>
<tr>
<td>Input condition</td>
<td>• Number of persons in a household</td>
<td>• Number of persons in a household</td>
</tr>
<tr>
<td></td>
<td>• Population composition by age and gender</td>
<td>• Weather data</td>
</tr>
<tr>
<td></td>
<td>• Weather data</td>
<td>• House model</td>
</tr>
<tr>
<td></td>
<td>• House model</td>
<td>• Thermal insulation levels of houses</td>
</tr>
</tbody>
</table>
3. Estimation of demand in the island

* Setting conditions

- Standard House Model by Architectural Institute of Japan
- Extended AMeDAS weather data

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<td></td>
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<td>House model</td>
</tr>
<tr>
<td></td>
<td>House model</td>
<td>Thermal insulation levels of houses</td>
</tr>
</tbody>
</table>
3. Estimation of demand in the island

**Weighted mean in consideration of the ratio of household types**

- Population composition by age and gender
- Thermal insulation levels of houses
- Number of persons in a household

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<tr>
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</tr>
<tr>
<td></td>
<td>Hot water</td>
<td>Cooling</td>
</tr>
</tbody>
</table>
| Input condition | • Number of persons in a household  
• Population composition by age and gender  
• Weather data  
• House model | • Number of persons in a household  
• Weather data  
• House model  
• Thermal insulation levels of houses |
### 3. Estimation of demand in the island

#### Lighting and home appliance electricity load (GJ/house/year)

<table>
<thead>
<tr>
<th>attribute</th>
<th>0-69 years old</th>
<th>70- years old</th>
<th>Weighted mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>female</td>
<td>male</td>
<td>female</td>
</tr>
<tr>
<td>Household by 1 person</td>
<td>17.46</td>
<td>16.60</td>
<td>17.01</td>
</tr>
<tr>
<td>Household by 2 person</td>
<td>14.95</td>
<td>11.37</td>
<td>14.98</td>
</tr>
<tr>
<td>Load (GJ/house/year)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Hot water supply heat load (GJ/house/year)

<table>
<thead>
<tr>
<th>attribute</th>
<th>male</th>
<th>female</th>
<th>Weighted mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household by 1 person</td>
<td>11.57</td>
<td></td>
<td>11.57</td>
</tr>
<tr>
<td>Household by 2 person</td>
<td>10.24</td>
<td>9.6</td>
<td>9.95</td>
</tr>
<tr>
<td>Load (GJ/house/year)</td>
<td></td>
<td></td>
<td>11.18</td>
</tr>
</tbody>
</table>

#### Heating heat load (GJ/house/year)

<table>
<thead>
<tr>
<th>attribute</th>
<th>No insulation</th>
<th>old</th>
<th>new</th>
<th>next</th>
<th>Weighted mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household by 1 person</td>
<td>11.23</td>
<td>5.99</td>
<td>4.19</td>
<td>2.77</td>
<td>8.64</td>
</tr>
<tr>
<td>Household by 2 person</td>
<td>10.91</td>
<td>5.68</td>
<td>3.9</td>
<td>2.52</td>
<td>8.33</td>
</tr>
<tr>
<td>Load (GJ/house/year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.41</td>
</tr>
</tbody>
</table>

#### Cooling electric load (GJ/house/year)

<table>
<thead>
<tr>
<th>attribute</th>
<th>No insulation</th>
<th>old</th>
<th>new</th>
<th>next</th>
<th>Weighted mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household by 1 person</td>
<td>2.10</td>
<td>2.11</td>
<td>2.18</td>
<td>2.30</td>
<td>2.13</td>
</tr>
<tr>
<td>Household by 2 person</td>
<td>2.21</td>
<td>2.24</td>
<td>2.33</td>
<td>2.45</td>
<td>2.26</td>
</tr>
<tr>
<td>Load (GJ/house/year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.23</td>
</tr>
</tbody>
</table>
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4.1 Woody biomass energy by forest utilization

Effect

Carbon neutral
Conservation of Satoyama

Vegetation distribution in Osakishimojima

Estimates the supply potential
of the broadleaf tree
4.1 Woody biomass energy by forest utilization

Creating of cutting strategy in consideration of multi function of forest

**Water source cultivation function**
- Estimated water storage capacity (mm)
- 170-: Recharge area
- -170: Non recharge area

**Mountain disaster prevention function**
- Estimated weight (g/m³)
- 1300-: Emergency area
- -1300: Safety area

**Forest zoning**

<table>
<thead>
<tr>
<th>Forest zoning</th>
<th>Cutting rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass production zone</td>
<td>100%</td>
</tr>
<tr>
<td>Soil conservation zone</td>
<td>70%</td>
</tr>
<tr>
<td>Water source cultivation zone</td>
<td></td>
</tr>
</tbody>
</table>
4.1 Woody biomass energy by forest utilization

**Calculations**

\[ G_t = \frac{A}{BC/DEF} \]

\[ = 579 \text{ (t/year)} \]

<table>
<thead>
<tr>
<th><strong>G_t</strong></th>
<th>Annual available woody biomass quantity by forest utilization (t/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>Total forest area of the zone to be logged (ha)</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>The age of the forest to be cleared (years)</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Forest volume of logging forest (m³)</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Forest area of logging forests (ha)</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Cut clearance rate (%)</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>Dry specific gravity of wood (0.6 t/m³)</td>
</tr>
</tbody>
</table>

**Pellet stoves**

\[ W_{tp} = G_t H_t I \]

\[ = 6883 \text{ (GJ/year)} \]

<table>
<thead>
<tr>
<th><strong>W_{tp}</strong></th>
<th>Available heat supply amount by using pellet stove (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H_t</strong></td>
<td>Calorific value of hardwoods (18.017GJ/t)</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>Thermal efficiency of pellet stove (66%)</td>
</tr>
</tbody>
</table>

**Gasification cogeneration**

\[ W_{th} = G_t H_t J \]

\[ = 4172 \text{ (GJ/year)} \]

\[ W_{te} = G_t H_t J K \times 0.8 \]

\[ = 667 \text{ (GJ/year)} \]

<table>
<thead>
<tr>
<th><strong>W_{th}</strong></th>
<th>Available heat supply amount by cogeneration (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>J</strong></td>
<td>Thermal efficiency by gasification (40%)</td>
</tr>
<tr>
<td><strong>W_{te}</strong></td>
<td>Available electric power supply amount by cogeneration (GJ/year)</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>Power generation efficiency (20%)</td>
</tr>
</tbody>
</table>
“Pruning branches” are branches discarded from the tree of the orchard in Osakishimojima.
### Calculations

**Gp** = LM

= 4055 (t/year)

- **Gp** = Annual available woody biomass quantity (t/year)
- **L** = Orchard area (ha)
- **M** = Pruned branch of oranges per unit of discharge (t/ha/year)

- **M** = 4.1 (Sano et al., 2003)

**Wpp** = \( G_p H_p N \)

= 16255 (GJ/year)

- **Wpp** = Available heat supply amount by pellet stove (GJ/year)
- **Hp** = Calorific value of pruned branch (7.95 GJ/t)
- **N** = Availability rate of pruned branch (76.4%)

**Wpe** = \( G_p H_p JKN \times 0.8 \)

= 1576 (GJ/year)

- **Wpe** = Available electric power supply amount by cogeneration (GJ/year)
4.3 Solar energy

Amount of solar radiation each area

<table>
<thead>
<tr>
<th>Area</th>
<th>Average Solar Radiation (kWh/m²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kubi</td>
<td>1463</td>
</tr>
<tr>
<td>Ocho, Mitarai</td>
<td>1200</td>
</tr>
<tr>
<td>Ohama</td>
<td>1240</td>
</tr>
<tr>
<td>Okitomo</td>
<td>1280</td>
</tr>
<tr>
<td></td>
<td>1320</td>
</tr>
<tr>
<td></td>
<td>1360</td>
</tr>
</tbody>
</table>

Average solar radiation of optimum inclination angle

\[ H_\theta = \frac{H_a}{\cos \theta} \]

\( \theta \): Optimum inclination angle

\( H_a \): Average solar radiation (kWh/m²/year)
4.3 Solar energy

**Calculations**

\[
E_H = A_h H_\theta a \times \frac{3.6}{1000}
\]

- **\(E_H\)**: Available heat supply by using solar heat (GJ/year/house)
- **\(A_h\)**: Solar collector area (40m^2)
- **\(a\)**: Heat collecting efficiency of solar heat (0.4)

\[
E_S = A_s H_\theta b \times \frac{3.6}{1000}
\]

- **\(E_S\)**: Electricity supply potential by solar power generation (GJ/year/house)
- **\(A_s\)**: Solar panel area (6m^2)
- **\(b\)**: Overall efficiency by solar power generation (0.084)
4.4 Small hydropower generation

A river is extracted using the hydrological analysis tool of GIS.

The power generation potentials

\[ P = 9.8 \times QHc/1000 \]

<table>
<thead>
<tr>
<th>P</th>
<th>Power generation by small hydropower (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Flow rate (m³/s)</td>
</tr>
<tr>
<td>H</td>
<td>Heading difference (m)</td>
</tr>
<tr>
<td>C</td>
<td>Overall efficiency of small hydropower generation (0.72)</td>
</tr>
</tbody>
</table>

Power output (kW)

Sites where the output is 20 kW or more are selected.
4.4 Small hydropower generation

Calculations

\[ E_{pm} = P_d \times 8640 \times 3.6 / 1000 \]

<table>
<thead>
<tr>
<th>Sites</th>
<th>Output (kW)</th>
<th>Annual power generation capacity (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.25</td>
<td>346.46</td>
</tr>
<tr>
<td>2</td>
<td>20.71</td>
<td>354.30</td>
</tr>
<tr>
<td>3</td>
<td>25.63</td>
<td>438.41</td>
</tr>
<tr>
<td>4</td>
<td>22.06</td>
<td>377.34</td>
</tr>
<tr>
<td>5</td>
<td>28.43</td>
<td>486.41</td>
</tr>
<tr>
<td>6</td>
<td>23.43</td>
<td>400.77</td>
</tr>
<tr>
<td>7</td>
<td>23.35</td>
<td>399.39</td>
</tr>
<tr>
<td>8</td>
<td>35.16</td>
<td>601.46</td>
</tr>
<tr>
<td>9</td>
<td>24.07</td>
<td>411.77</td>
</tr>
<tr>
<td>10</td>
<td>32.95</td>
<td>563.64</td>
</tr>
<tr>
<td>11</td>
<td>20.84</td>
<td>356.44</td>
</tr>
<tr>
<td>12</td>
<td>21.12</td>
<td>361.25</td>
</tr>
<tr>
<td>13</td>
<td>23.09</td>
<td>395.01</td>
</tr>
<tr>
<td>14</td>
<td>21.39</td>
<td>366.01</td>
</tr>
<tr>
<td>15</td>
<td>25.26</td>
<td>432.15</td>
</tr>
<tr>
<td>16</td>
<td>28.21</td>
<td>482.63</td>
</tr>
<tr>
<td><strong>Amount</strong></td>
<td><strong>6773.44</strong></td>
<td></td>
</tr>
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5. Evaluation of the renewable energy use potential

6. Renewable energy utilization recommended map

7. Conclusion
### 5. Evaluation of renewable energy

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Method</th>
<th>Heat (GJ/year)</th>
<th>Electric (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woody biomass energy by forest utilization</td>
<td>using pellet stoves</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cogeneration</td>
<td>10000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cogeneration</td>
<td>15000</td>
<td></td>
</tr>
<tr>
<td>Woody biomass energy by pruning branches</td>
<td>using pellet stoves</td>
<td>20000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cogeneration</td>
<td>25000</td>
<td></td>
</tr>
<tr>
<td>Solar energy</td>
<td>using solar heat</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>solar power</td>
<td>35000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>small hydropower</td>
<td>40000</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**
- **Solar energy** has high potential.
- Wind energy is not shown but could be included.
- Forest utilization (< pruning branches) is less compared to using pellet stoves.

**Conclusion:** Renewable energy is considered remarkable, and a local characteristic is promising.
Energy independence in target island is feasible
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6. Renewable energy utilization recommended map

Potential quantity of each energy evaluated in each district, and promising areas is extracted.

<table>
<thead>
<tr>
<th>Renewable energy</th>
<th>Evaluated potential quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woody biomass energy by forest utilization</td>
<td>· Forest area (ha)</td>
</tr>
<tr>
<td></td>
<td>· Percentage of biomass production zone in forest zoning (%)</td>
</tr>
<tr>
<td>Woody biomass energy by pruning branches</td>
<td>· Percentage of orchard area to district area (%)</td>
</tr>
<tr>
<td></td>
<td>· Thermal load (GJ / year)</td>
</tr>
<tr>
<td>Solar energy</td>
<td>· Average solar radiation in residential area (kWh / ㎡)</td>
</tr>
<tr>
<td></td>
<td>· Average amount of solar radiation throughout the district (kWh / ㎡)</td>
</tr>
<tr>
<td>Small hydropower generation</td>
<td>· Sites where the power output is 20 kW or more (sites)</td>
</tr>
</tbody>
</table>
This map makes it possible to grasp renewable energy suitable for each district, and it is expected to be a guideline for the introduction of regional renewable energy business.
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7. Conclusion

Findings

• Target island has high potential of renewable energy considering local characteristics.

• Energy independence is feasible by using renewable energy in the target island.

• Grasping the promising potential by using renewable energy in each district, renewable energy utilization policy map is created.

Future works

• To consider about renewable energy use in islands including the other aspects such as an economic, environment, resident’s intention, and so on.
Thank you for your kind attention