APERC Workshop
The 48th APEC Energy Working Group and Associated Meetings
Port Moresby, Papua New Guinea, 17 November, 2014

3-3. Quantitative Analysis of Potential Benefits of Power Grid Interconnection in Northeast Asia

Takashi Otsuki
Researcher, Asia Pacific Energy Research Centre (APERC)

Asia-Pacific
Economic Cooperation

Outline

Introduction

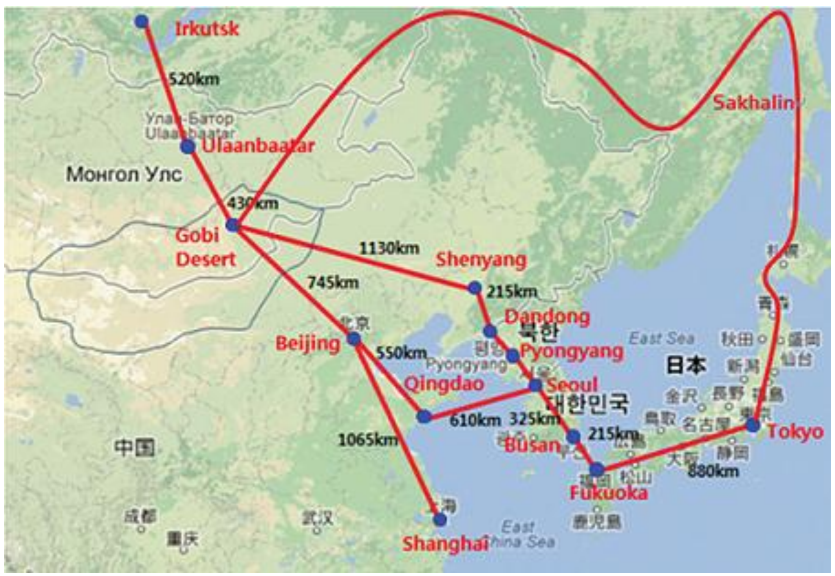
- Electricity trade is bringing various benefits to several parts of the world, including Europe and ASEAN.
- Due to current policies encouraging self-sufficiency, power grid interconnection is very limited in Northeast Asia.
- However, several recent events in the region have made regional power interconnection more attractive in terms of promoting renewable energy and enhancing resilience to emergency situations.
  - **Fukushima Dai-ichi nuclear accident in Japan** (March 2011).
  - **Power shortage and rolling blackouts in Korea** (September 2011).
  - **Unhealthy air quality in China** over the past several years.

Proposed concepts of interconnection

- Several concepts of grid interconnection were proposed by several organizations, including: EC, KEPCO(Korea), EN+(Russia) and Softbank(Japan).

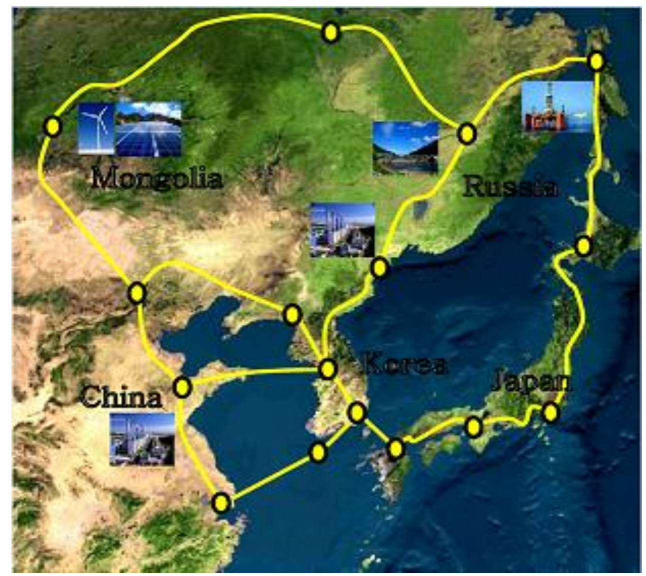
Proposed concepts (example):

Energy Charter



Source: "Gobitech and Asian Super Grid for Renewable Energies in Northeast Asia", Energy Charter (2014)

KEPCO (Korea)



Source: "KEPCO's Future Plans of Northeast Asia Supergrid", KEPCO (June, 2014)

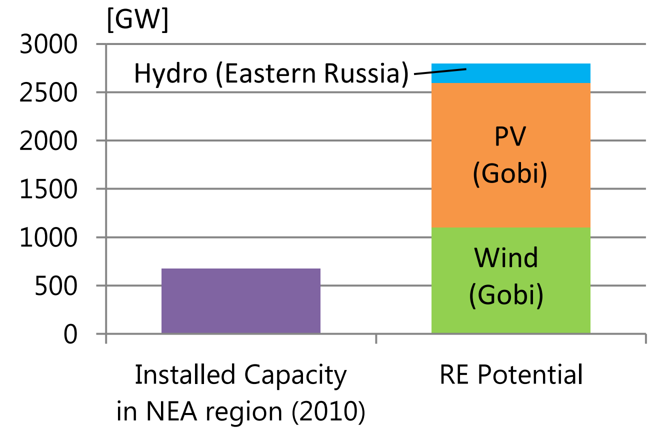
Objective

- This study macroscopically examine the potential benefits of connecting power grids in NEA* region, using a multi-regional power system model

*NEA region in the study: North China grid, China northeast grid, Japan, Korea, Russia Fareast grid

Environmental

- ✓ **CO_2 emissions reduction** by utilizing wind/solar resource in Gobi desert area and hydro resources in Eastern Russia, etc.



Source: Energy Charter(2014), IEA(2003), APERC(2014)

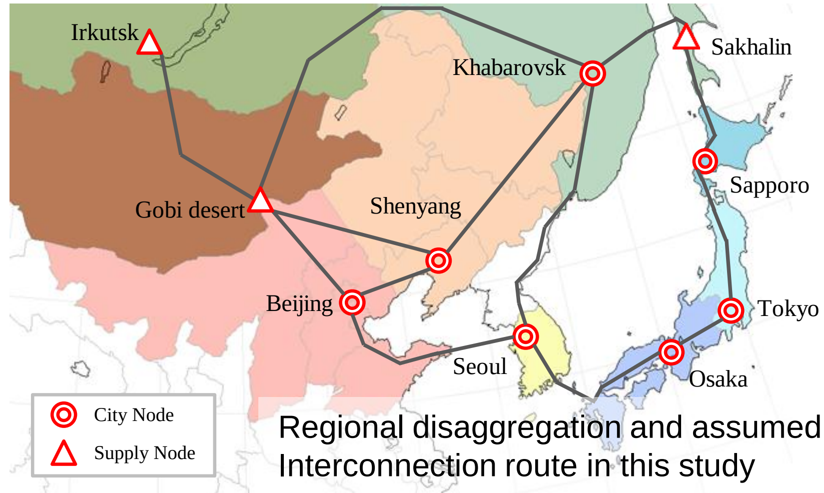
Economic

- ✓ **Cost saving** by providing access to cheap electricity
- ✓ Enhancing resilience to power supply shortage, etc.

Overview of the model

Multi-regional Power System Model

- **LP** Model: Single Period Cost Optimization.
- **Single year** model.
- Representative **hourly load curve** for **five seasons** are considered.
  (Summer-Peak, Summer-Average, Winter-Peak, Winter-Average, Intermediate)



Regional disaggregation and assumed Interconnection route in this study

Objective Function

$$Min.\ System\ cost = Capital\ cost + Fuel\ cost + O\&M\ cost + Carbon\ cost$$

Technology

- Coal-fired
- Gas-fired
- Oil-fired
- Nuclear
- Hydro
- Wind
- PV
- Pumped Hydro
- HV line/Cable

City Node

- China-North
- China-Northeast
- Japan-Hokkaido
- Japan-East
- Japan-West
- Korea
- Russia-Fareast

Supply Node

- Gobi Desert Area
- Russia-Siberia
- Russia-Sakhalin

Overview of the model

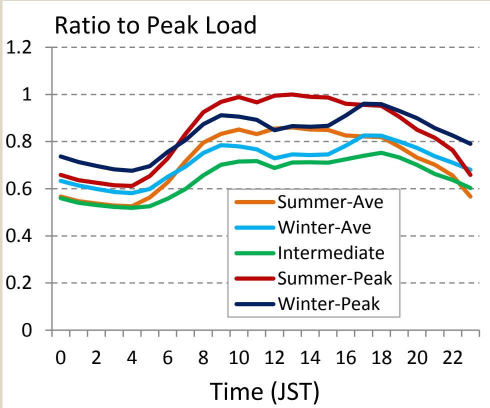
Constraints

(e.g.) Electricity supply demand balance

Supply and demand are balanced based on hourly load curve for 5 season types

$$\sum_{p} xp_{p,s,t} + \sum_{r}\sum_{l}(xtx_{r,l,s,t} \cdot TXE_{r,l} - xtx_{r,l,s,t}) + \sum_{st}(xdc_{r,st,s,t} - xch_{r,st,s,t}) = LOAD_{s,t}$$

$xp_{p,s,t}$: Output of power plant type *p* at time *t* in season *s* [MW]
$xtx_{r,l,s,t}$: Transmitted power of line type *l* from region *r* at time *t* in season *s* [MW]
$xdc_{r,st,s,t}$: Electricity discharge of storage facility type *st* at time *t* in season *s* [MW]
$xch_{r,st,s,t}$: Electricity charge of storage facility type *st* at time *t* in season *s* [MW]
$TXE_{r,l}$: transmission efficiency of line type *l* from region *r*
$LOAD_{s,t}$: Electricity load at time *t* in season *s* [MW]



Other constraints

- Reserve margin constraint
- Load following constraint
- Max. availability constraint
- Minimum output constraint for thermal power plant
- Capacity additions constraint
- Upper bound constraint for power imports, etc.

Simulation of NEA Grids in 2030: 4 scenarios

1. BAU scenario: No new grid interconnection.
2. OPT scenario: Grid interconnection allowed (Cost optimized).
3. ASG scenario: Proposed Gobitec/ASG transmission capacity+Cost optimized, 50 GW PV and 50 GW wind in Gobi region
4. RES scenario: ASG scenario condition + additional hydro potential in Russia.

<Upper bound constraint for power imports>

- In general, power importing economies need to be prepared for a sudden power supply interruption.
- In this study, net imports from other economies is limited to less than operating reserve level of the importing region.
- Simulations under different conditions (e.g. no upper bounds case) need to be investigated as a part of future work.

$$\underbrace{nimp_{r,s,t}}_{\text{Net imports from other economy [MW]}} \leq \underbrace{ORM_r}_{\text{Operating Reserve (6\%~10\%)}} \cdot \underbrace{ELD_{r,s,t}}_{\text{Electric Load [MW]}}$$

Assumptions

Electricity Demand [TWh] in 2030

APEC Energy Demand & Supply Outlook 5th Edition (APERC).

Costs

Power plant: IEA WEO 2013, etc.

HV line/cable: reviewed paper[1)2)] and APERC's assumptions.

Fuel price in 2030: estimated from export/import price and WEO NPS price.

Carbon price: 30$/t-$CO_2$.

Transmission line costs	HV Line	HV Cable
Station cost [$/kW/station]	70	70
Line cost [$/kW/km]	0.4	2.4
Loss [%/thousand km]	5	5
Fixed O&M cost (ratio to "initial cost")	0.003	0.003

+500kV Bipole (3GW) Station cost: $210M/station[1)]

Line costs: $1.2M/km[1)2)]

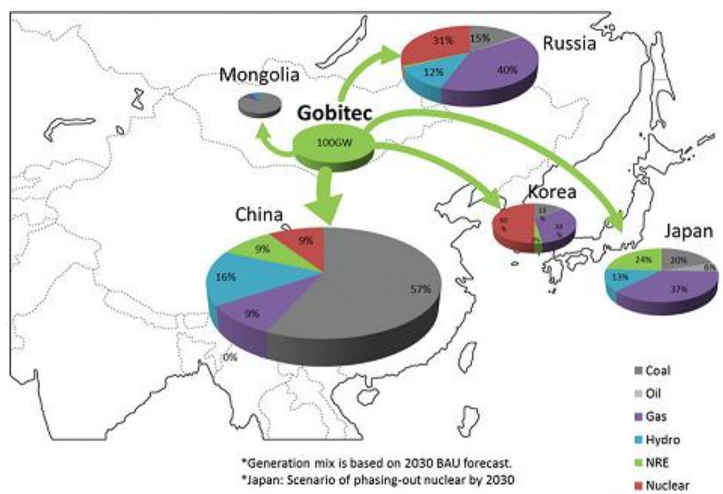
1)M.P. Bahrman et al.: "The ABCs of HVDC Transmission Technologies", IEEE, 2007

2)K Schaber et al.: "Transmission grid extensions for the integration of variable renewable energies in Europe: Who benefits where?", Energy Policy, 2012

Concept of Gobitech/ASG[3)]

Install 50GW wind and 50GW solar in Gobi by 2030.

	China	Japan	Korea
T/L capacity conneced to ASG [GW]	81	10	5

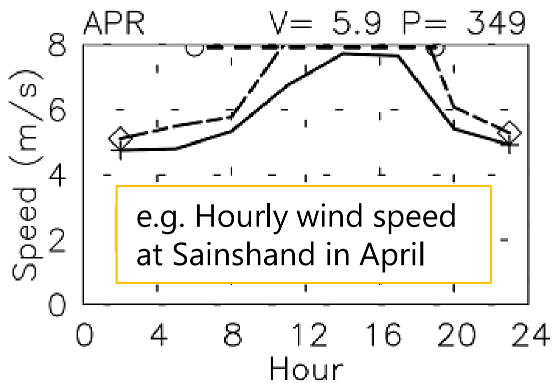


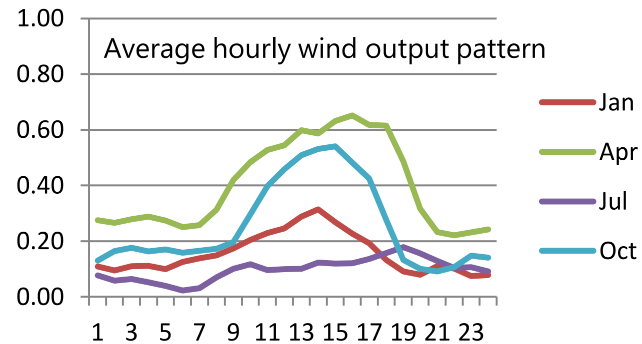
3)"Gobitech and Asian Super Grid for Renewable Energies in Northeast Asia", Energy Charter (2014)

Assumptions

Wind and PV hourly output pattern in Gobi area (for ASG and RES)

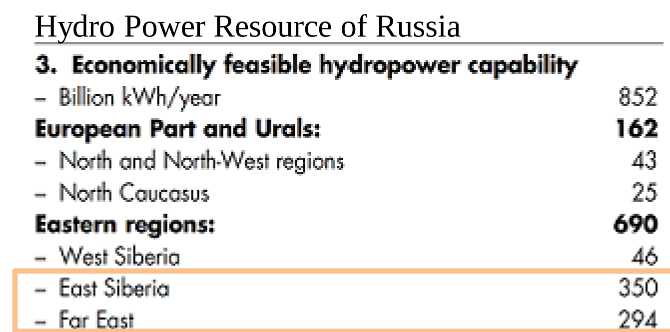
Estimated output pattern for each season from observation data reported in NREL[4)] and Zhao et al.[5)] Average wind CF (5 station) is 23%, PV is 20%.





Additional hydro resource in Russia (for RES)

Estimated from economic potential reported in IEA[6)].



Hydro Power Resource of Russia

3. Economically feasible hydropower capability	
– Billion kWh/year	852
European Part and Urals:	**162**
– North and North-West regions	43
– North Caucasus	25
Eastern regions:	**690**
– West Siberia	46
– East Siberia	350
– Far East	294

4)NREL: “Wind Energy Resource Atlas of Mongolia”, 2001

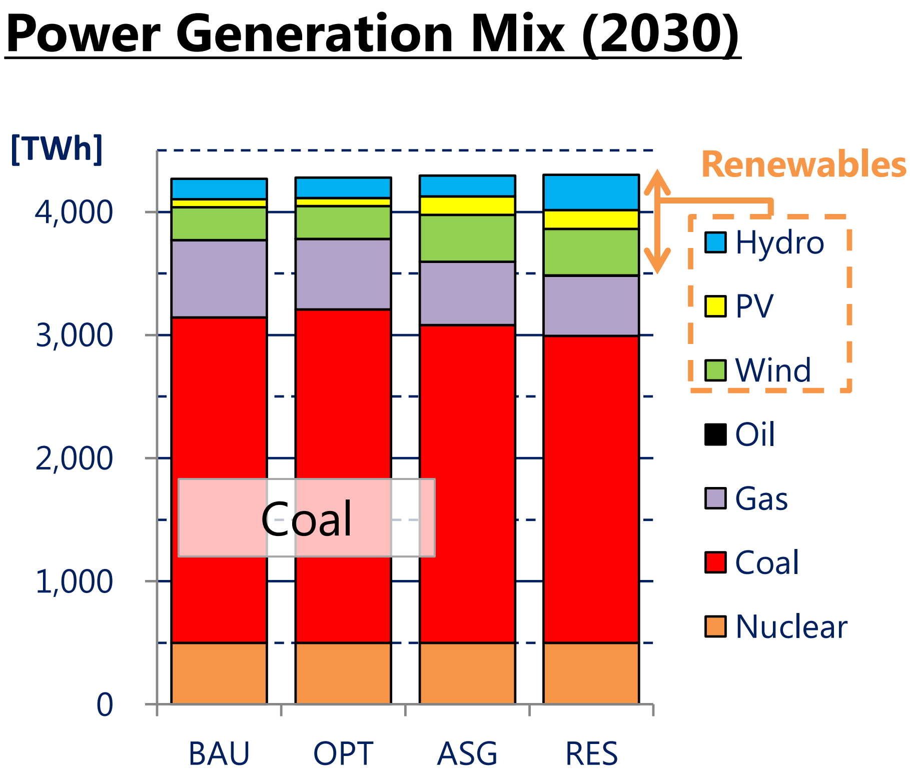
5)M Xhao et al.: “Testing and Analyzing of Solar Energy Resource Assessment in Inner Mongolia”, ICEIA, 2009

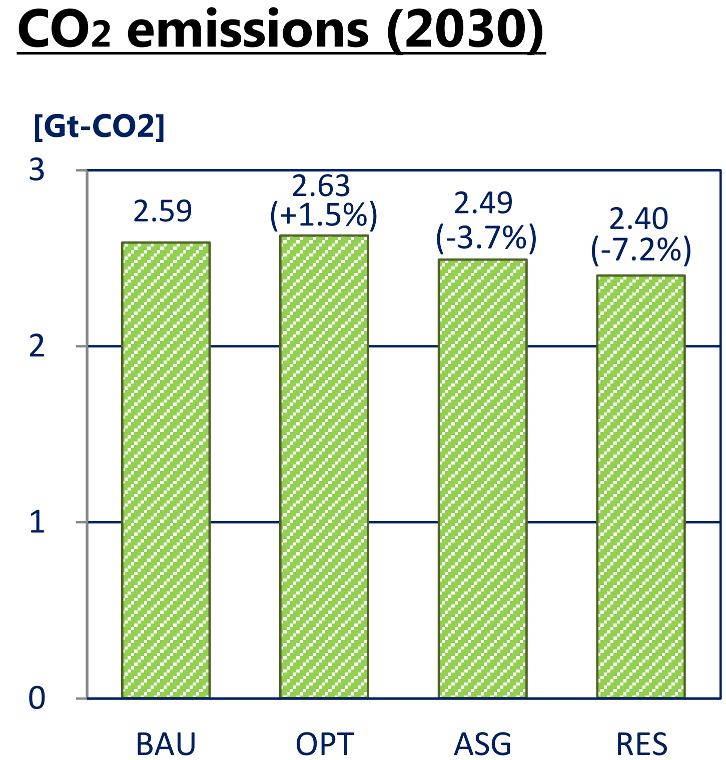
6)IEA: “Renewables in Russia from opportunity to reality”, 2003

Outline

1. Introduction
2. Brief overview of the model
3. Scenario settings
4. Results
5. Concluding remarks

Power Generation Mix and CO_2 emissions

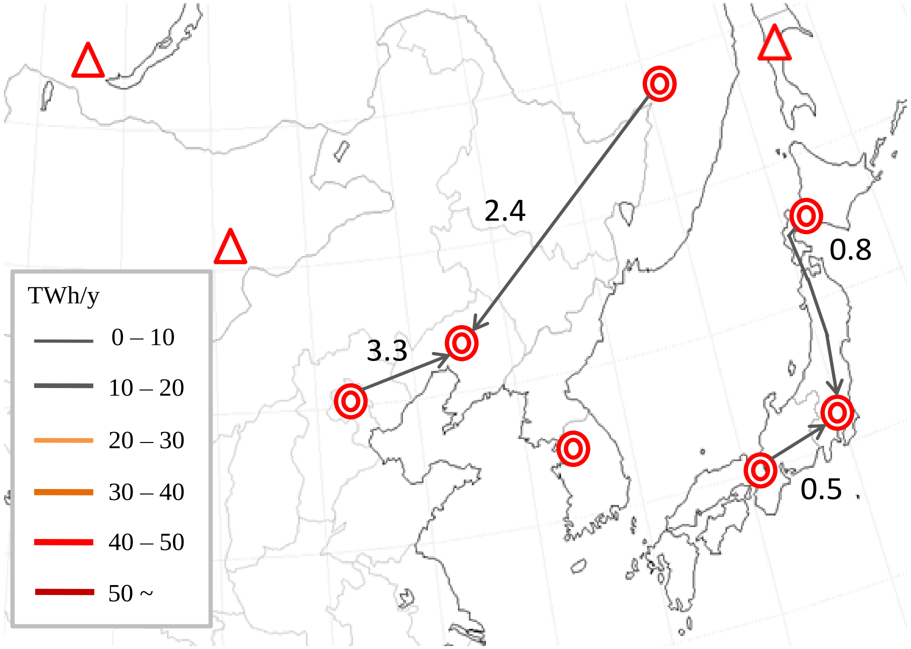




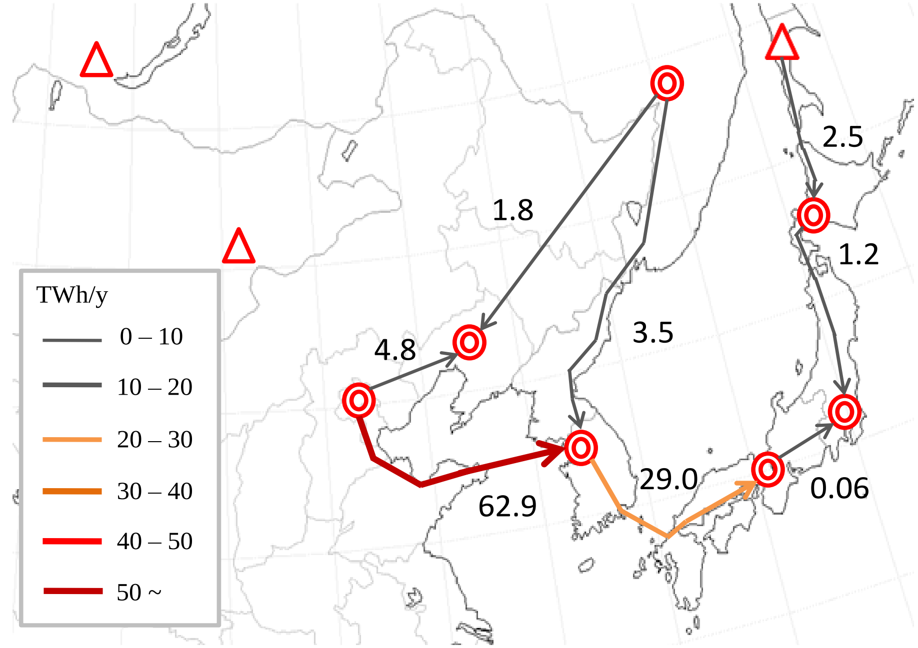
- In OPT, grid interconnections allow Japan/Korea to access cheaper coal electricity from China, and the share of coal-fired increases slightly, resulting in larger CO_2 emissions.
- The share of renewables in BAU is about 12%. In ASG and RES, renewables account for 16% and 19%, respectively, and contribute to CO_2 emissions reduction by 3.7% and 7.2%.

Net electricity flow [TWh/year] in BAU and OPT scenario

BAU scenario



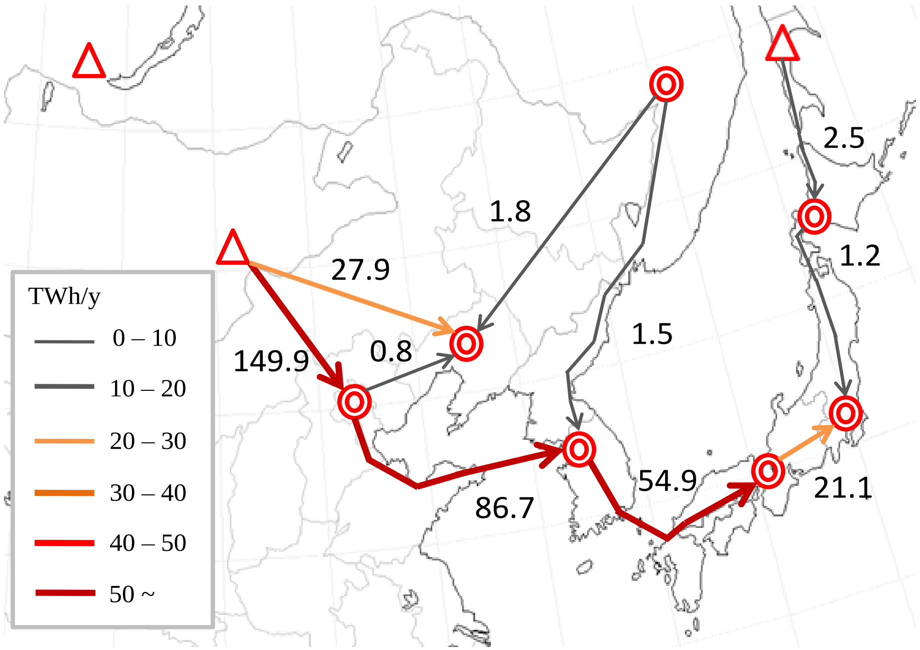
OPT scenario



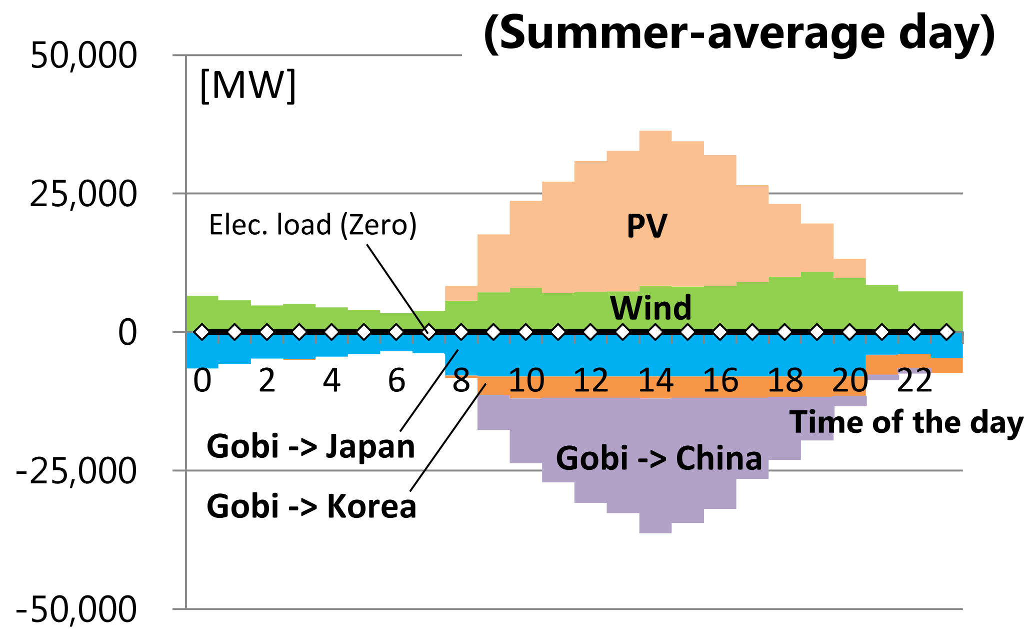
- In OPT, the major exporter to Japan and Korea is China due to the region's cheap electricity generating cost.

Net electricity flow [TWh/year] in ASG scenario

ASG scenario



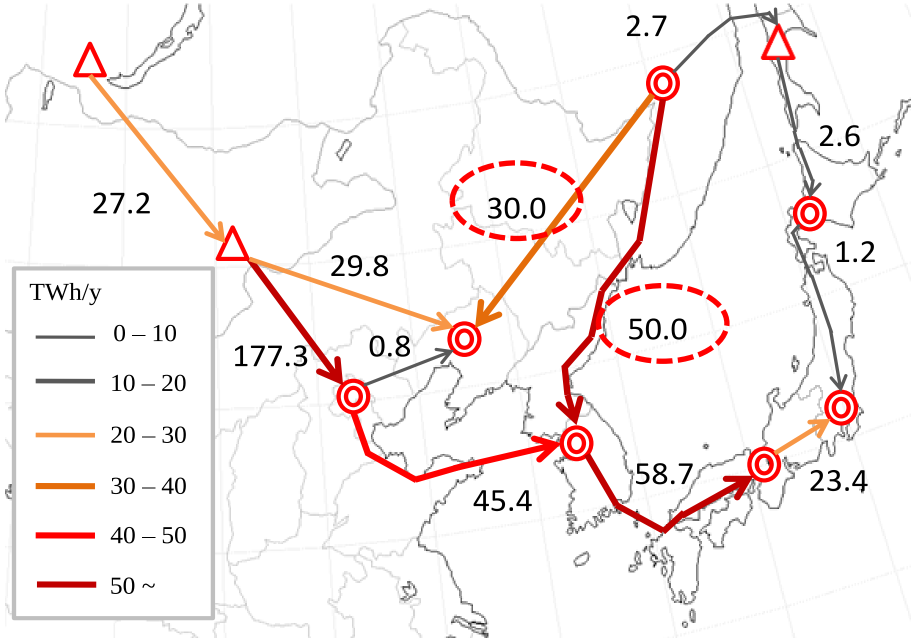
Supply-demand balance in Gobi



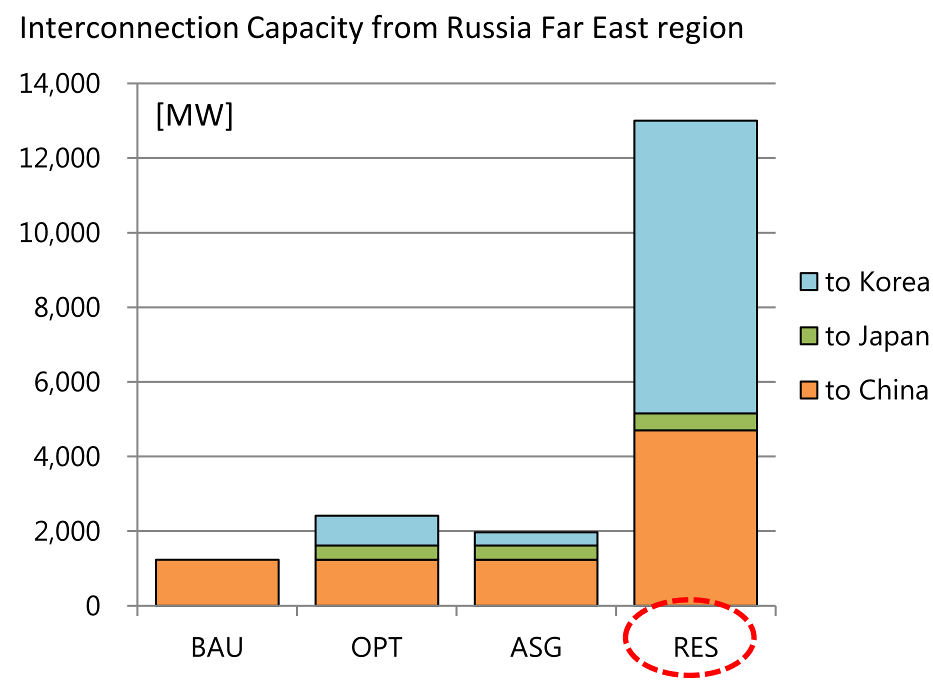
- Most PV/wind electricity generated in the Gobi area is sent to China (57%), followed by Japan (29%) then Korea (14%).
- From the view point of cost-optimization, electricity from the Gobi desert is primarily sent to regions with high electricity prices (like Japan and Korea). China, which has a large demand, plays a role for absorbing large PV outputs during the daytime.

Net electricity flow [TWh/year] in RES scenario

RES scenario



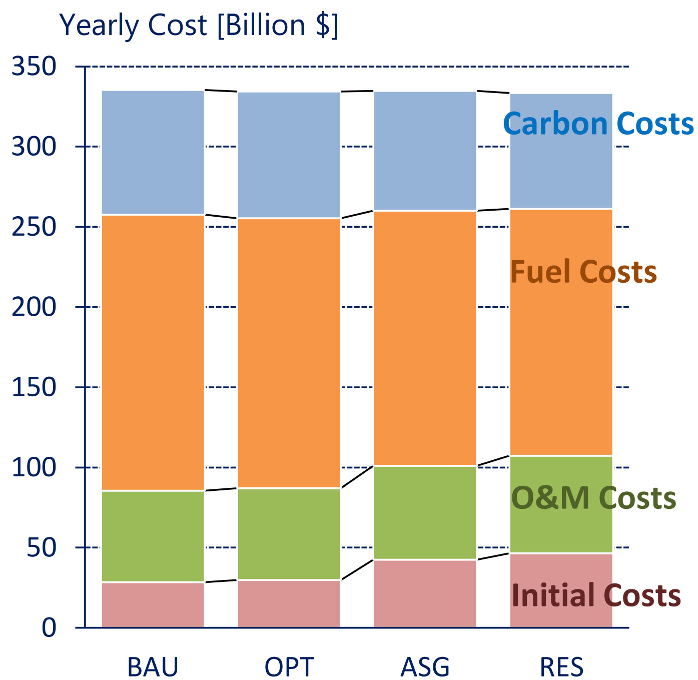
T/L between Russia-FE and other regions



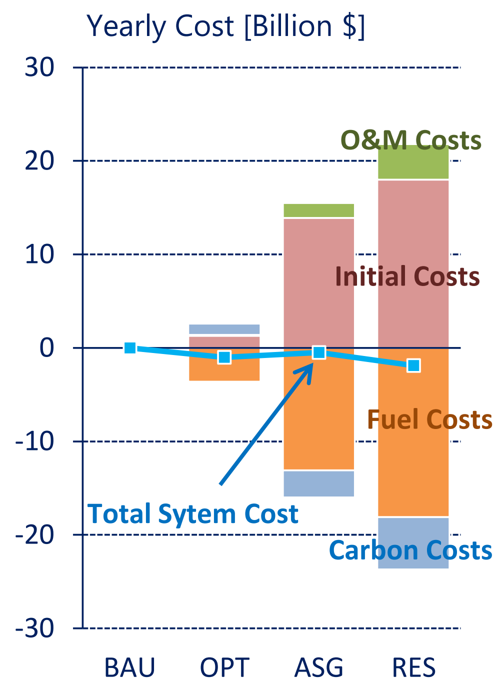
- Interconnection capacity between Russia and China/Korea expands under this "Additional Hydro in Russia" scenario, and Russia largely exports to these economies.
- These results may imply that there is a room for additional hydro development in Russia. This could be a key factor for the scale of future interconnection between Russia and other regions.

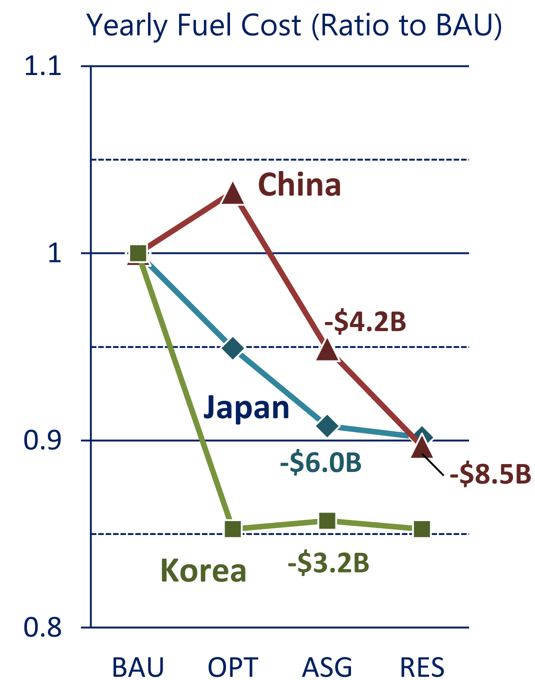
Costs and benefits

Total system cost



Changes from BAU





- Yearly total system costs decline by $1B/y, $0.5B/y and $1.9B/y in OPT, ASG and RES, respectively. Marginal impacts on the total system cost (-0.1% ~ -0.6%).
- In ASG and RES, although deployment of renewables and transmission lines pushes up initial costs and O&M costs, RE resource sharing contributes to fuel cost reduction by about 8% and 11%, respectively.

Summary and Conclusion

- This study aims to examine four scenarios about power interconnections with a multi-regional power system model.

- In order to reap both economic and environmental benefits, power interconnection projects need to be in tandem with renewable energy sharing projects.
  - ✓ Interconnections WITHOUT renewable resource sharing (“OPT scenario”) increases CO_2 emissions.
  - ✓ In ASG and RES, massive deployment of renewable energy pushes up initial costs and O&M costs. On the other hand, it potentially contributes to fuel cost saving in NEA region by 7~10% compared to BAU.

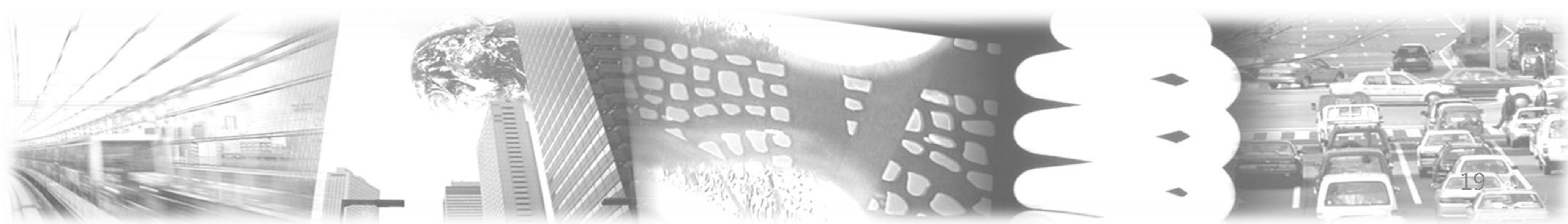
- Additional hydro potential (“practically exploitable potential”) in Eastern Russia appears to be a key factor for the interconnection scale between Russia-FE and other regions.

- However, this study focuses on a macroscopic analysis of the connectivity in NEA region, and in order to further promote the grid interconnection projects, detailed research about the economics of specific sites will be needed.

Future work

- Examine the interconnection impacts on power system reliability
  - ✓ We are now trying to develop a simple model to evaluate power system reliability (LOLP, LOEP, etc.) using Monte Carlo method.
- Refine data collection and assumptions
  - ✓ How can we describe RE intermittency and its management measures (electricity storage, suppression, etc.) in detail?
- Explore other scenarios with the model
  - ✓ Current set-up is for a single year in the future year, how about multi-year scenario?
  - ✓ What if specific routes are not an option?
  - ✓ How will power interconnections help in the event of LNG supply shortage to Japan or Korea?
- Detailed studies about the economics of specific sites

Thank you for your kind attention



Appendix: Summary of Major Results and Findings-1

Region	Major Results and Implications
NE Asia	1-1: In the ASG(Gobitec) and RES(Gobitec+hydro in Russia) scenario, renewables expand from 12% to 16% and 19%, respectively. However, even under these "RE aggressive" scenarios, coal-fired is still a dominant electricity source in NEA region(58%~62%). – Slide12 1-2: The impacts of power grid interconnection on the total system cost seems marginal (-0.3% , -0.1%, and -0.6% in OPT, ASG and RES, respectively). – Slide16 1-3: However, the share of total system cost changes; in ASG and RES scenario, the deployment of RE and transmission line pushes up initial costs and O&M costs. On the other hand, RE sharing contributes to fuel cost reduction by 8% and 11% respectively. – Slide16 1-4: CO_2 emissions increases in OPT (+1.5%), and declines in ASG (-3.7%) and RES (-7.2%). – Slide12 1-5: Interconnections WITHOUT RE energy development (=OPT scenario) allow high cost regions (like Japan/Korea) to access cheaper fossil fuel electricity in China, resulting in larger emissions. – Slide12 1-6: In order to reap both economic and environmental benefits, power grid interconnection needs to be in tandem with renewable energy sharing projects.

Appendix: Summary of Major Results and Findings-2

Region	Major Results and Implications
NE Asia	1-7: In OPT, China becomes major exporter to Japan/Korea due to chap electricity generating cost, and interconnection from Russia is limited– Slide13 1-8: Destination of "Gobi electricity" in ASG scenario: 57%(114TWh) to China, 29%(58TWh) to Japan, and 14%(27TWh) to Korea. – Slide14
China	2-1: Fuel cost in ASG and RES are -5% (-\$4.2B/y) and -10% (-\$8.5B/y), respectively. Fuel cost increases by +3% in OPT for electricity exports. – Slide16 2-2: CO2 emissions: +3% (+60Mt) in OPT, -3.5% (-66Mt) in ASG, and -7.8% (-146Mt) – Slide12 2-3: Access to additional hydro developments in Russia potentially brings significant benefits to China from economic and environmental perspectives. 2-4: In ASG scenario, China, which has huge electricity demand, plays a role to absorb large "Gobi" PV output during the daytime. – Slide14

Appendix: Summary of Major Results and Findings-3

Region	Major Results and Implications
Japan	3-1: Fuel cost: -9.2% (-\$6B/y) in ASG, and -10% (-\$6.4B/y) in RES. – Slide16 3-2: CO_2 emissions: -5% (-21Mt) in ASG, and -5.3% (-23Mt) . – Slide12 3-3: Connecting to China/Korea is potentially an economic option. Interconnection to Sakhalin also can be, but its scale is likely to be limited. – Slide13~15 3-4: As mentioned in 3-1, “Gobi electricity” in ASG can significantly contribute fuel saving (around 10% scale).
Korea	4-1: Fuel cost: -14% (-\$3.2B/y) in ASG, and -15% (-\$3.3B/y) in RES. – Slide16 4-2: CO_2 emissions: -5% (-13Mt) in ASG, and -6% (-15Mt) . – Slide12 4-3: Korea plays a role as a transit economy (“bridge”) between China and Japan. – Slide13~15 4-4: Largest fuel cost savings can be expected on % basis (about 15% reduction) among the regions. – Slide16
Russia	5-1: Interconnection capacity between Russia Far Eastern region and other region: 1.2GW (BAU), 2.4GW(OPT), 2.0GW(ASG), and 13.0GW(RES). – Slide15 5-2: Room for additional hydro development appears to be a key factor for the interconnection scale between Russia and other NEA region. – Slide 15 5-3: Korea and China Northeast region are major destination of exports in RES scenario (50TWh/y to Korea, 30TWh/y to China). – Slide15