Assessment of Large Scale Penetration of Variable Renewables in Japan Considering Suppression of Power Fluctuation

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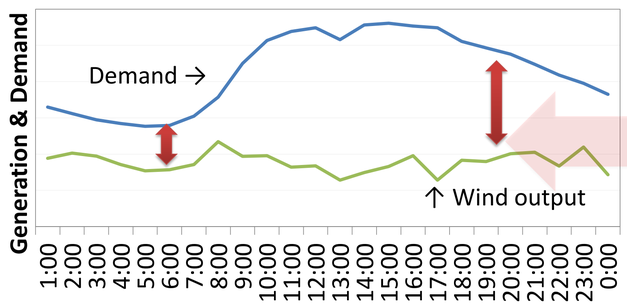
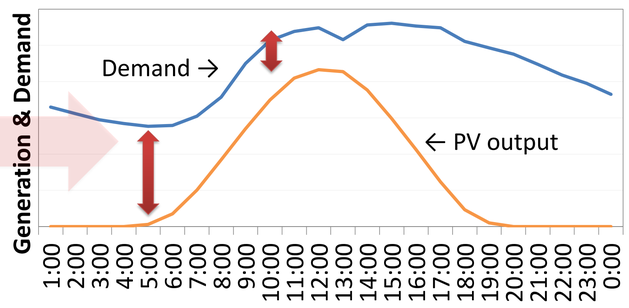
Introduction

Increase of interests in renewables
GHG emission reduction, Energy security, Uncertain nuclear policy

Issue of renewables
Generation cost, Long-term/Short-term power fluctuation



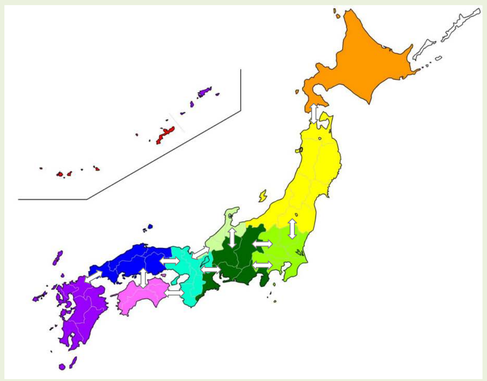
How to fill the gap?
- Backup by fire power plants → CO_2 emission
- Introduce battery → Increase of cost
- Parallel off of renewables → Decrease of benefit



Objectives: To estimate generation mix & costs under various penetration rate of renewable energy
To estimate suppression of power fluctuation under various penetration rate of renewable energy

Method

Multi-regional generation planning model



Type: Bottom-up technology selection model
Objective function: minimize total system cost
Region: 10 region w/ interregional transmission line
Year: 2030
Demand pattern: 19 representative days, 1 hour step
Countermeasures against power fluctuation:
- Load frequency control (LFC)
- Parallel off
- Battery for long –term fluctuation (SBST)
- Battery for short-term fluctuation (SBLT)

→ **Constr. Balancing short-term fluctuation** $\mathrm{LFC\_}S_{r,d,h} \geq \mathrm{LFC\_}D_{r,d,h}$

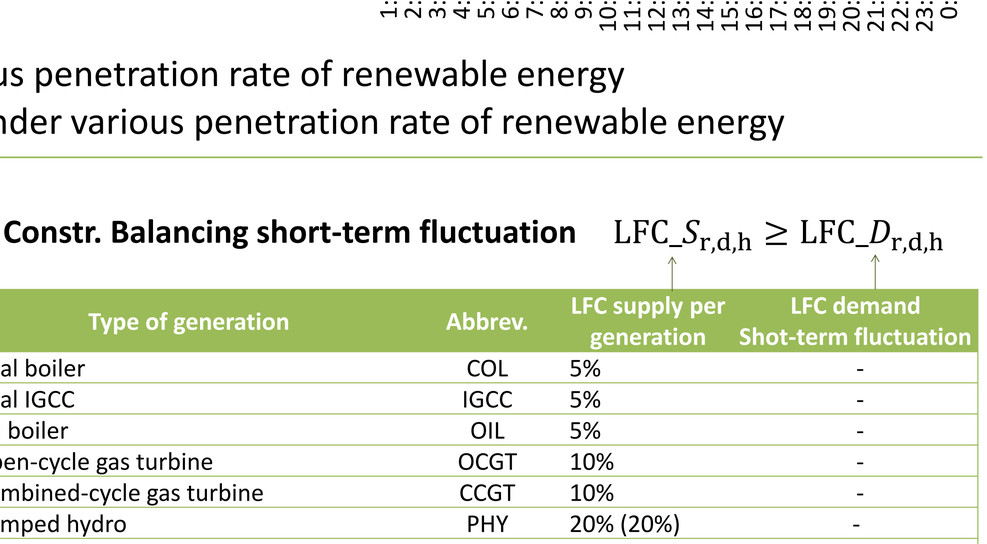
Type of generation	Abbrev.	LFC supply per generation	LFC demand Shot-term fluctuation
Coal boiler	COL	5%	-
Coal IGCC	IGCC	5%	-
Oil boiler	OIL	5%	-
Open-cycle gas turbine	OCGT	10%	-
Combined-cycle gas turbine	CCGT	10%	-
Pumped hydro	PHY	20% (20%)	-
Solar photovoltaic	PV	-	10% per generation
Wind power w/o battery	WT	-	15% per capacity
Wind power w/ SBST(50% suppression)	WT w/SBST1	-	7.5% per capacity
Wind power w/ SBST(100% suppression)	WT w/SBST2	-	0% per capacity
Battery for long-term fluctuation	SBLT	20% (20%)	-

Electricity demand: 1005TWh, **Nuclear:** max 344TWh, **Energy price:** Reference case in WEO2009
45 emission case: NO emission target, +60% to -80% of emission in 1990 (5% step), -80% to -95% of emission in 1990 (1% step)

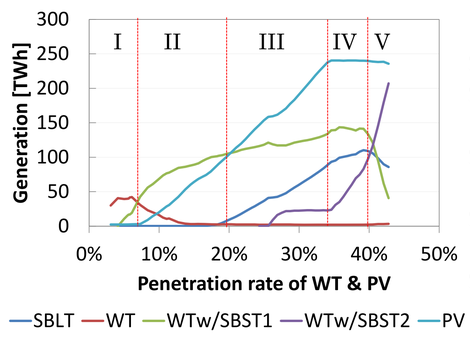
Results : impact of power fluctuation

Generation mix & cost

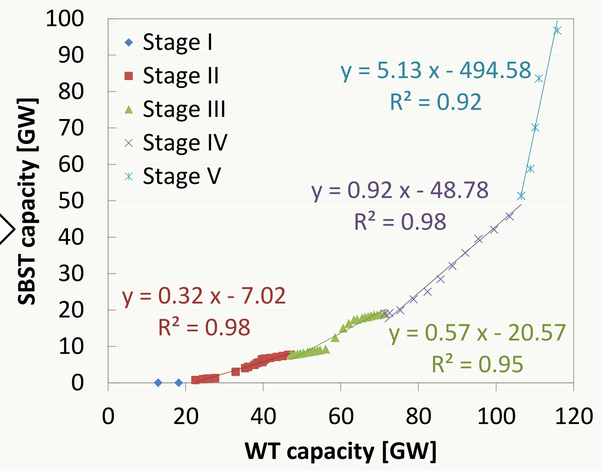
- No emission target case: 484Mt-CO_2 (+67% of 1990)
- Main energy sources would change : COL → CCGT → WT&PV w/ SB
- 40% of electricity come from variable renewables in -90% emission case.
- WT w/ SBST2 (100% suppression of short-term fluctuation) will drastically introduced in the case stronger than -70% emission target.
- Generation cost in 90% emission reduction case → 1.7 times higher than that in NO emission target case.



For analysis… distinguished penetration stage

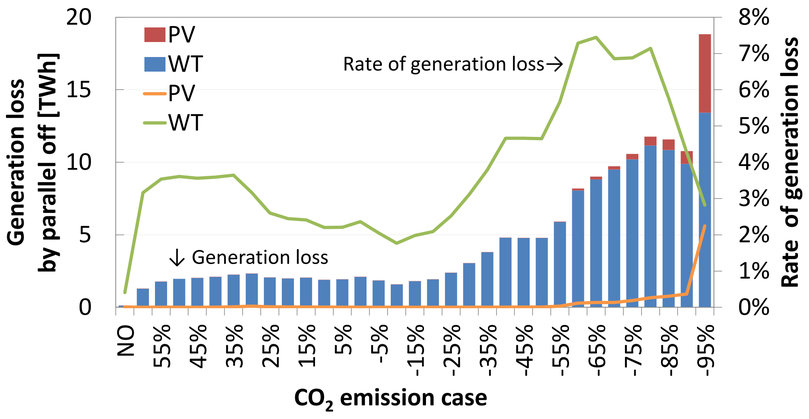


Stage I : WT w/o SB
Stage II : WT w/ SBST1 & PV
↓ *Long-term fluctuation increased*
Stage III : Stage II + SBLT
↓ *PV saturation*
Stage IV : WT w/ SBST2
↓ *LFC supply from GTCC reduced*
Stage V: WT w/ SBST2



Installed capacity of battery

- Regression analysis with simulation results
- Required capacity of SBST per 1GW penetration of WT was estimated
- Short-term fluctuation could be balanced without SBST if WT capacity was less than 20GW
- 5GW of SBST would be necessary for 1GW of additional WT in stage V because LFC supply from fire power plants was restricted.



Parallel off of renewables

- NO to +30% case: WT w/o SB was increased → Parallel off would increase
- +30% to -15% case: WT w/o SB was substituted by WT w/ SBST1 → Parallel off would decrease
- -15% to -70% case: WT w/ SB ST1 was increased → Parallel off would increase
  - ➢ In -65% case, more than 7% of electricity generation was lost.
- -70% to- 95% case: WT w/ SBST2 was increased → Parallel off would decrease
- Parallel off of PV was increased in the case stronger than -90% emission target

Summary & next step

- Generation mix : 40% of electricity would be supplied by variable renewables in 90% emission reduction case.
- Generation cost: in 90% emission reduction case → 1.7 times higher than that in NO emission target case.
- Suppression of power fluctuation: Capacity of battery & parallel off would increase drastically if LFC from fire plants were restricted
- Impact assessment of daily load curve change and geographical smoothing effect would be next research step

References 1) H. Shiraki, S. Ashina, Y. Kameyama, Y. Moriguchi, S. Hashimoto; Energy and Resources, 33-1, (2012), 1-10. (in Japanese) 2) S. Ashina, J. Fujino; (2008) Energy and Resources, 29-1, (2008), 1-7. (in Japanese)

The research works have been conducted with Dr. Ashina, Prof. Kameyama, Prof. Tasaki, Prof. Matsuhashi, and Prof. Moriguchi.