Consistency between carbon neutrality and spatial issue of renewable energy: A case in Japan

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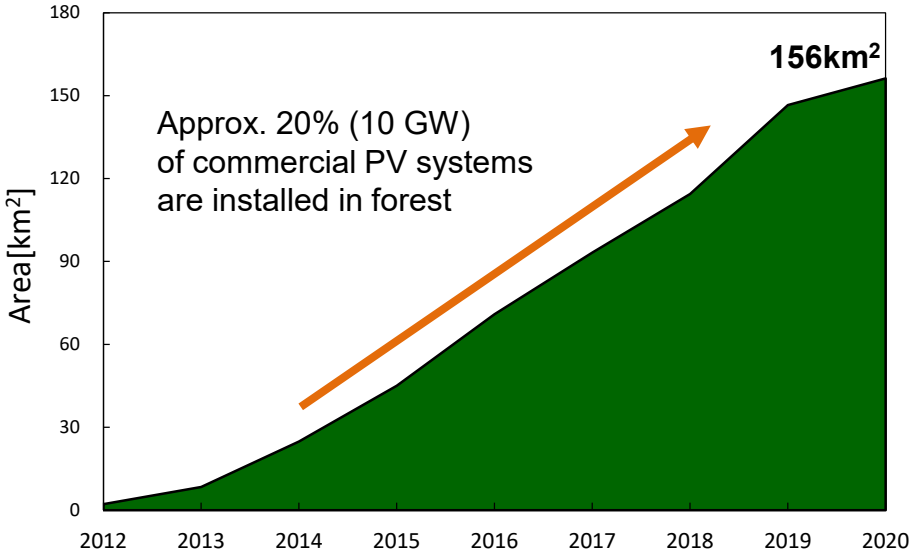
Background

Up to now, some of RE plants had a negative effect on the local environment.
While spatial planning is currently considered by Japanese government,
the expansion of RE toward CN and regulating installation is trade-off relationship.

Solar power plant in the forest

Ref: GoogleMap

Installation in forest in Japan



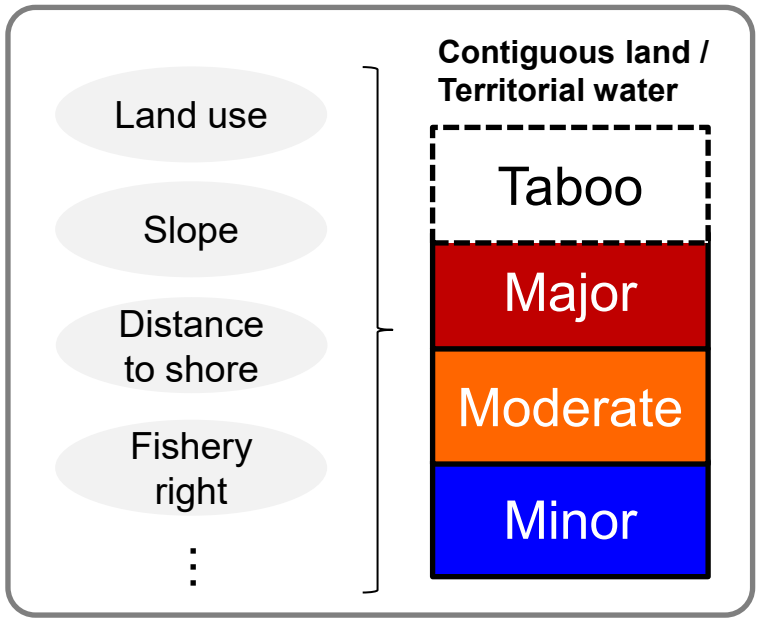
Data ref: Japanese forest agency

It is essential for decision makers to understand how total amount of renewable energy depending on spatial planning can affect realizing carbon neutrality.

Objective

In order to assess how total amount of RE can affect realizing CN, this study developed GIS model to assess potential installation and *Technology selection model*.

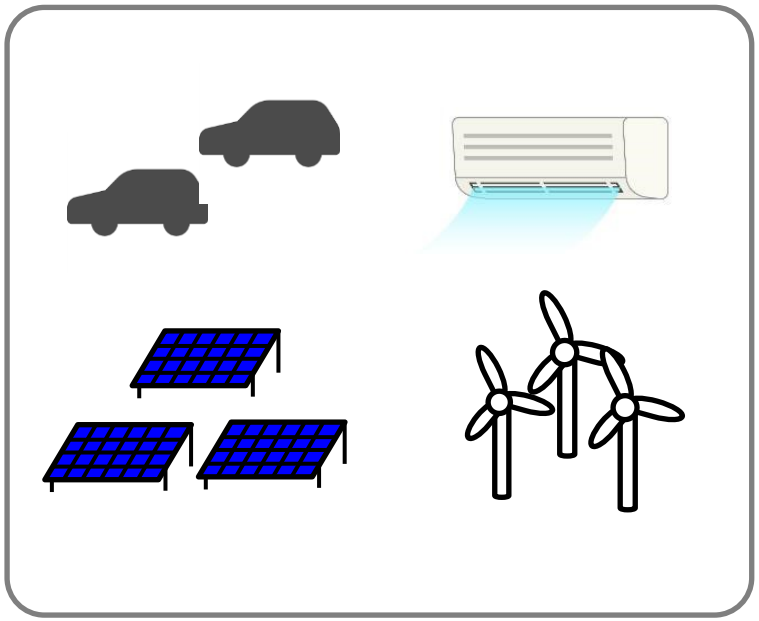
GIS Model



Level of concern by stakeholder conflict

Potential installation capacity

Technology selection model



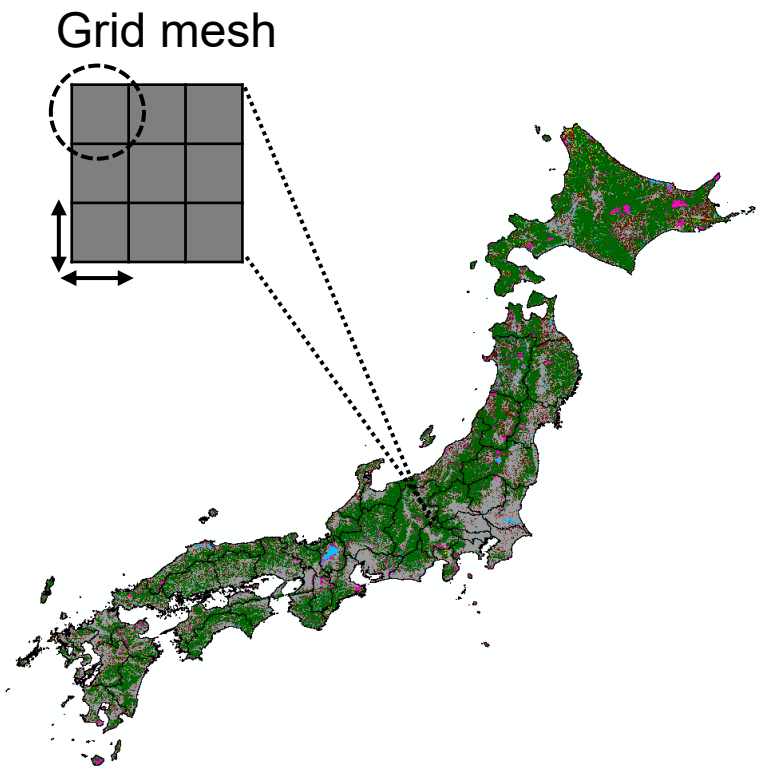
Combination of energy technologies under constraints (CO_2, demand, etc..)

By integrating these models, this study aims to assess the impact to energy system by spatial planning under carbon neutrality.

Method - GIS model -

Input (Spatial data)

Element	Definition
Land use	Forest, weedland, etc..
Population	Population in each grid mesh
Legal area (Land)	Natural park etc..
Terrain (Land)	Slope
Natural condition	Wind speed / irradiance
Legal area (Sea)	Fishery right etc…
Terrain (Sea)	Distance to shore, water depth
Ship	The number of ship



Output

- Total area according to level of concern
- Conflict area between PV and wind energy systems

Method - Technology selection model -

Input

Energy technologies
- **Upper limit of facility**
- CAPEX
- Fuel cost / O&M cost

Fuel price
- LNG price
- Coal price
- H_2 price etc..

Service demand
- Production of material (e.g. Iron)
- Transportation (e.g. passenger km)
- Residential / Commercial (e.g. Heating)

-> Based on GIS model, upper limit of RE are given.

Model

$$minJ = \sum_{y=1}^{y_e} \sum_{i=1}^{k} \left(Fix_{y,i} + Fuel_{y,i} + Variable_{y,i} \right) \cdot r_y$$

Year | Technology | CAPEX | Fuel cost | O&M cost | Discount coefficient

Constraints:
Service demand
CO_2 emission
Supply-demand balance
Reserved capacity etc..

-> Minimizing total cost under several constraints

Output

- The number of each technology -> Generation mix, Land use impact
- Total cost of selected technology -> Cost impact

2. Assumption

Installation scenario

This study developed 4 installation scenarios according to level of concerns.

Installation scenario

	Minor conflict	Moderate conflict	Major conflict	RE100
Land use	Weed land / Bare land / Devasted land			
Exclusion	Natural park, Nature protected area, Wildlife sanctuary, Residence area			
Slope	< 10°	< 20°	< 30°	
Forest	Excluded		Included	
Farmland	Excluded		Included	
Wind speed	≥ 7.0 m/s			
Water depth	0 - 200 m			
Distance from shore	0 – 5 km	5 – 10 km	10 – 22.2 km(Territorial water)	
Shipping density	0-3 ships/month	4-20 ships/month	21-30 ships/month	
Fishery rights	None	None	Inside fishery rights	

* RE100 scenarios assumes to supply almost all electricity energy by renewable energy

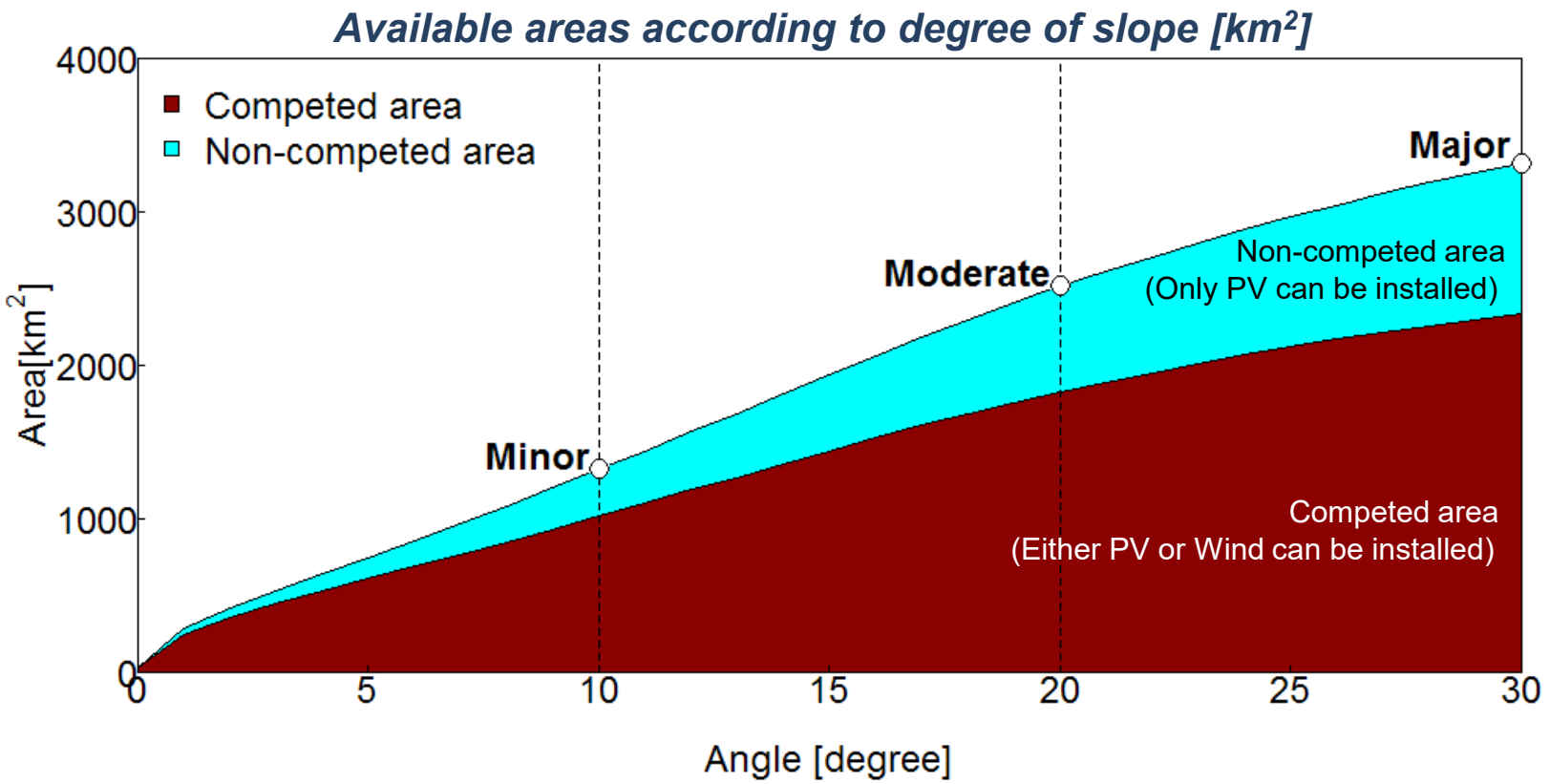
Upper limit of installation capacity

	Minor conflict	Moderate conflict	Major conflict	RE100
Weed land (wind speed < 5 m/s)	PV: 9.3 GW	PV: 19.7 GW	PV: 65.7 GW	
Weed land (wind speed ≥ 5 m/s)	PV: 38.9 GW or Wind: 5.8 GW	PV: 68.2 GW or Wind: 10.2 GW	PV: 156.8 GW or Wind: 21.5 GW	
Farmland	0	0	PV: 1793.2 GW	
Forest (wind speed ≥ 6 m/s)	0	0	Wind: 186.5 GW	
Territorial water (Water depth < 60 m)	Wind: 5.3 GW	Wind: 30.8 GW	Wind: 150.2 GW	
Territorial water (Water depth ≥ 60 m)	Wind: 34.7 GW	Wind: 142.4 GW	Wind: 255.2 GW	
Building (Roof)	PV: 202.8 GW (Fixed)*			
Building (Wall)	PV: 95.7 GW (Fixed)*			

* In this study, installation capacity of PV on building was fixed assuming PV mandates on buildings as optimistic assumption.

Level of concern (Land)

This study assumes RE can be installed in weed land, bare land, devasted farmland out of nature park, nature protected area, wildlife sanctuary, residence area. Among these land uses, level of concern is classified by slope angle.



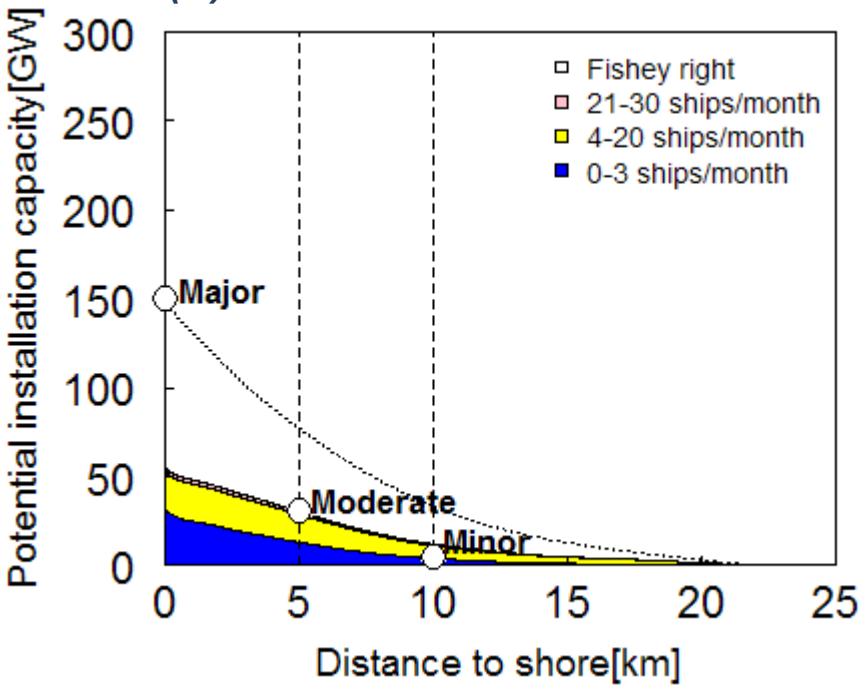
30° : Constructing faculties in the area with over 30° are prohibited by building ordinance.
20° : Threshold of available area for on-shore wind in the report by Japanese Ministry of Environment.
10° : Half of the threshold on above.

Level of concern (Territorial water)

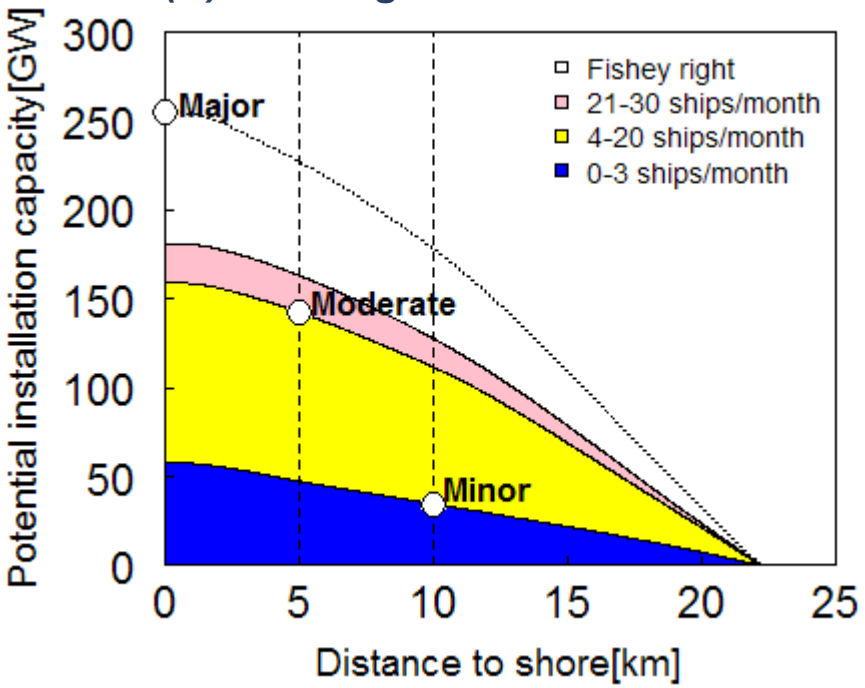
This study assumes offshore wind can be installed potential *promoting zone* determined by zoning rules. Among this level of concern is classified by the distance to shore, fishery right, shipping density.

Potential installation capacity according to distance to shore [GW]

(A) Bottom-fixed wind turbine



(B) Floating wind turbine



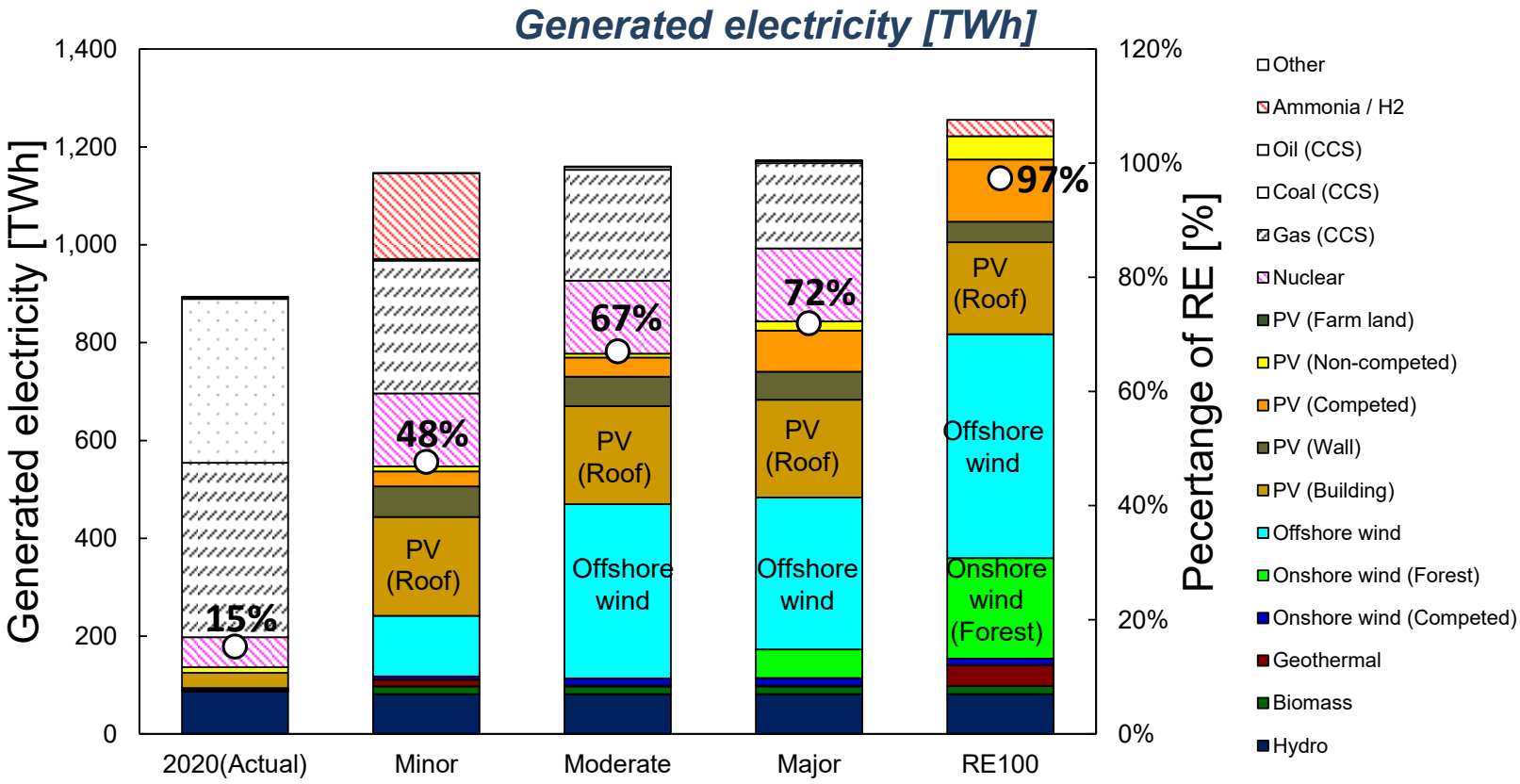
Other assumption

	Minor conflict	Moderate conflict	Major conflict	RE100
Thermal power	Possible (CCS would be used)			None
Nuclear power	Only existing or planned plants are worked			None
Cost of power plants	Based on Working group on examining generation cost CAPEX of offshore wind was estimated by recent auction result			
Fuel costs	Based on IEA world energy outlook 2020 (SDS scenario)			
Capacity of CO_2 capture	Domestic:100 million t-CO_2/year Oversea: 150 million t-CO_2/year			
CO_2 constraint	2030: -46% to 2013 2040: -73% to 2013 2050: 0 t-CO_2			
Service demand	2015's service demand			

3. Results and discussion

Generated electricity

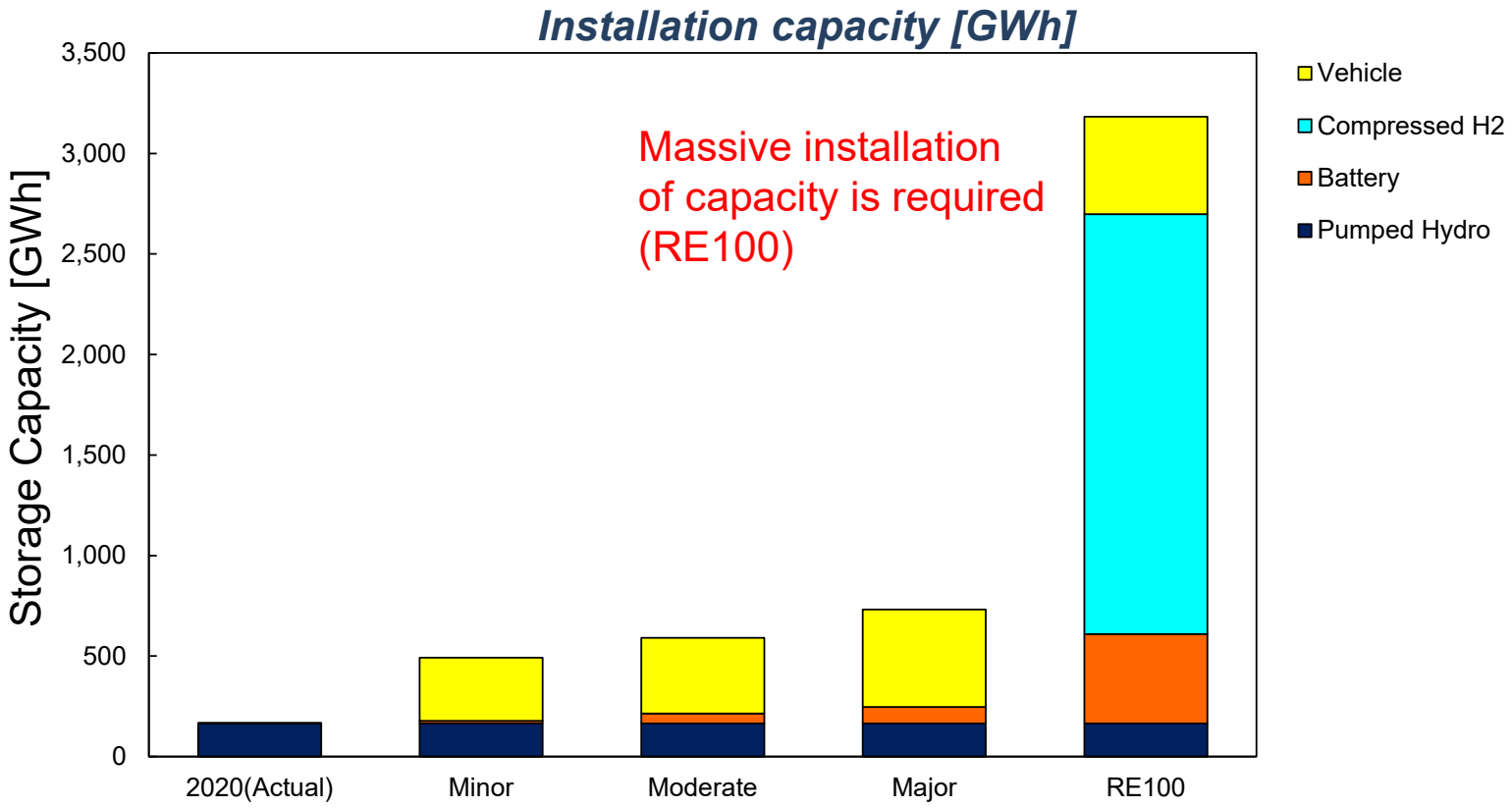
Generated electricity and perchance of RE were assessed in each scenario



If RE is installed only in the area with a few or no conflicted area (Minor conflict), the percentage of RE is approximately 50%.
-> If social acceptance is considered, generation by RE is insufficient for CN

Storage capacity

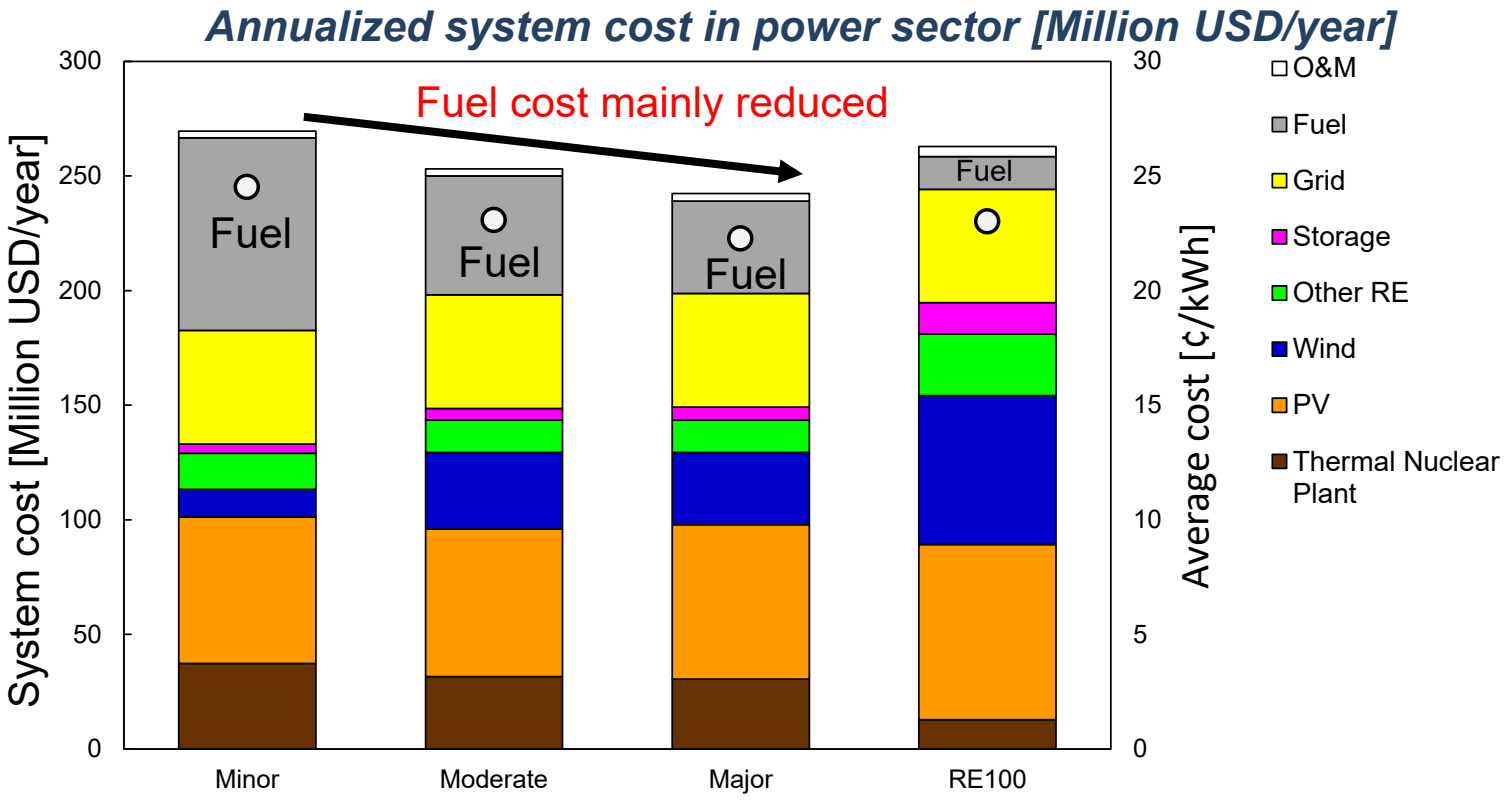
Storage capacity to maintain supply-demand balance were assessed.



If the percentage of RE is significantly increased, a massive installation of storage (≥ 3000 GWh) is required to maintain supply-demand balance when generations from both PV and wind are low for long term.

System cost in power sector

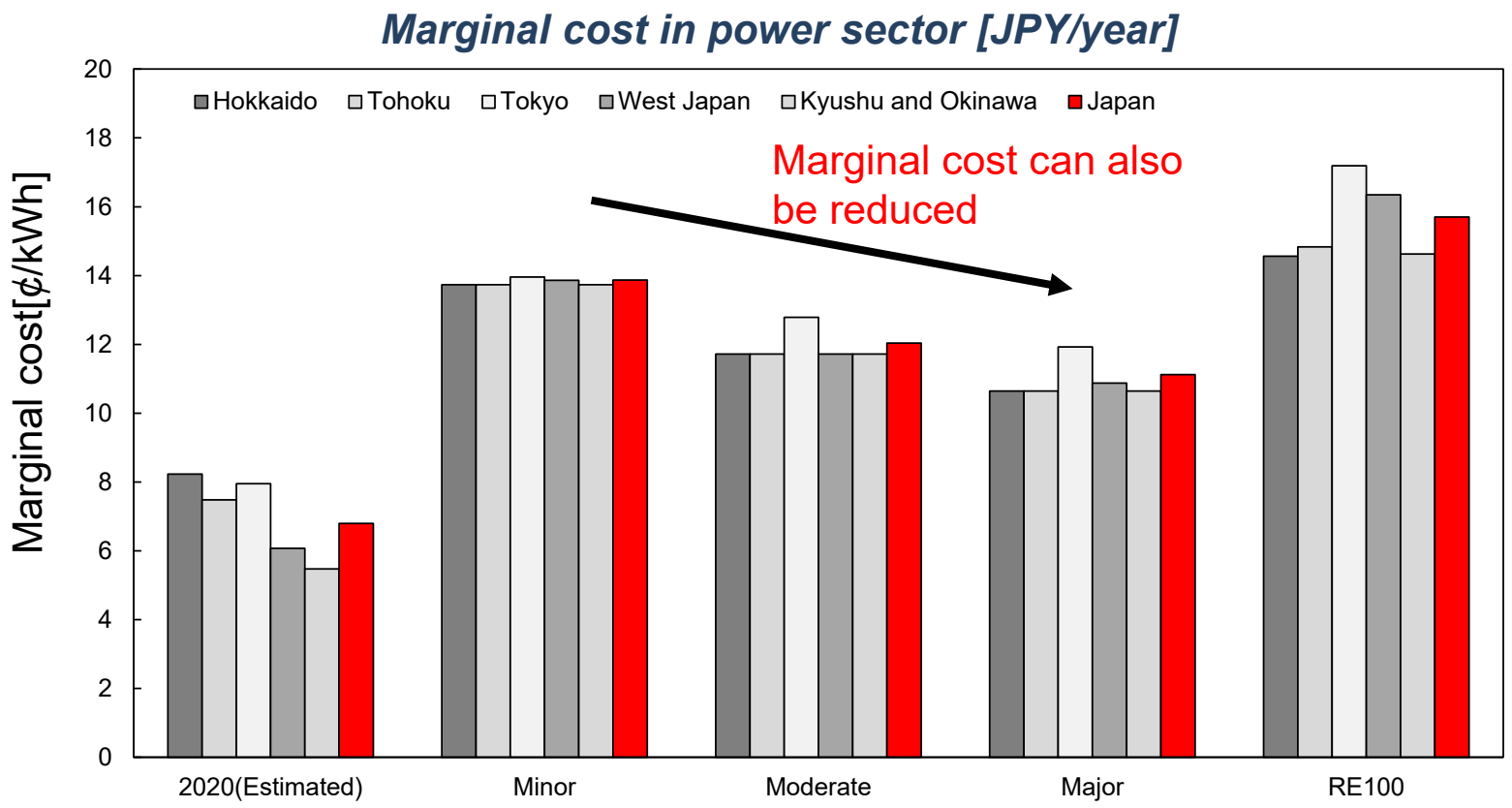
Annualized system cost in power sector was assessed.



As RE is allowed to be installed in Moderate or Major conflict area, system cost in power sector reduces because use of fuel decreases.
However, if a massive RE is installed (RE100), system cost will be increased.

Marginal cost in power sector

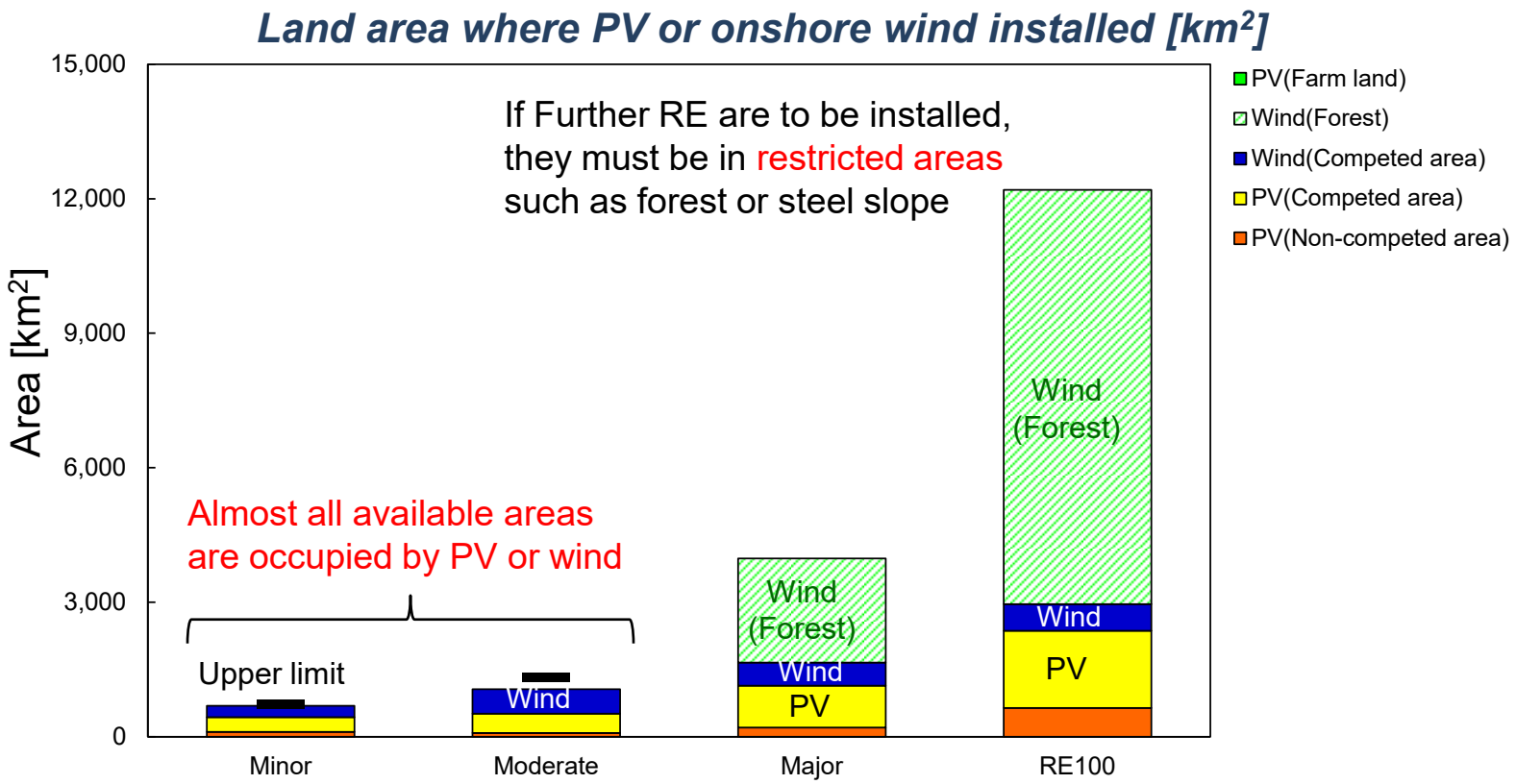
Marginal cost in power sector was assessed.



As RE is allowed to be installed in Moderate or Major conflict area, marginal cost in power sector is also reduced because the time when Ammonia or Gas+CCS power plant works decreases.

Land use impact

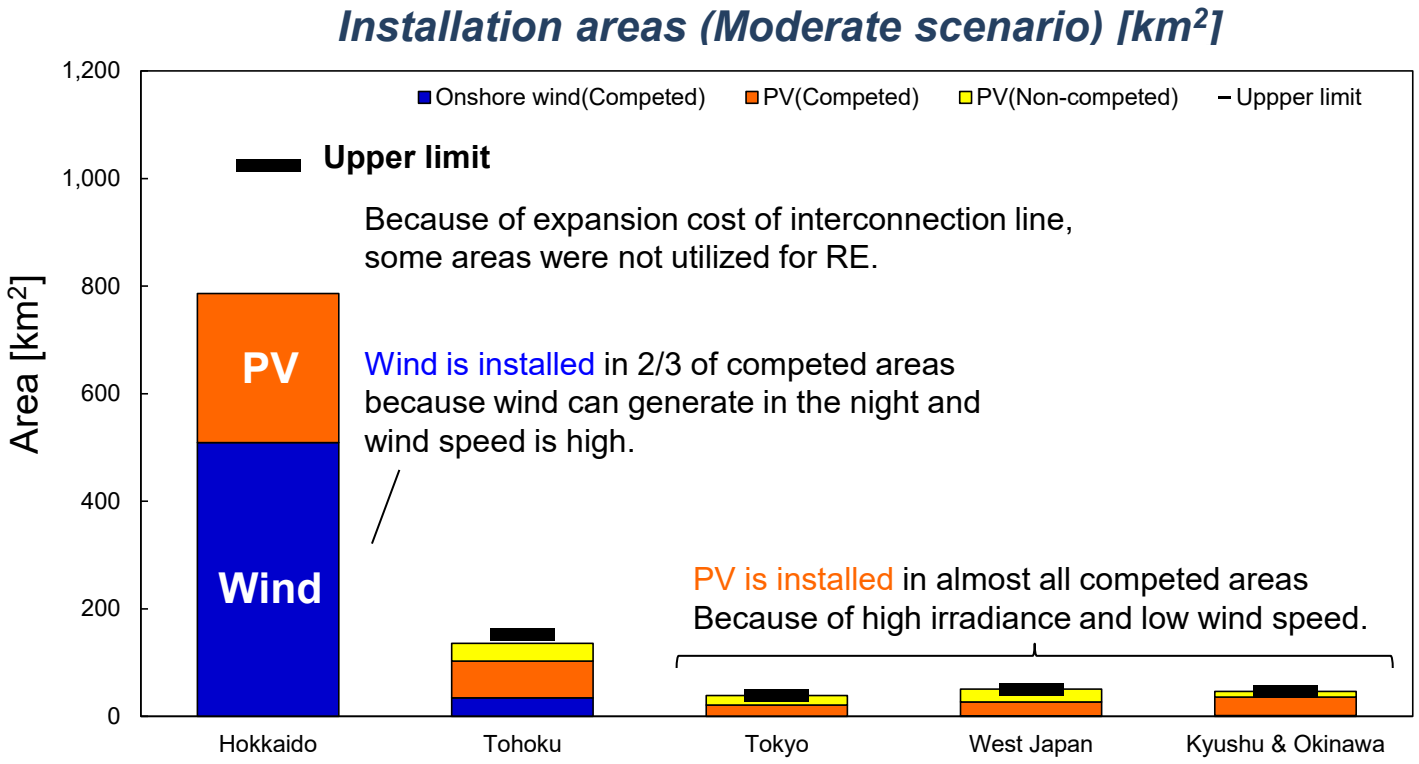
Area where PV onshore wind were installed and the upper limit were compared.



Even if thermal and nuclear power were utilized, almost all available areas (weed land etc.) are occupied by PV or onshore wind energy systems.
If further RE are to be installed, they must be installed in restricted areas.

Type of energy in competed areas (Moderate scenario)

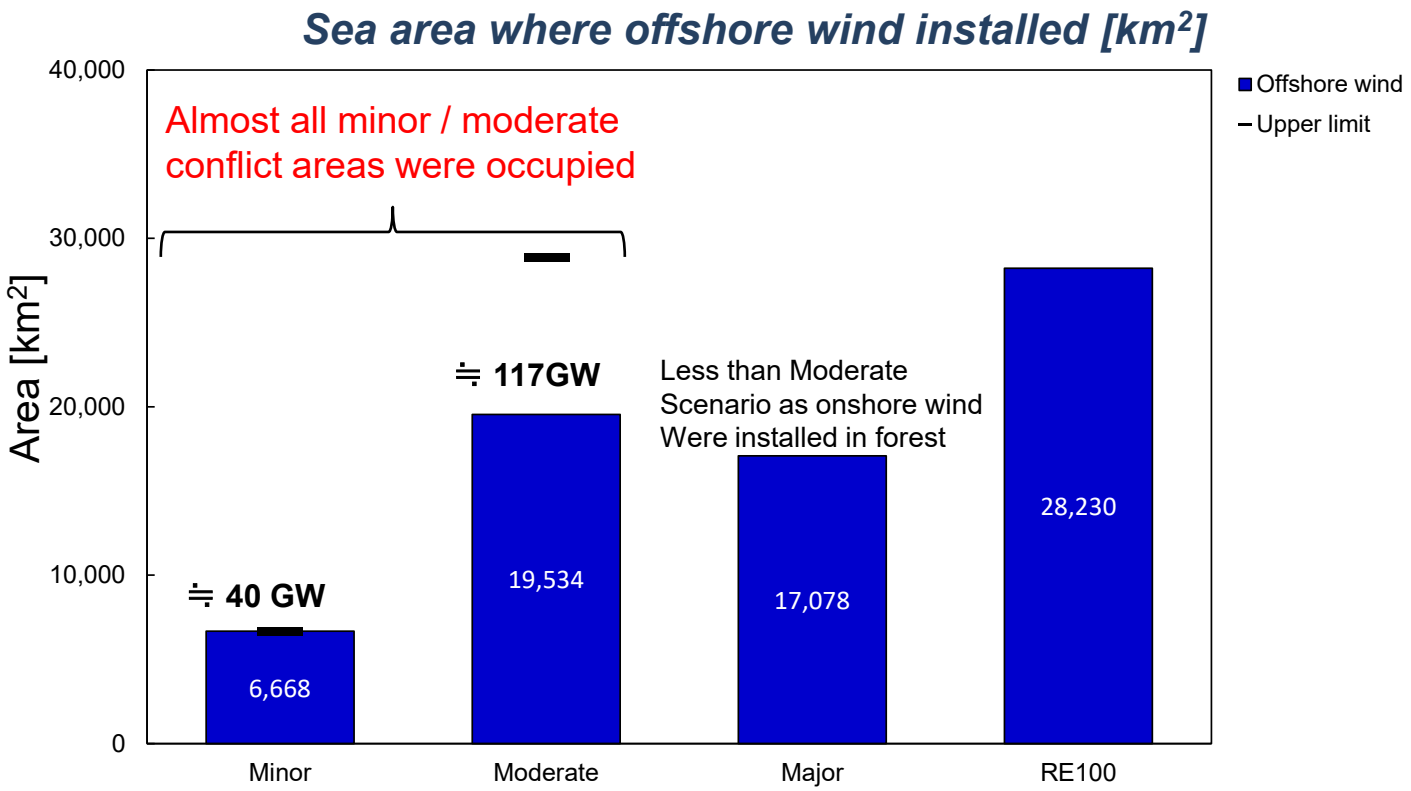
Type of energy in competed areas between PV and wind was shown in each grid area.



Suitable type of energy in competed areas between PV and wind energy is different because of supply-demand balance in each grid area or natural conditions.

Sea use impact

Area where offshore wind were installed, and the upper limit were compared.



In the Moderate scenario, 2/3 moderate conflicts area were occupied by wind turbines (≒ 11,700 turbines or 117 GW). As this is 6 times of current cumulative installed capacity in the world, see use impact is also large.

Conclusion

This study assessed the impact to energy system by spatial planning under CN.

Potential generated electricity in minor conflict areas

RE installed in the area with low probability of conflicts (Minor conflict) can cover approximately 50% of electricity supply. Thus, if social acceptance or competition between PV and wind are considered, generation by RE is insufficient for CN.

Cost impact

As renewable energy is allowed to be installed in Moderate or Major conflict area, system cost in power sector and marginal costs reduces because use of fuel decreases. However, if a massive number of renewable energies are to be installed, both costs will be increased.

Land / sea use impact

Even if thermal and nuclear power were utilized, almost all available areas (weed land etc.) are occupied by PV or onshore wind energy systems. If further energies to be installed, they must be installed in restricted areas such as forest or steep slope. Furthermore, see use impact is also critical.

Political implication

Establishing process of building consensus

This study showed installation in Moderate conflict areas can contribute to reduce average electricity costs or marginal costs. On the other hands, the process of building consensus has not been determined. Hence, it is important to establish process of building consensus.

Type of energy in priority areas

Spatial planning is currently considered for PV and wind separately. Despite this, this study showed suitable type of energy is different by the competed area between PV and wind energy. Hence, it is also important to consider spatial planning for PV and wind energy together.

Total amount of areas for PV and wind energies by spatial planning

If the percentage of renewable energies are significantly high, cost impact increased despites its land / sea use impact. Hence, it is important to determine the total amount of areas for PV or wind energies by considering both cost and land / sea use impact.

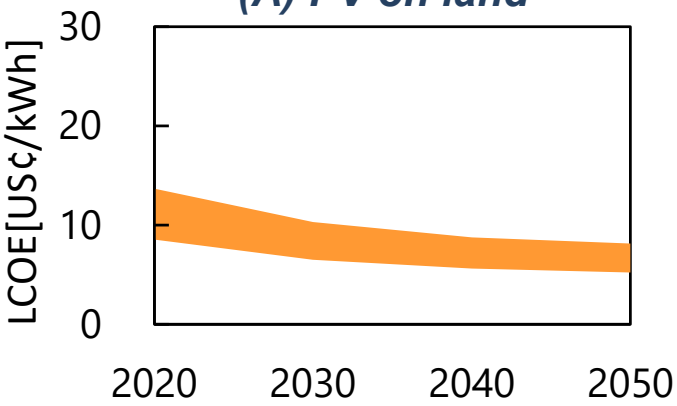
Reference

(Assumption) Levelized cost of electricity

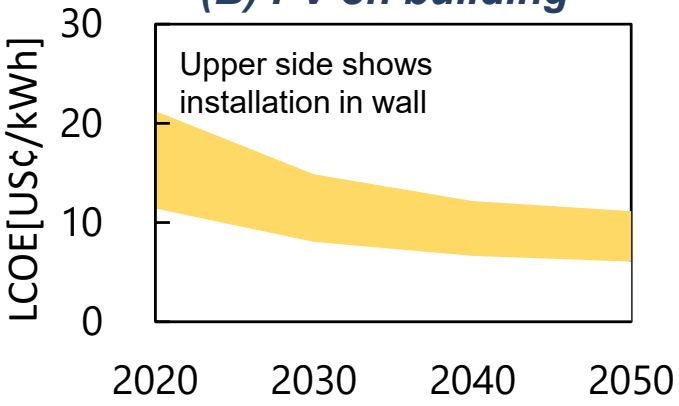
CAPEX of PV and wind energy assume to decrease based on learning curve by referring to Japanese Calculation Committee for Procurement Price.
This study considered irradiance and windspeed in installed areas.

Levelized cost of electricity

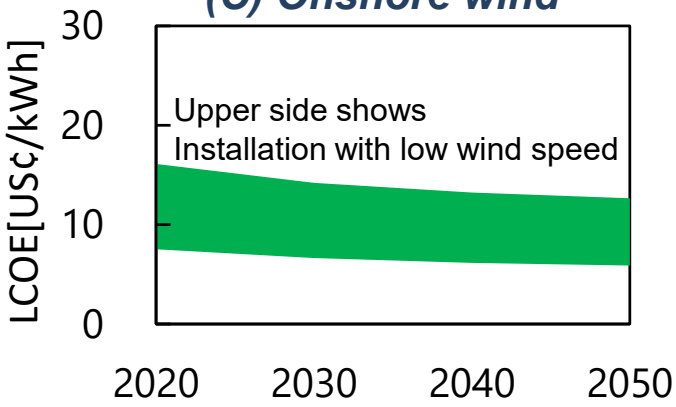
(A) PV on land



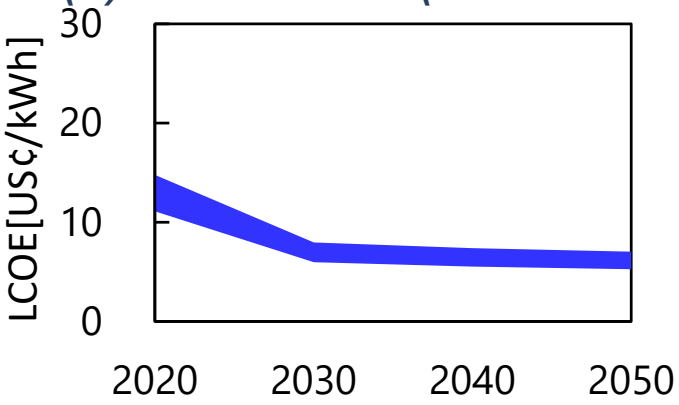
(B) PV on building



(C) Onshore wind



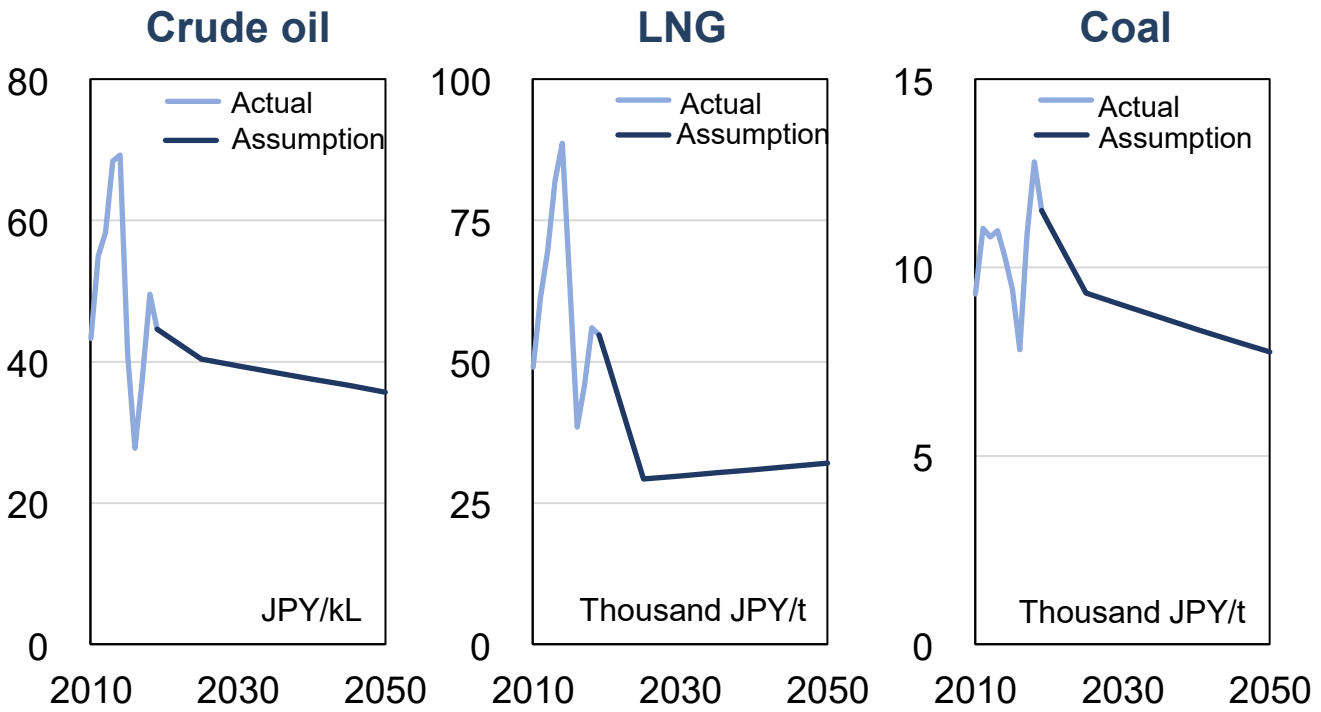
(D) Offshore wind(Bottom-fixed)



(Assumption) Fuel price

- Fossil fuel price was assumed by referring to IEA WEO2020(Sustainable Development Scenario). The price of these fuel will decrease compared to 2020's
- The price of H_2 and Ammonia was estimated by bottom-up approach by considering future technology innovation.

Fossil fuel

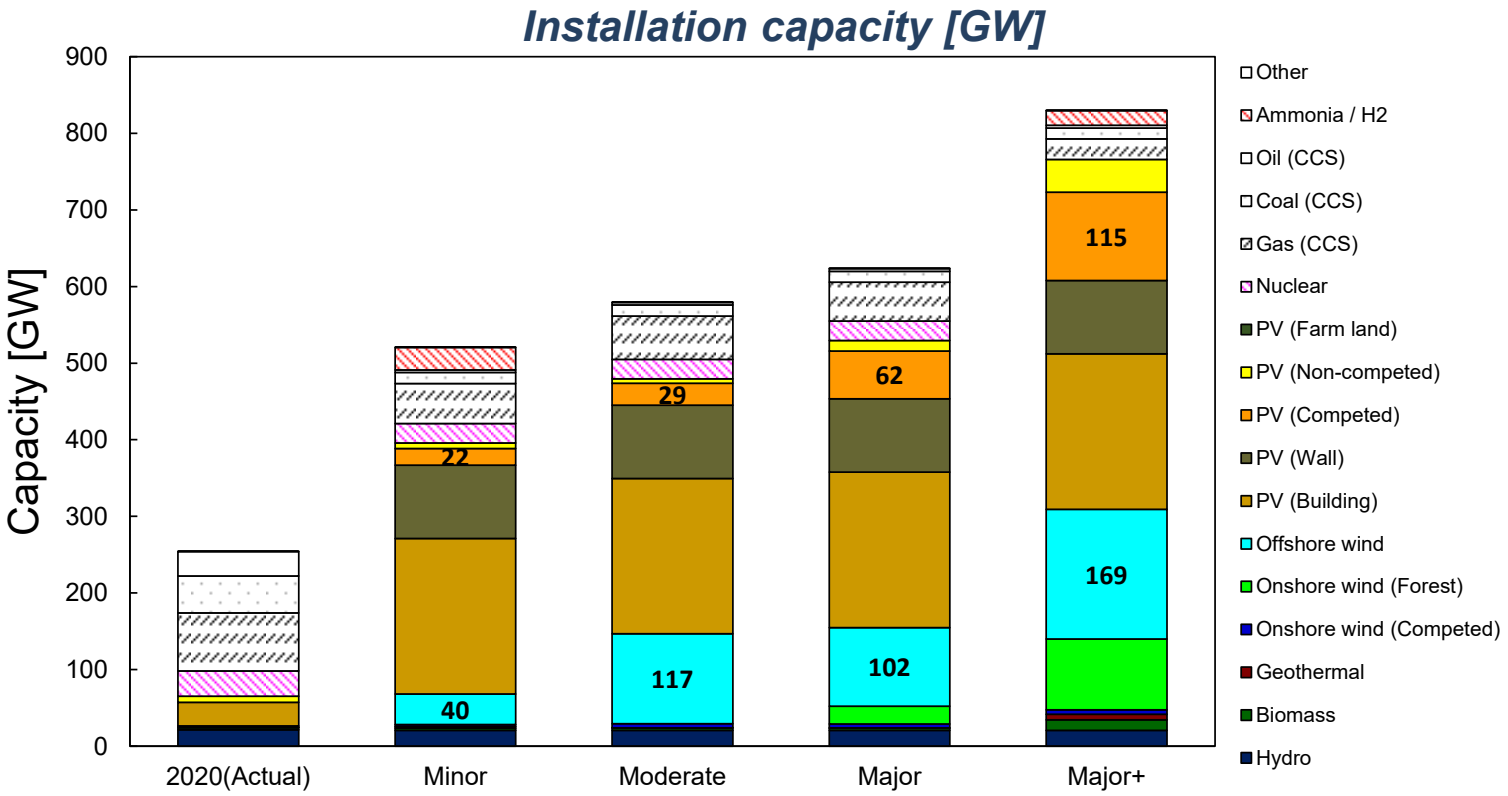


H_2・Ammonia

	(in 2050)
H_2	1,060USD/toe (27¢/Nm^3-H_2)
Ammonia	990USD/toe (398USD/t)
Synthetic methane	1,600USD/toe (40USD/Mbtu)
Synthetic petroleum	1,755USD/toe

(Result) Installation capacity

Installation capacities were assessed in each scenario.



Even if RE is installed in moderate conflict area, a massive installation of offshore wind (117 GW = 11,700 km^2) is required.
-> Sea use impact is not small even in Moderate conflict scenario.