Introducing a large-scale renewable energy supply system

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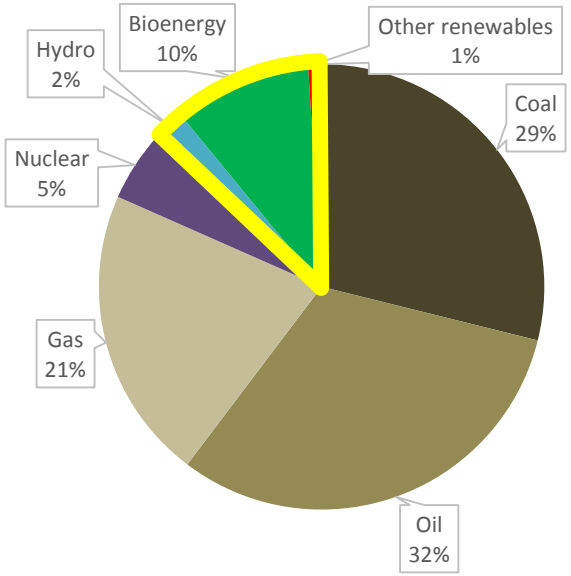
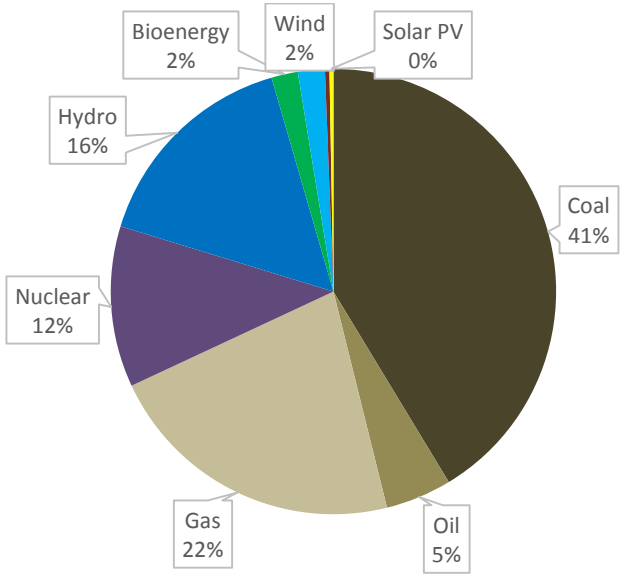
Renewable Energy in the World



Shares of primary energy supplies in 2011



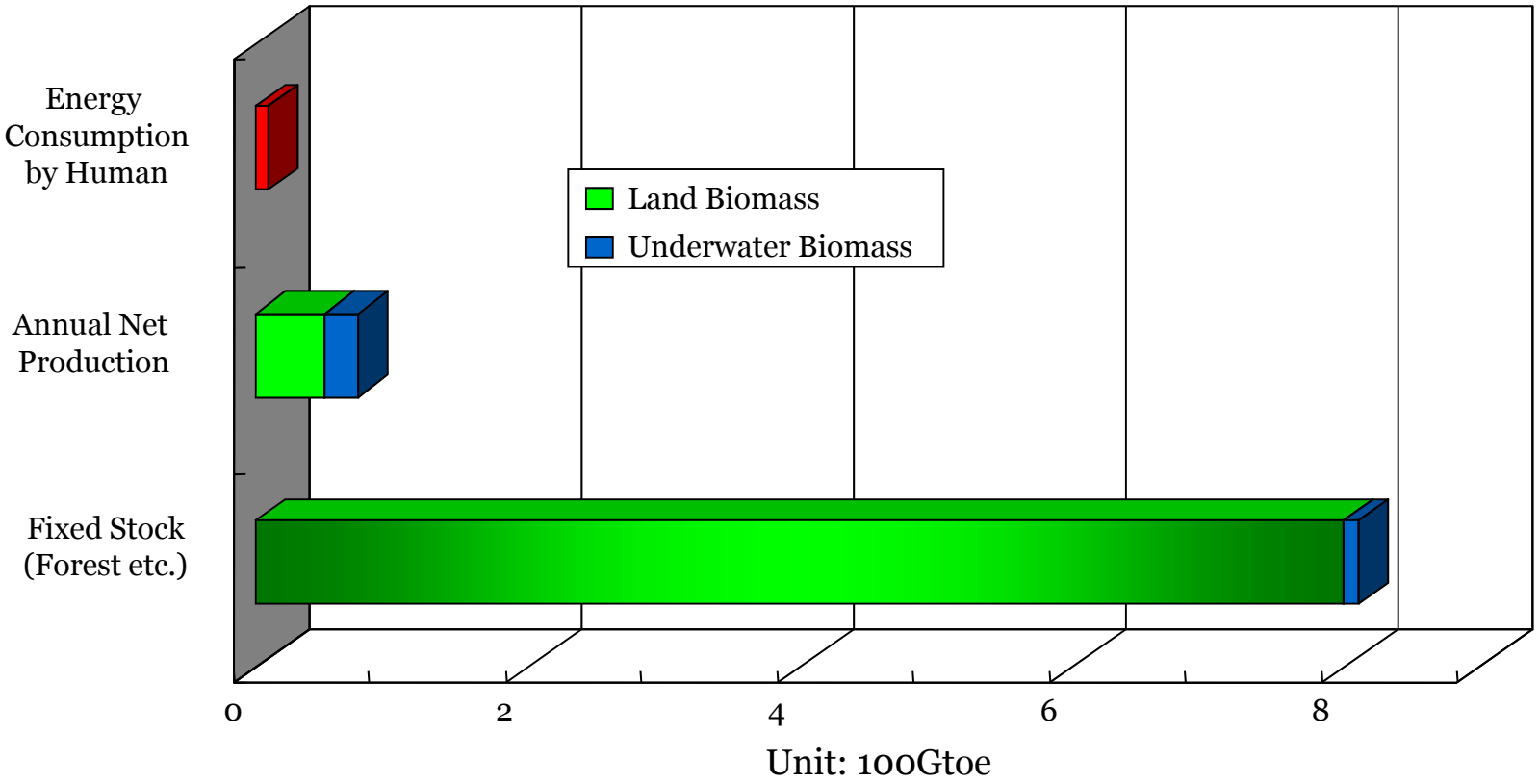
Shares of electricity generations in 2011

Types of Renewable Energy

- Stable type
  - Biomass
  - Hydro power generation
  - Geothermal power Generation
  - Oceanic Energy
    - Marine currents
    - Ocean thermal energy conversion

- Intermittent type
  - Wind power generation
  - Solar power generation
    - Photo-voltaics (PV)
    - Solar thermal power
  - • • •

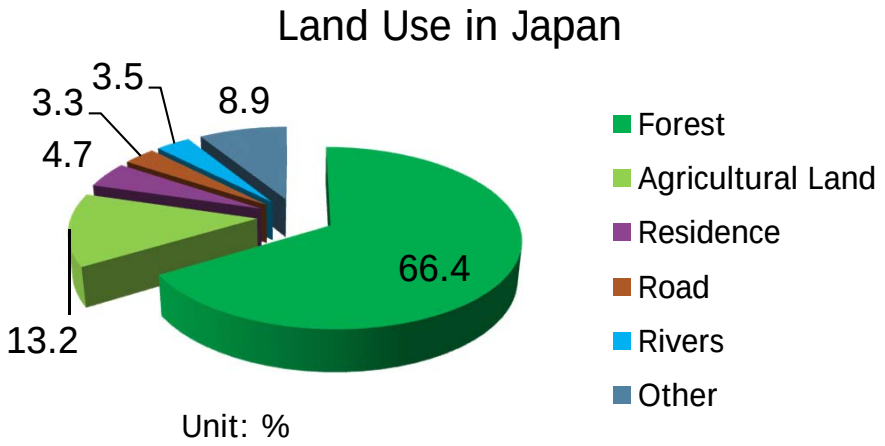
Biomass Energy (Production and Stock)



Biomass Energy in Japan

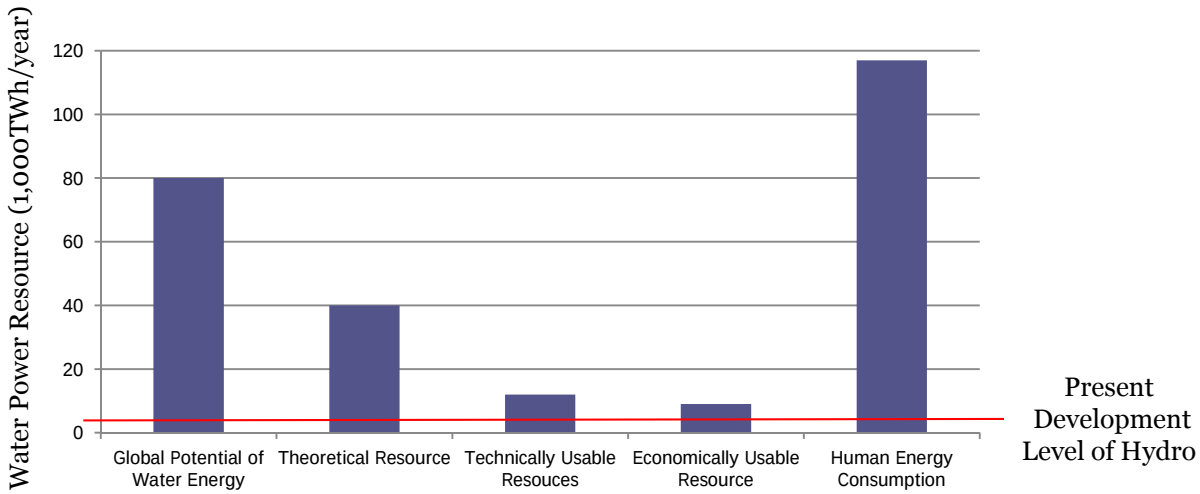
- Supply Potential of Forestry Biomass in Japan is estimated to be around 25 millions tones of oil equivalent annually.
  - This is about 5 % of the total energy requirements of Japan.

- The average conversion efficiency of photosynthesis is less than 1 %, whereas that of solar cells is around 15 %.



Hydro Power

- Development by 2009
  - 3,150TWh/year
  - Untapped resources are rich in Latin America and Siberia.
  - About 60% of water power resources in North America, Western Europe and Japan have been already developed.

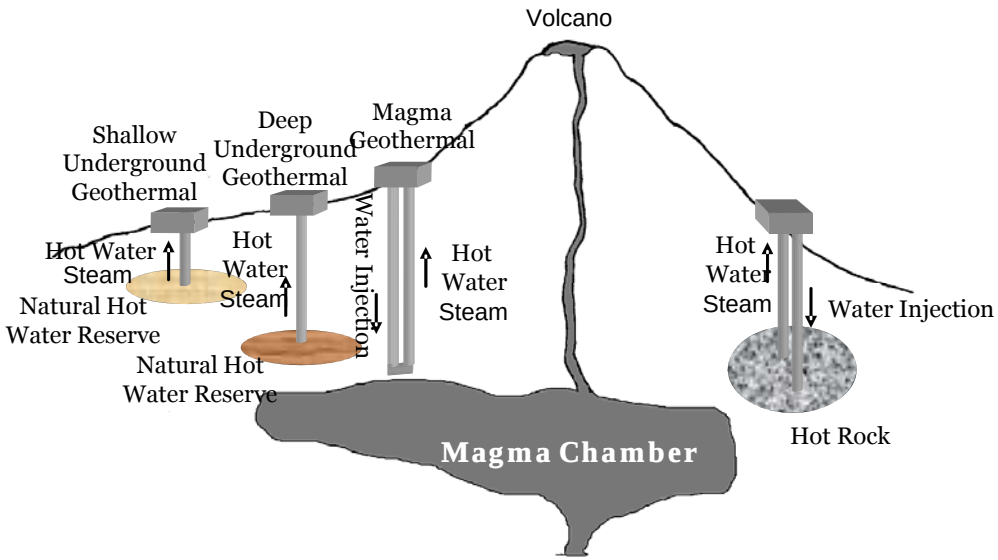


Geothermal Energy

- Geothermal power is power extracted from heat stored in the earth, and it originates mainly from radioactive decay of minerals.
  - The total geothermal power of the earth is about 3 times as large as human energy consumption. But most of it is emitted from sea bed to sea water.

Installed geothermal electric capacity as of 2010 (Top 10)

Country	Capacity (MW)
USA	3086
Philippines	1904
Indonesia	1197
Mexico	958
Italy	843
New Zealand	628
Iceland	575
Japan	536
El Salvador	204
Kenya	167



Geothermal Energy

- Geographical distribution
  - Geothermal energy resource can be found only in regions of specific geological structure, such as volcanic belts.
  - Prospective regions
    - Pacific Rims, Southern Europe, Iceland and East Caribbean Sea
- Resource

	today	Minimum	Maximum
Power[GW]	10	140	6,000
Energy[PWh/year]	0.05	1.0	40
Energy[Gtoe/year]	0.004	0.09	3.4

  - Geothermal Power Generation in Japan
    - Present capacity is about 0.5GW, and the potential is around 20GW.
  - Energy of a large scale volcanic eruption
    - The size of explosion energy is about 0.01Gtoe.
      - If the heat energy of erupted lava is included, the size of energy is around 0.1Gtoe.

Oceanic Energy

- Potential of oceanic energy resources
  - Marine current power
    - Marine current power P [W] can be calculated with the following equation.

$$P = \frac{1}{2}\rho S V^3$$

      where current cross section: S[m²], current speed: V[m/s], density :ρ [kg/m³]
    - The power of the Kuroshio current is 3~6GW.
      - current width: 250km, current depth: 1,000m, current speed: 0.3～0.4m/s
  - Ocean Thermal Energy Conversion (OTEC)
    - The power output P [W] of OTEC can be estimated with the following equation.

$$P = A\rho dc\frac{(T_H - T_L)}{365\times 24\times 3600\times Y}\times\frac{(T_H - T_L)}{T_H}$$

      - where Available ocean area: A[m²], depth of surface mixed layer: d[m], seawater density: ρ[kg/m³], specific heat: c [J/kg], thermo-haline circulation cycle of ocean: Y[year], temp. of surface water: T_H[K] and temp. of seawater at the seabed : T_L[K].
  - Estimated total potential of oceanic energy resources is around 7TW (5Gtoe/year).

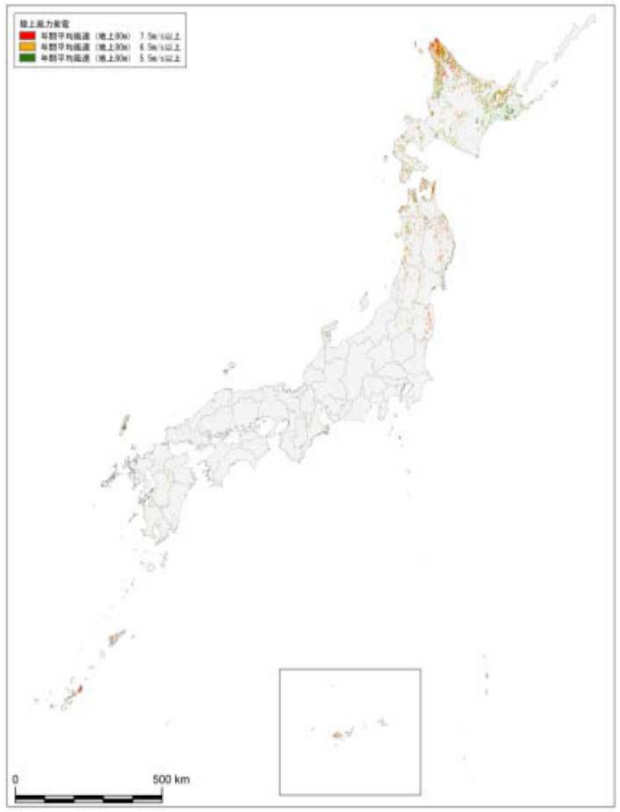
Wind Energy

- Wind Energy Resource of the World
  - Theoretical Resource: 100Gtoe/year
  - Technically Usable Resource 500PWh/year 43Gtoe/year
    - PWh=trillion kWh=10^{15}Wh
  - Practically Usable Resource 50PWh/year 4Gtoe/year
  - Exploited Resource in 2012 0.46PWh/year (capacity of 283GW)
    - Ref. World electricity consumption is about 20PWh/year.

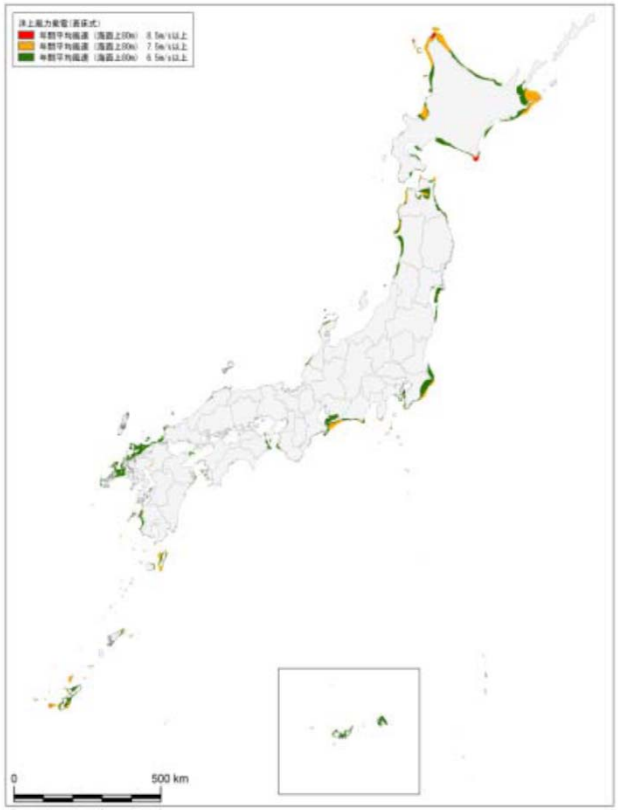
- Wind Energy Potential in Japan
  - 0.45~4.9PWh/year (Onshore: 70~300GW, Offshore: 61~1610GW)
    - Japanese total power generation is about 1.0PWh/year (270GW).

Wind Energy in Japan

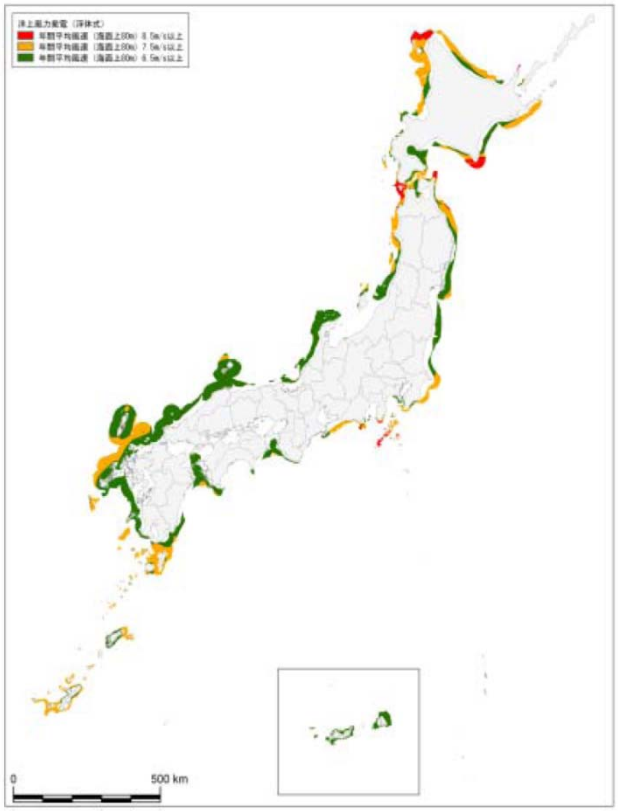
Wind Energy Potential Distribution



Onshore



Offshore Fixed-bottom

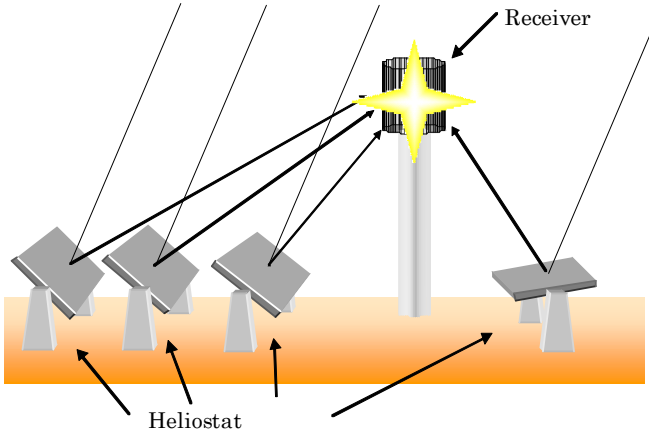


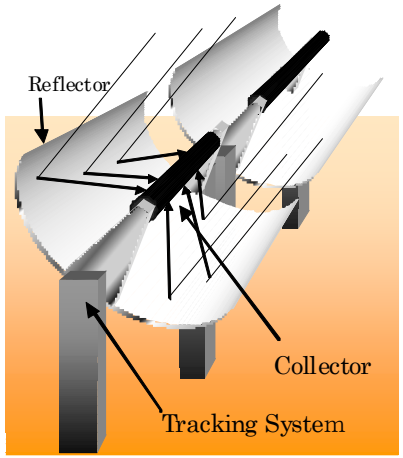
Offshore Floating

平成２１年度　再生可能エネルギー導入ポテンシャル調査報告書　（環境省）

Solar Energy

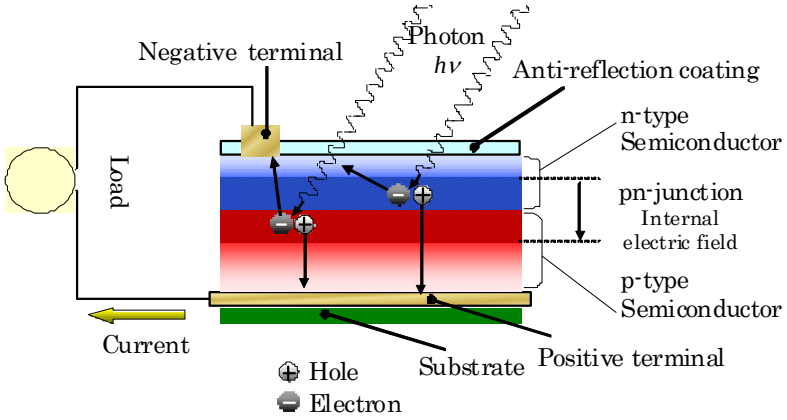
- Solar thermal





- Photo-voltaics

Silicon base	Monocrystalline silicon
	Polycrystalline silicon
	Amorphous silicon
	Microcrystalline silicon (thin film)
Other non-organic materials	Gallium arsenide multijunction
	Cadmium telluride
	Copper indium gallium selenide
Organic materials	Light-absorbing dyes
	Polymer film



Solar Energy in Japan

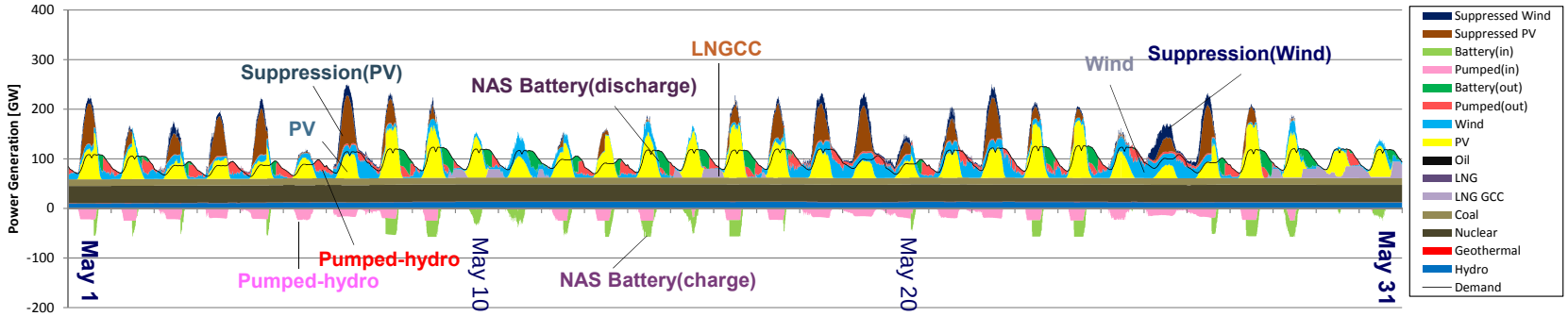
- If we expand solar cells on 5 % of our land area of Japan, we may obtain sufficient amount of energy supply without any fossil fuel import.
  - The share of agricultural land in Japan is 13.2 %.

- 1m² of PV generates 100～150kWh per year, and the sale of the electricity at 40yen/kWh will bring about the annual income of 4,000～6,000yen.
  - We can produce 500 g of high grade rice from 1m² of rice field, and can earn 300 yen/year.

Large-scale Integration of Variable Renewables in Japan (Simulation analysis)

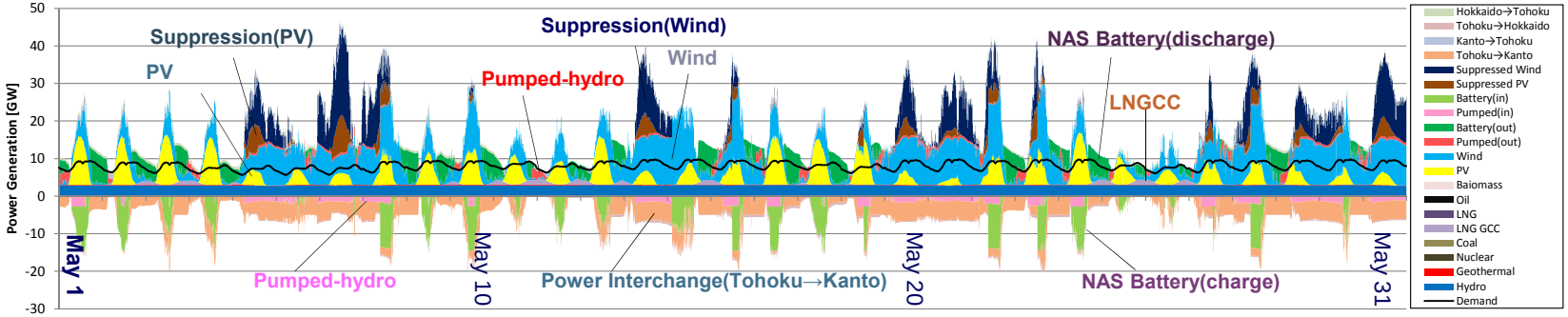
- Quick load following control by thermal power plant (e.g. LNGCC)
- Energy storage such as electricity storage(Li-ion, NAS etc.), hydrogen storage, pumped-hydro etc.
- Demand-side management (demand extension(EV, heat-pump water heater),BEMS, HEMS)
- Suppression control(PCS, Interactive communication)
- Reinforcement of transmission and distribution, nationwide grid control

Optimal Power Dispatch in Japan (May) (PV ratio(kWh):20%, Wind ratio(kWh):10%)



(Source) R.Komiyama,Y.Fujii, *IEEJ Transaction B*,Vol.132,No.7,pp.639-647,2012

Optimal Power Dispatch in Tohoku (May) (Wind ratio(kWh):10%)

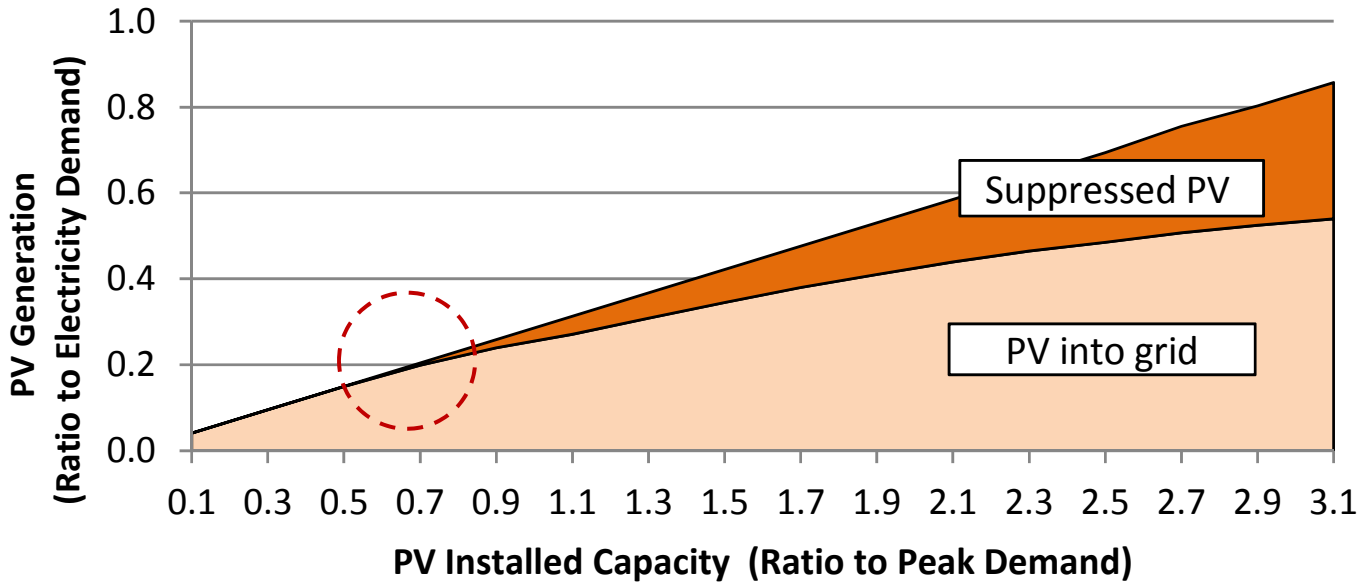


(Source) R.Komiyama,S.Shibata,Y.Fujii, *IEEJ Transaction B*,Vol.133,No.3,pp.263-270,2013

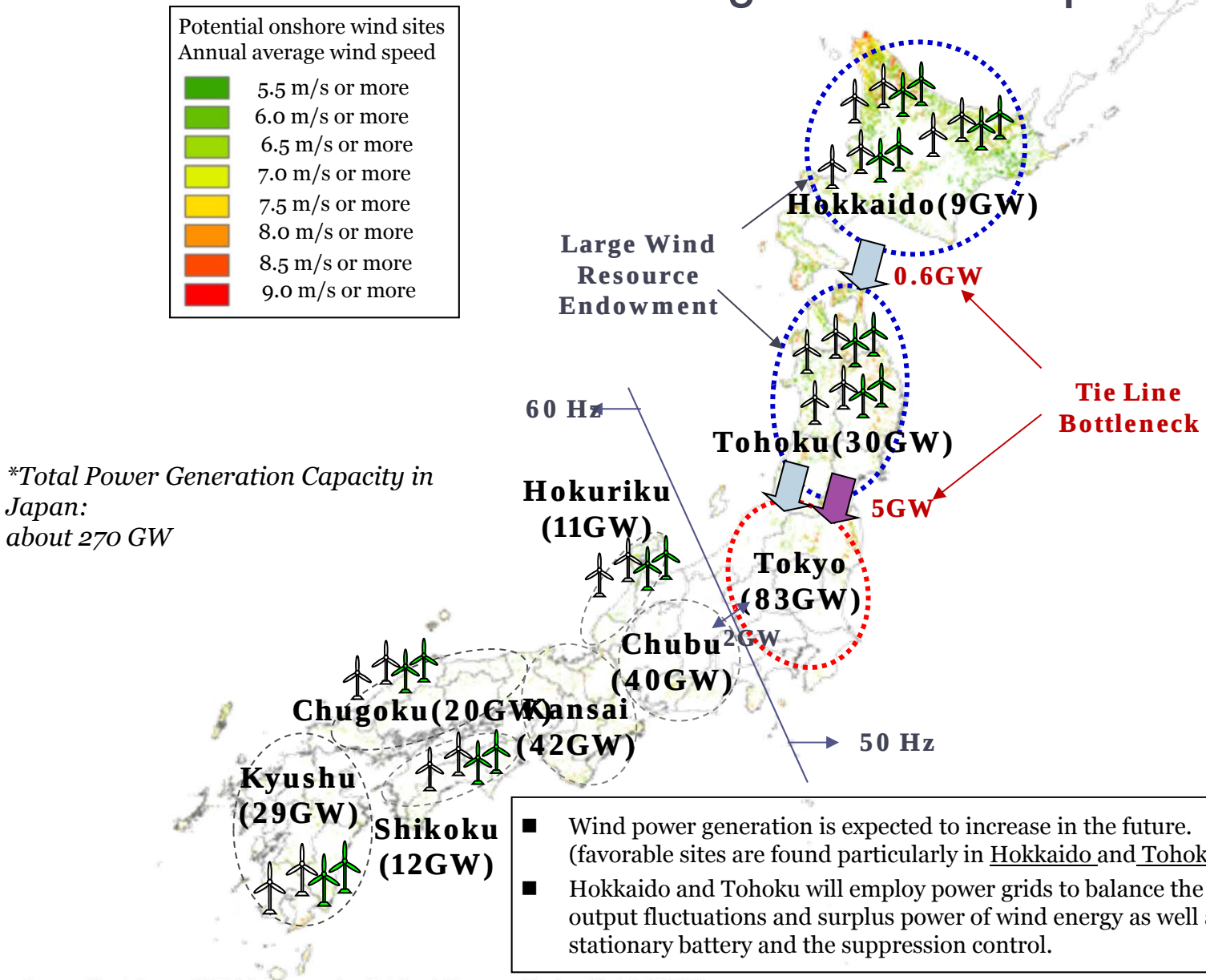
Large-scale Integration of PV System in Japan (Simulation analysis)

- As installed PV capacity increases up to almost the same scale of peak demand or 20 percent in total power generation, PV output is integrated into the grid almost without the suppression control. When the PV installs at more than that level, the ratio of suppressed PV shows a significant increase.
- The reason to suppress PV output instead of storing its surplus output in the battery is attributable to the high battery cost. And it should be recognized that the growth of PV integration into the grid shows slow-down by expanding PV capacity at more than the same scale of the peak demand.

PV integrated into the grid and its suppression in different PV capacity.



Potential of Wind Power Integration in Japan



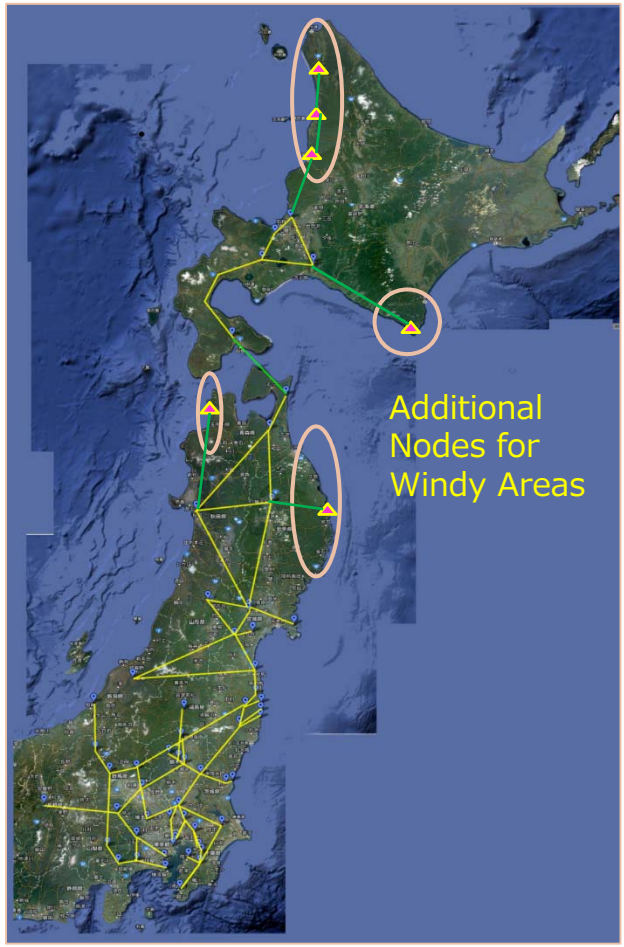
**Total Power Generation Capacity in Japan: about 270 GW*

- Wind power generation is expected to increase in the future. (favorable sites are found particularly in Hokkaido and Tohoku.)
- Hokkaido and Tohoku will employ power grids to balance the output fluctuations and surplus power of wind energy as well as stationary battery and the suppression control.

(Source) Compiled from "2010 Report of Wind Power Potential," METI

Optimal Power System Model for east Japan with geographical distribution

- The modeled power system network has
  - 63 Nodes and
  - 78 Branches.
- Optimal Power flows at 10 minute-intervals are calculated with DC power flow approximation method.
- Linear programming technique is employed as an optimization method.
- The number of the constraints of the linear programming problem is about 70 millions.



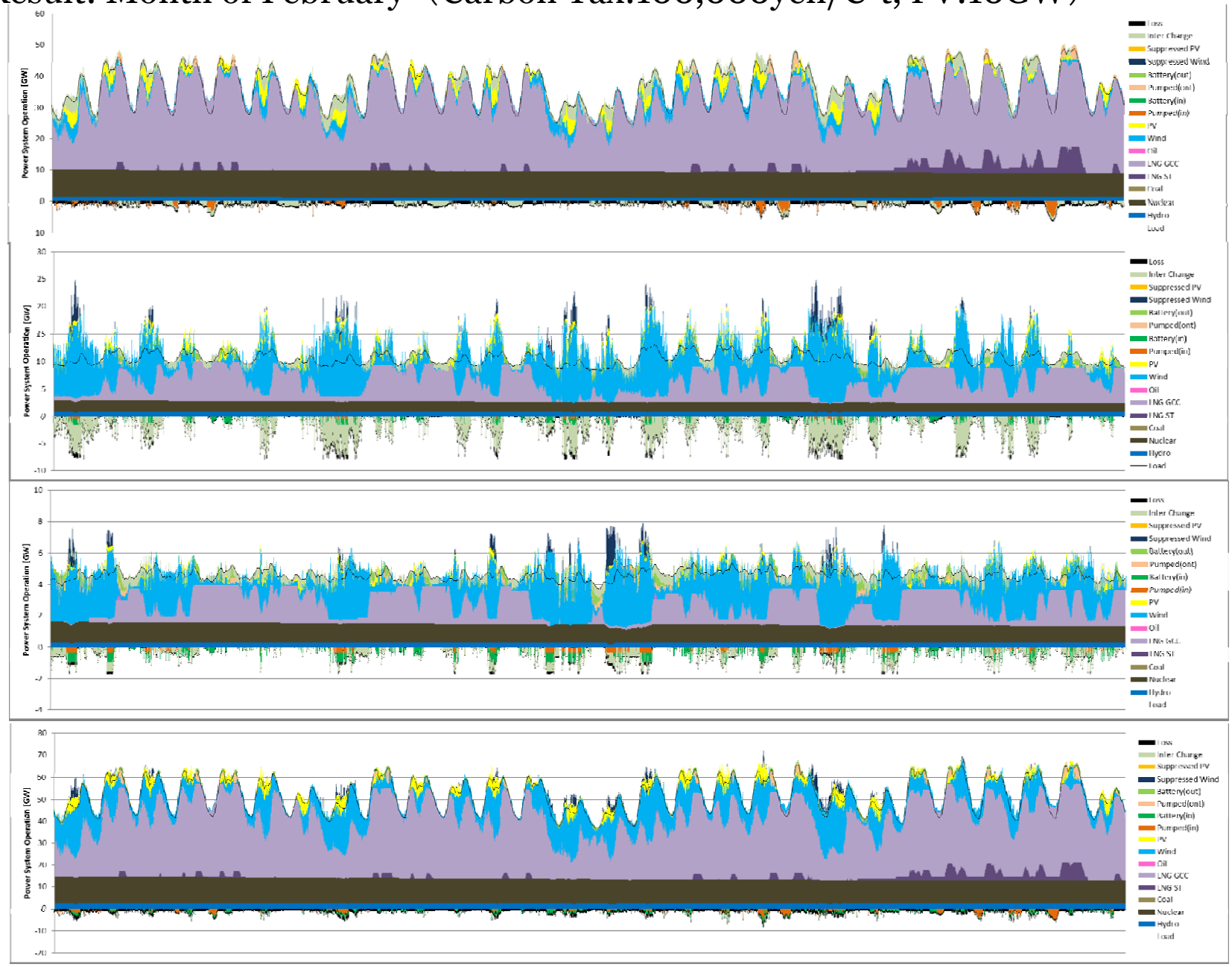
Tentative Result: Month of February（Carbon Tax:100,000yen/C-t, PV:10GW）

Kanto

Tohoku

Hokkaido

East Japan Total



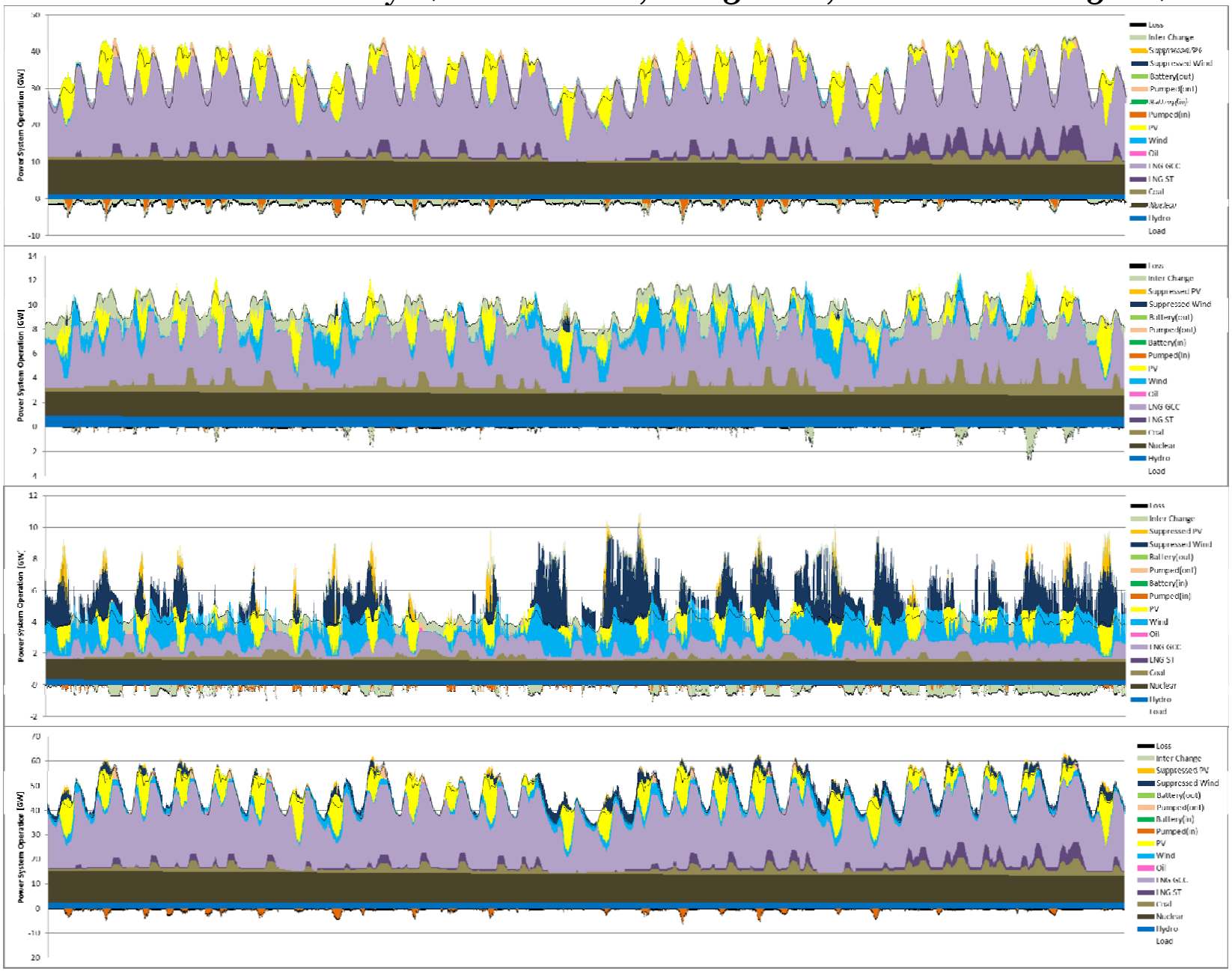
Tentative Result: Month of February（Wind: 11GW, PV: 30GW, RE Max share: 50%）

Kanto

Tohoku

Hokkaido

East Japan Total



Concluding Remarks

- Stable Renewables
  - Biomass, hydro and geothermal energy are stable renewables, but the available amounts of those in Japan are fairly limited.

- Intermittent Renewables
  - There seems to be sufficient amounts of available resources of wind and solar energy even in Japan. The problems associated with the large-scale introduction of those resources are accommodation measures to integrate them in the national power grid. The specific measures are listed below.
    - Quick load following control by thermal power plants
    - Reinforcement of transmission and distribution, nationwide grid control
    - Suppression of excessive outputs
    - Demand-side management
    - Deployment of electricity storage
  - The possibility of intermittent renewable energy dominant systems is highly dependent on the electricity storage cost. The uncertainty about the costs makes the long-term scenario of those renewables very unclear.