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Asia Super Grid

Renewables in an Interconnected System

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North-East Asia Regional Power Interconnection and Cooperation Forum 2019
SEOUL

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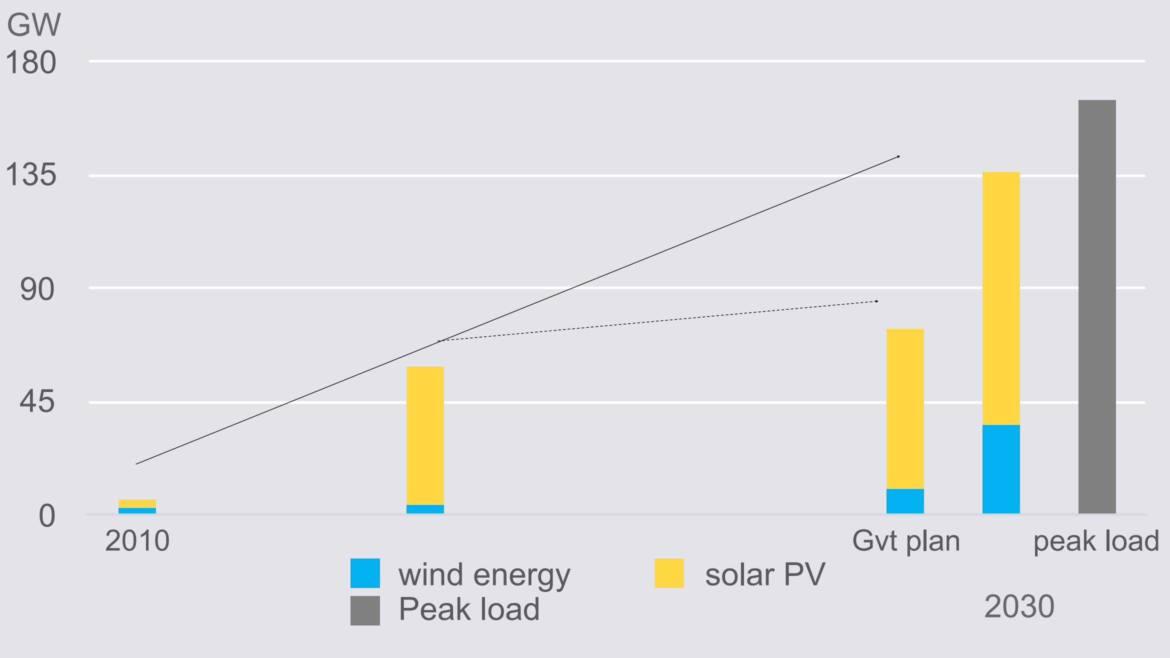
Solar PV has risen rapidly in Japan over the last 6 years, but concerns regarding grid integration could raise the possibility of a renewables slow-down

Installed solar and wind capacities in Japan in 2010 and 2018. Projection for 2030 according to the government plan and the forecast of RES sector



Source (REI, BP, GWEC, METI), data for 2018 are preliminary, peak load data from 2017, Gvt plans 2030 represents current targets, RES 2030 forecasts from the RES sector (2017)

Solar PV has risen rapidly over the last five years in Japan (55.5* GW installed capacity end of 2018), making the country one of the most dynamic PV markets outside of China.

In Kyushu and Shikoku islands, hourly VRES infeed already covered respectively 84% and 79% of demand in summer (~ over 55% of hourly production)

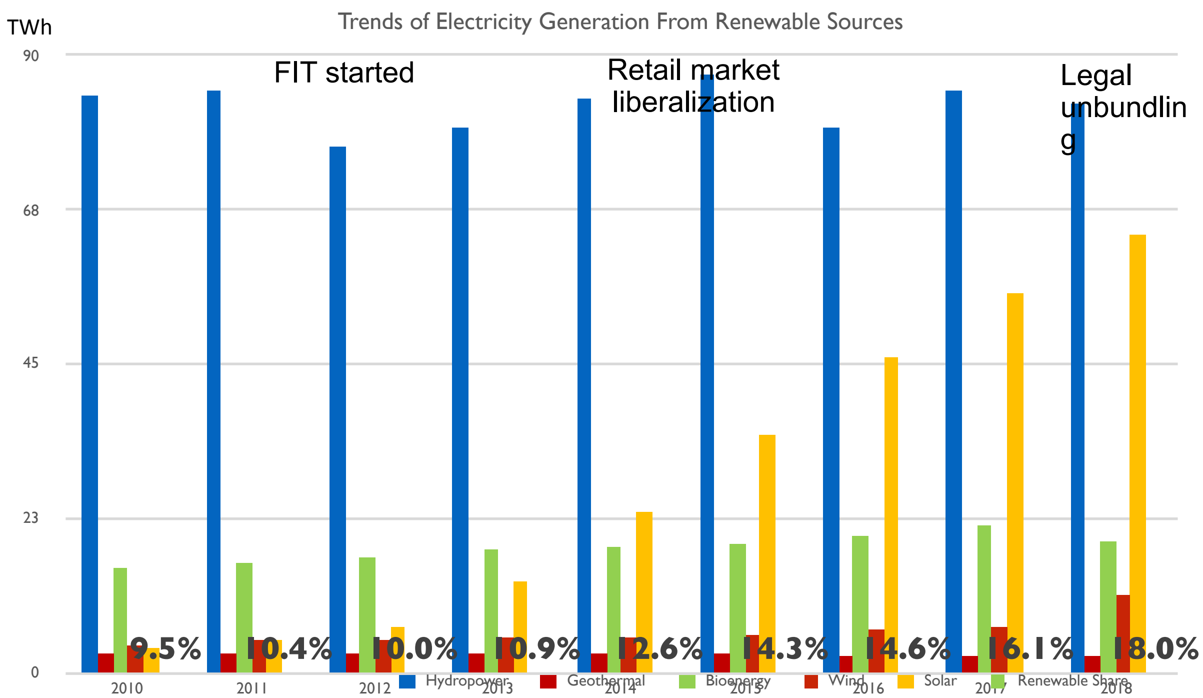
However, the annual share of VRES is still rather low (~7%) , especially low profile of wind (3.8GW), and governmental renewables targets for 2030 (22-24% RES, i.e. ~10% VRES) are significantly below international averages.

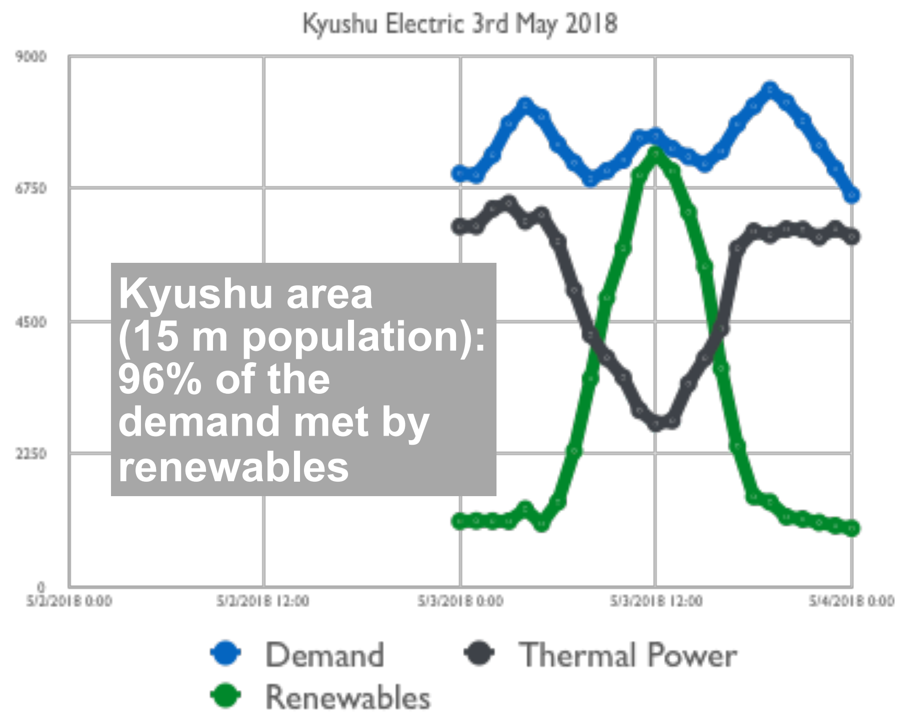
Concerns over whether RES can be efficiently integrated into Japan's power grid without endangering grid stability raised the possibility of renewables slow-down in the country.

* preliminary data (BP, 2019)

Renewables temporarily supply 17.3% (2018) and more than 70% of the electricity demand in 7 out of 10 service areas across Japan (Findings from data 1st Quarter of 2018)

Renewables share in electricity generation may reach 20% soon (Gov's target: 22-24% by 2030)
Cost of solar generation halved in 5 years (2012-2017)





Source：経済産業省資源エネルギー庁「総合エネルギー統計」および「電力調査統計」(参照：2018/07/20)より作成
2018年のみ西暦年、『電力調査統計」（参照：2019/04/26）より自然エネルギー財団作製

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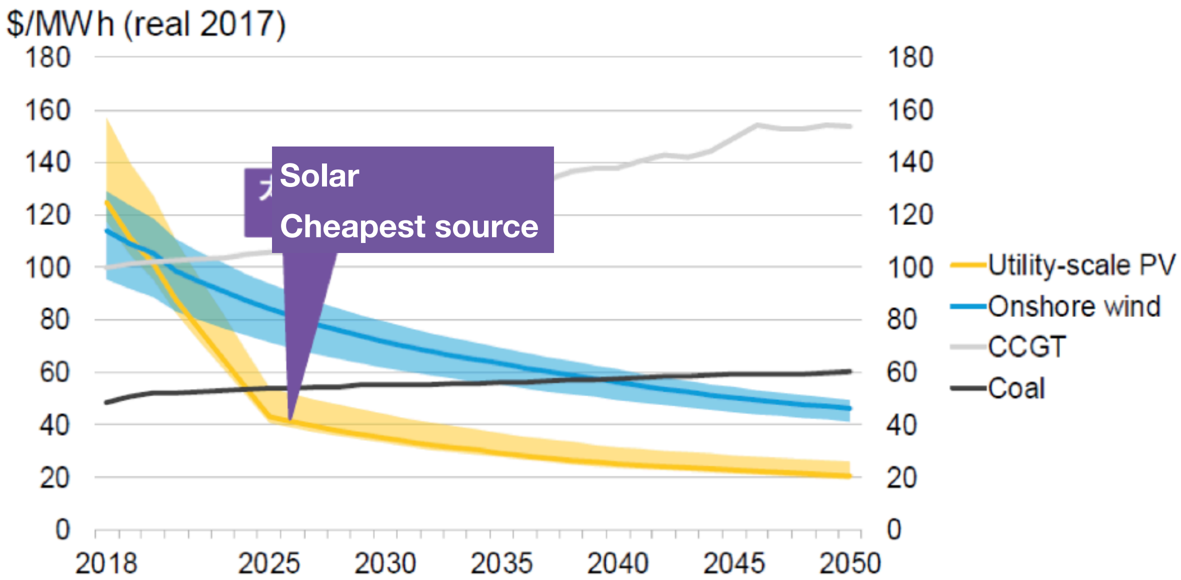
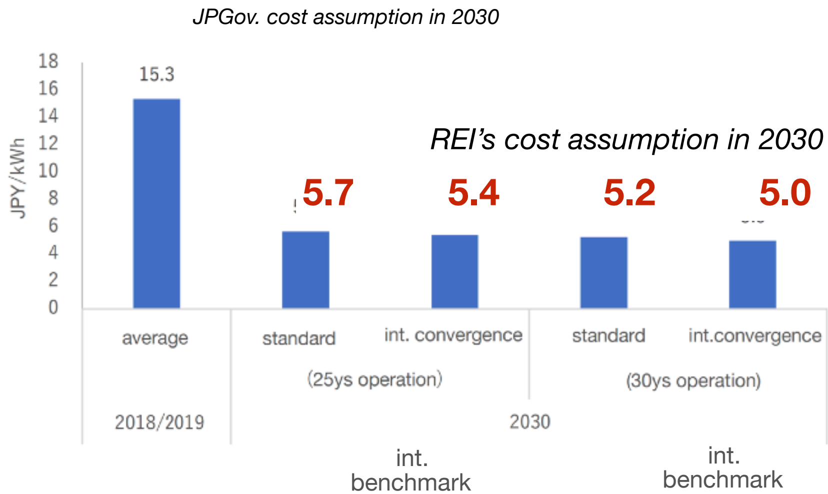
BNEF estimates PV would be the cheapest source of new electricity in early 20's.
Onshore wind would be cheaper than CCGT in early 20's.
A new REI study predictsRE cost is declining far below than Gov. assumption





Generation cost prediction in Japan by Bloomberg NEF

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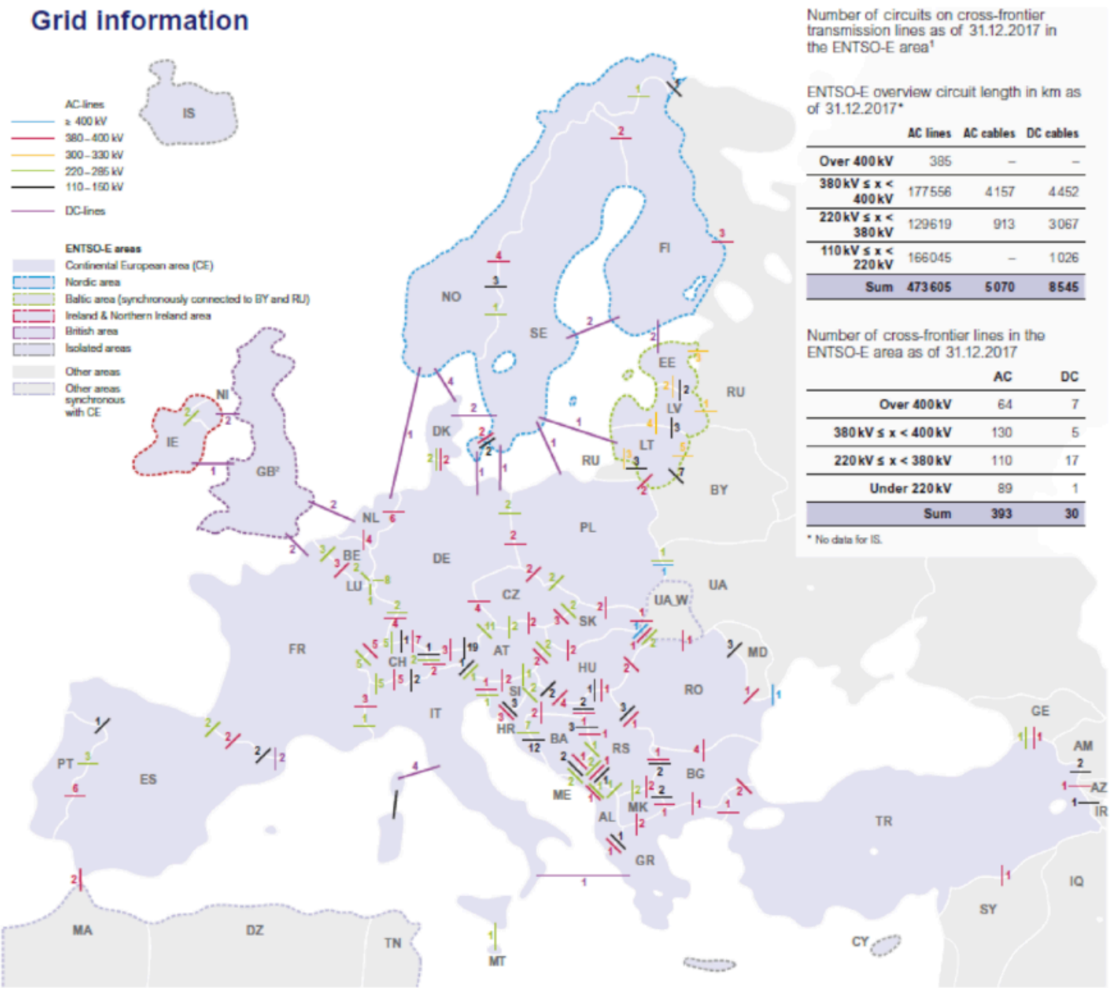
Interconnectors are usual business in some parts of the world



Number of circuits on cross-frontier transmission lines as of 31.12.2017 in the ENTSO-E area[1]

ENTSO-E overview circuit length in km as of 31.12.2017*

	AC lines	AC cables	DC cables
Over 400 kV	385	–	–
380 kV ≤ x < 400 kV	177556	4157	4452
220 kV ≤ x < 380 kV	129619	913	3067
110 kV ≤ x < 220 kV	166045	–	1026
Sum	**473605**	**5070**	**8545**

Number of cross-frontier lines in the ENTSO-E area as of 31.12.2017

	AC	DC
Over 400 kV	64	7
380 kV ≤ x < 400 kV	130	5
220 kV ≤ x < 380 kV	110	17
Under 220 kV	89	1
Sum	**393**	**30**

* No data for IS.

Figure: Grids in Europe in 2017

Source: ENTSO-e, Statistical Factsheet 2017

【Since 1910s】

- 1915 Denmark-Sweden Interconnection
- 1920 Interconnection between France, Switzerland and Italia.

【After WWII】

- 1951 UCPTE among 8 countries. (West-Germany, France, Italy and others)
- 1963

  NORDEL in Northern Europe
  UFIPTE by France, Spain and Portugal

【Currently】

The region is divided into four synchronous grids, Continental Europe, Nordic, UK, and Baltic, and they are connected asynchronously through direct current transmission, so that electricity trade can be conducted among them.

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Lessons learnt from recent cases - cost for interconnectors are eco. feasible

NO.	Project		Distance (km)	Strait, etc. (km)	Trans-mission method	Grid voltage (kV)	DC voltage (kV)	Transmission capacity (MW)	Came into operation in	Transformer cost	Transmission line cost	Total cost	¥10,000/ MW km (reference)*
1	SAPEI	Italy	435	420	line-Commutated	400	±500	1,000	2011	$180m	€400m	€750m	20
2	BritNed	UK - Netherlands	259	250	line-Commutated	400 380	±450	1,000	2011	€220m	$350m	€600m	26
3	Nemo Link	UK - Belgium	141	130	self-Commutated	400 380	±400	1,000	2019	—	—	€500m	40
4	Estlink 2	Estonia - Finland	171	145	line-Commutated	330 400	450	650	2014	€100m	$180m	€320m	32
5	NorNed	Netherlands - Norway	583	580	line-Commutated	380 300	±450	700	2008	$270m	€51m	€600m	17
6	Fenno-Skan 2	Sweden - Finland	196	194	line-Commutated	400	±500	800	2011	$170m	€150m	€315m	23
7	Skagerak 4	Denmark - Norway	243	140	self-Commutated	400 300	±500	700	2014	$180m	€87m	—	17
8	Nord.Link	Germany - Norway	623	516	self-Commutated	380 420	±525	1,400	2019	$900m	€500m	€1.5—2.0b	20~26

*Converted at ¥114.0/€ and ¥103.8/$ (forex rates on October 19)

Table: Transmission capacities and other data of some of the existing interconnectors in the world

Source: Organization for Cross-regional Coordination of Transmission Operators

Source：ASG Study Group Interim Report, 2017, REI

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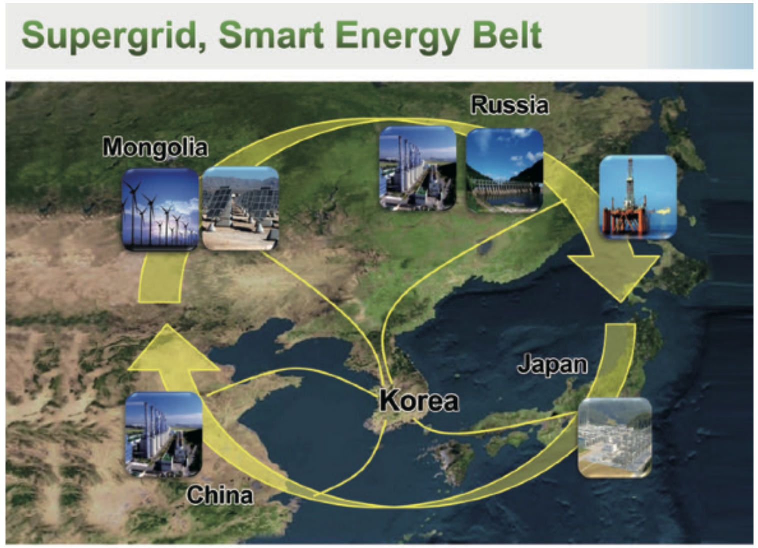
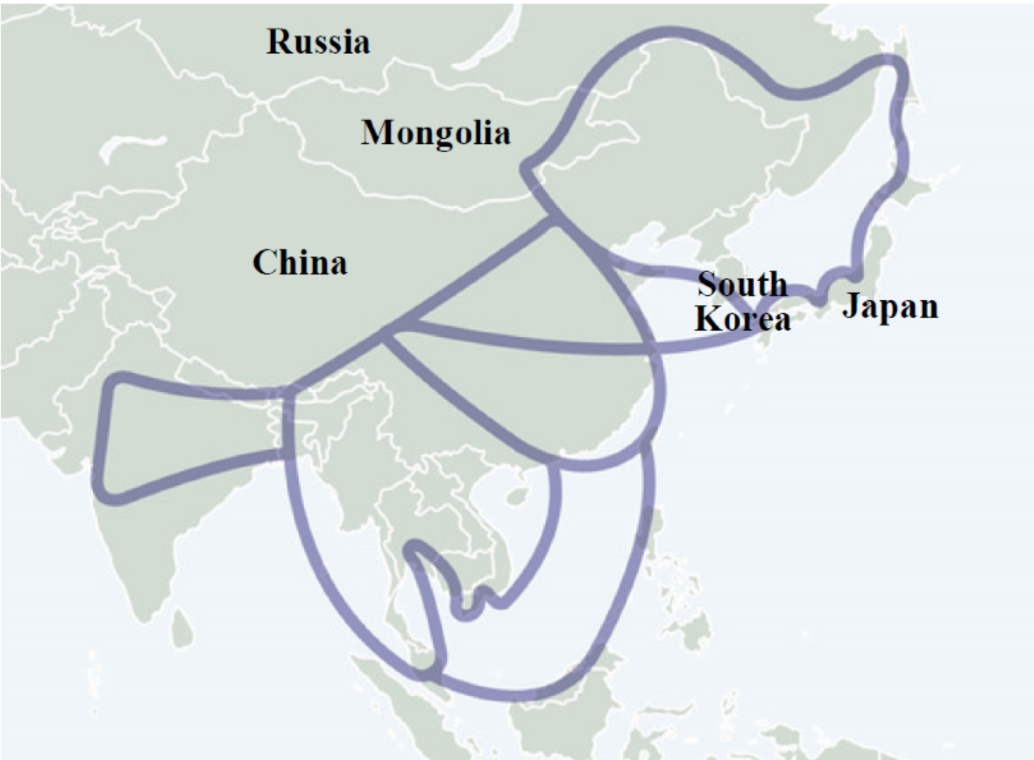
Scheme name	Scheme owner	Year of scheme proposal
North East Asian Electrical System Ties	Korea Electrotechnology Research Institute and ESI in Russia	2002
GOBITECH Initiative	Seoul Office of Hanns Seidel Foundation, etc.	2009
Asia Super Grid	Renewable Energy Institute	2011
Asia Pacific Power Grid	Japan Policy Council	2011

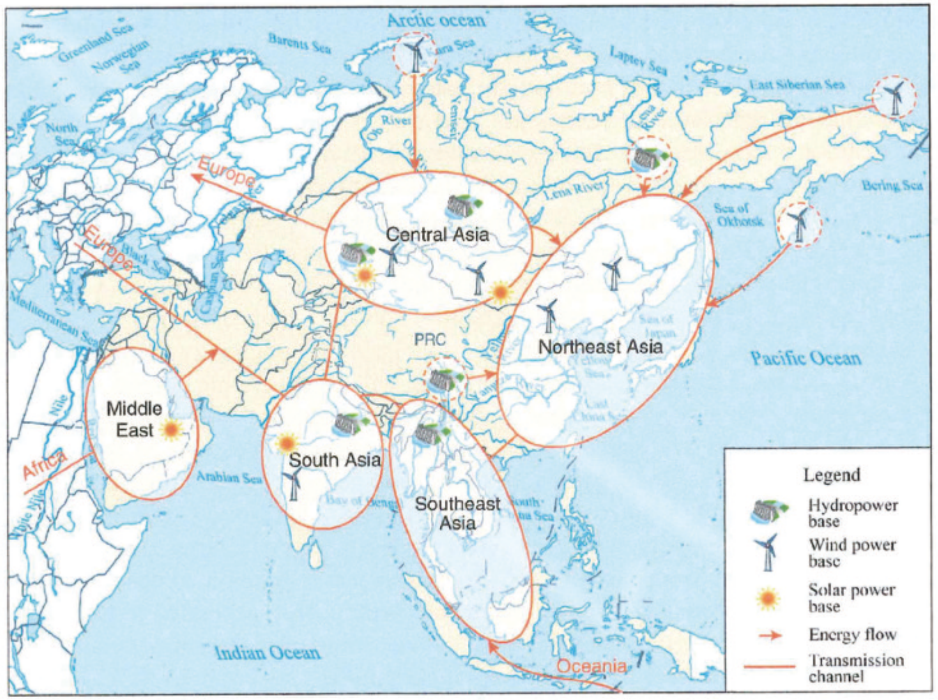


Korea Electric Power Corporation "Northeast Asia Interconnection Vision"
Source: Hwan-Eik Cho, President of Korea Electric Power Corporation, lecture document September 9, 2016)



Source：ASG Study Group Interim Report, 2017, REI

International power grid in Asia in the GEI vision



Source: Official website of the international non-profit organization "Global Energy Interconnection Development and Cooperation Organization (GEIDCO)"

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Asia Super Grid is a concept to maximize RE use in Asian region

North East Asian countries are very close compare to European nations; Souya - Sakhaling 43km, Fukuoka-Busan 200km.
Big consumption areas - economically very active areas are close to each other.
Combining three countries, China, Korea and Japan, the biggest electricity market emerges. Covers 75% of power generation and 77% of electricity consumption in Asia.
In Asian region, especially Mongolia, Russia and China, there are vast potential of renewables which can cover whole electricity consumption in the area.

	GDP (in billion dollars) Figures in parentheses are GDP per capita (in thousand dollars)	Population (in million people)	Electricity generated (in TWh)	CO_2 emissions (in million tons CO_2)
China	8,909 (6.5)	1,376	5,811	9,154
Japan	5,986 (47.2)	127	1,036	1,208
South Korea	1,267 (25.0)	50	522	649
Mongolia	12 (3.9)	3	5	18
Russia	1,616 (11.0)	143	1,063	1,483
Northeast Asia	17,790 (~10.5)	1,699	8,437	12,512
World	74,889 (10.2)	7,349	24,098	33,508
Share of Northeast Asia	20-25%	20-25%	30-35%	～37%
Source	World Bank *Constant 2010	United Nations	BP; For Mongolia, figure from IEA in 2014	BP; For Mongolia, figure from IEA in 2014

Source: Created by Renewable Energy Institute based on data released by national governments and international organizations.

Source：ASG Study Group Interim Report, 2017, REI

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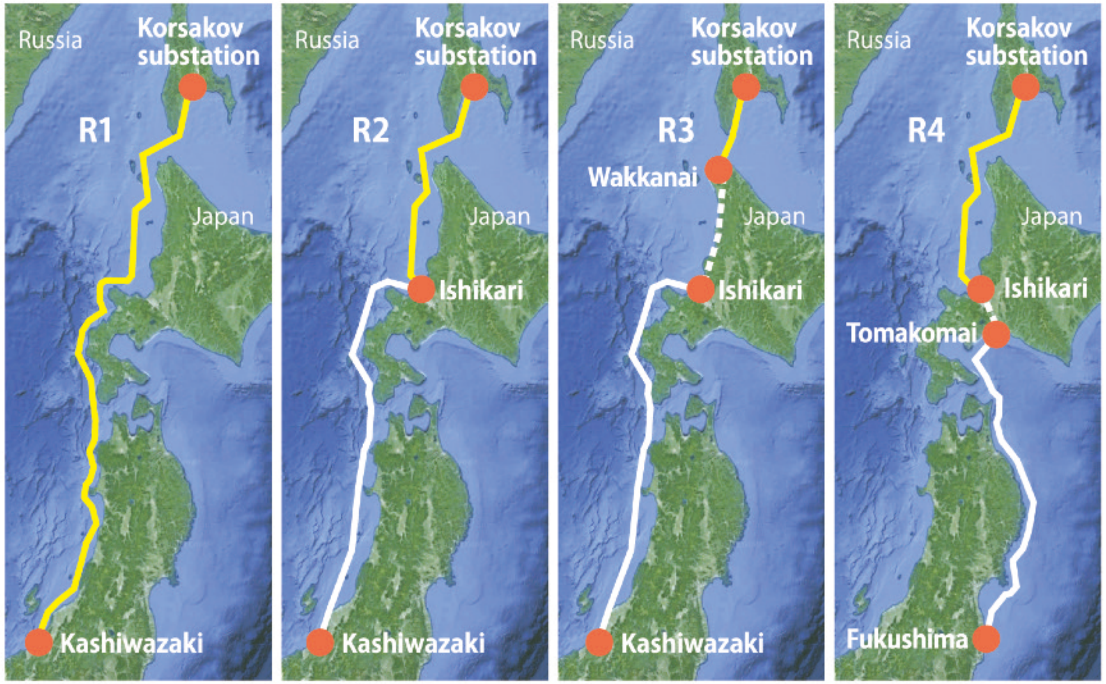
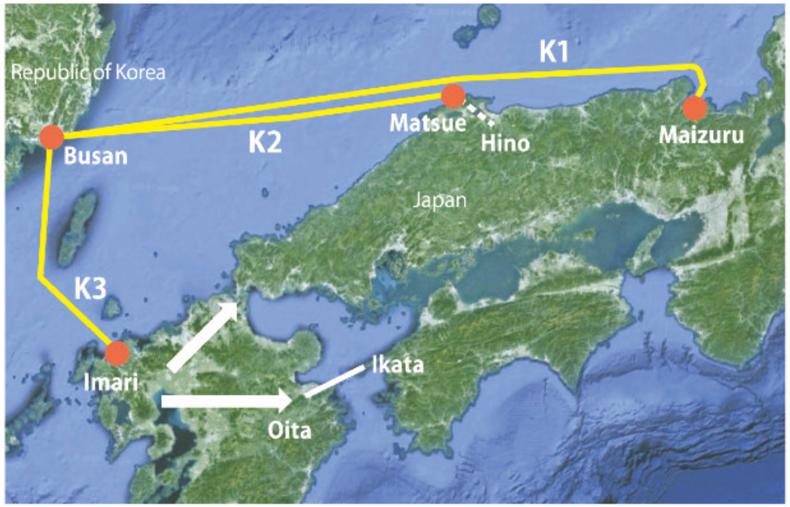


R1 Sakhalin—Kashiwazaki
Length: 1,255 ㎞

R2 Sakhalin—Ishikari—Kashiwazaki
Length: 1,255 ㎞

R3 Sakhalin—Wakkanai—Ishikari—Kashiwazaki
Length: 1,258 ㎞
(161+297+800 ㎞)

R4 Sakhalin—Ishikari—Tomakomai—Fukushima
Length: 1,246 ㎞
(455+108+683 ㎞)



K1 Busan—Maizuru
Length: 627㎞

K2 Busan—Matsue (→Kansai)
Length: 372㎞
+41 km grid reinforcement
(Matsue-Hino)

K3 Busan—Imari (→Kansai)
(via Chugoku & Shikoku region)
Length: 226㎞
+70 km grid extension (Oita-Ikata)

Japan-Russia			Japan-South Korea		
Route	Length	Max. Depth	Route	Length	Max. Depth
Sakhalin-Kashiwazaki	1,255 km	300 m	Busan-Maizuru	627 km	200 m
Sakhalin-Ishikari	455 km	300 m	Busan-Matsue	372 km	150 m
Sakhalin-Wakkanai	161 km	≤ 100 m	Busan-Imari	226 km	120 m

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The Cost estimation of interconnectors between Russia-Japan, Korea-Japan

Routes	Specifications	AC/DC converter	Interconnector	Domestic lines	Total
R1: Sakhalin-Kashiwazaki	Submarine cables	4 units	JPY 430.5 bn.	-	$ 4.3 bn.
R2: Sakhalin-Ishikari-Kashiwazaki	Submarine cables	6 units	JPY 196.1 bn.	JPY 265.8 bn.	$ 4.6 bn.
R3: Sakhalin-Wakkanai-Ishikari-Kashiwazaki	Onshore; Overhead lines	6 units	JPY 110.0 bn.	JPY 463.0 bn.	$ 5.7 bn.
R4: Sakhalin-Ishikari-Tomakomai-Fukushima	Onshore; Underground cables	6 units	JPY 196.1 bn.	JPY 330.3 bn.	$ 5.3 bn.

Routes	Specifications	AC/DC converter	Interconnector	Domestic lines	Total
K1: Busan-Maizuru	Submarine cables	4 units	JPY 246.5 bn.	-	$ 2.5 bn.
K2: Busan-Matsue-Hino	Matsue-Hino to be reinforced	4 units	JPY 171.8 bn.	30.6 bn. JPY	$ 2.0 bn.
K3: Busan-Imari/Oita-Ikata	Submarine cables	8 units	JPY 129.0 bn.	83.3 bn. JPY	$ 2.1 bn.

Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results

Based on the preceding studies including the Interim Report and researches in Europe/North America, the investment recovery method of interconnectors is classified into the following four types or combinations of them.

Business model	Contents	Examples
1) Generators/ suppliers dedicated line model	Interconnector is laid as a part of a power supply project to specific customers or markets from specific generators or suppliers, and investment is carried out by power sales income.	Russia - China Canada - US
2) Regulated grid tariff model	The construction and maintenance costs of the interconnector are regarded as the fully distributed costs (FDC) of the power transmission operators and all consumers in the business area will bear the transmission fee for the investment recovery.	Skagerrak 4 (Denmark - Norway)
3) Transmission rights sales model	The transmission operators sell the right to use the transmission line to power generators and/or retail electricity companies.	
4) Congestion charge model	The transmission operators obtain the congestion charge which is calculated as “multiplication of wholesale price difference and actual transmitted electricity amount” as a revenue at the time of market segmentation in the interconnector between consolidated markets.	European markets, North American markets (e.g. PJM)

Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results

1) Generators/suppliers dedicated line model: Japan-South Korea route

Assumptions

Payback period	25 years
O&M ratio	1 - 3% of initial investment cost
Supplied power	Minimum: 1 GW; Maximum: 2 GW
JEPX price	For each year of 2016 and 2017 (every 30 minutes)
Set value of FOB prices	JPY 5-9 /kWh (every 1 yen)

*Set the electricity generation cost as X (JPY/kWh), transmission cost as Y (JPY/kWh). The total of X + Y (JPY/kWh) would bid into JEPX as FOB price. The investment for the construction cost (JPY Z billion) will be recovered by the difference between the JEPX system price and FOB price. System price data of Japanese connection point in 2016 and 2017 are used as JEPX's system price data.

Table 12: Japan-South Korea route: Estimated results of Generators/suppliers dedicated line model (Unit: IRR%)

Set value of FOB prices	5 yen /kWh	6 yen /kWh	7 yen /kWh	8 yen /kWh	9 yen /kWh
[K1] Busan-Maizuru (Electricity market: Kansai area; Construction cost: JPY 246.5 billion)					
1 GW	**4.0% to 13.8%**	**-1.2% to 10.1%**	**-7.8% to 6.6%**	**Max. 3.5%**	**Max. 0.7%**
2 GW	**15.3% to 29.7%**	**8.5% to 23.0%**	**2.4% to 17.3%**	**-3.1% to 12.5%**	**-9.5% to 8.5%**
[K2] Busan-Matsue-Hino (Electricity market: Chugoku area; Construction cost: JPY 202.4 billion)					
1 GW	**6.8% to 17.4%**	**1.4% to 13.0%**	**-4.5% to 9.2%**	**-13.0% to 5.7%**	**Max. 2.7%**
2 GW	**19.7% to 36.3%**	**11.8% to 28.2%**	**5.1% to 21.5%**	**-0.4% to 15.8%**	**-5.7% to 11.3%**
[K3] Busan-Imari/Oita-Ikata (Electricity market: Kyushu area; Construction cost: JPY 212.3 billion)					
1 GW	**5.7% to 15.6%**	**0.3% to 11.5%**	**-5.7% to 7.9%**	**-16.6% to 4.7%**	**Max. 1.7%**
2 GW	**17.9% to 33.0%**	**10.4% to 25.5%**	**4.0% to 19.3%**	**-1.3% to 14.2%**	**-6.9% to 9.9%**

*In the red frames, the IRR median value is positive.

Source：ASG Study Group Second Report, 2018, REI

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1. Business models for investment recovery and estimated results

2) Regulated grid tariff model:
Japan-Russia route
and Japan-South Korea route

Assumptions

Payback period	25 years	
O&M ratio	1 - 3% of initial investment cost	
Set value of grid tariff	0.06 - 0.10 JPY/(every 0.01 JPY)	
Japan's share of defrayment	50% of interconnector and 100% of lines in Japan	
Power demand	Tokyo Electric Power area	289.9 TWh
	Kansai Electric Power area	148.6 TWh
	Chugoku Electric Power area	60.2 TWh
	Kyushu Electric Power area	85.7 TWh

Table 14: Japan-Russia route: Estimated results of regulated grid tariff model (Unit: IRR%)

Set value of grid tariff	Billing area (Power demand)	0.06 yen / kWh	0.07 yen / kWh	0.08 yen / kWh	0.09 yen / kWh	0.10 yen / kWh
[R1] Sakhalin-Kashiwazaki (Construction cost: JPY 430.5 billion)	Tokyo Electric Power Company area (289.9 TWh)	1.9% to 5.0%	4.0 to 6.8%	5.9 to 8.5%	7.7 to 10.1%	9.3 to 11.7%
[R2] Sakhalin-Ishikari-Kashiwazaki (Construction cost: JPY 461.9 billion)		-5.5% to -0.4%	-3.1 to 1.1%	-1.3 to 2.4%	0.3 to 3.7%	1.7 to 4.8%
[R3] Sakhalin-Wakkanai-Ishikari-Kashiwazaki (Construction cost: JPY 573.0 billion)		-13.6 to -3.7%	-9.1 to -2.3%	-6.5 to -1.0%	-4.6 to 0.1%	-3.1 to 1.1%
[R4] Sakhalin-Ishikari-Tomakomai-Fukushima (Construction cost: JPY 526.4 billion)		-8.4 to -2.0%	-5.6 to -0.5%	-3.6 to 0.8%	-1.9 to 1.9%	-0.5 to 3.0%

Table 15: Japan-South Korea route: Estimated results of regulated grid tariff model (Unit: IRR%)

Set value of grid tariff	Billing area (Power demand)	0.06 yen / kWh	0.07 yen / kWh	0.08 yen / kWh	0.09 yen / kWh	0.10 yen / kWh
[K1] Busan-Maizuru (Construction cost: JPY 246.5 billion)	Kansai Electric Power Company area (148.6 TWh)	0.4 to 3.8%	2.5 to 5.5%	4.4 to 7.1%	6.0 to 8.6%	7.6 to 10.0%
[K2] Busan-Matsue-Hino (Construction cost: JPY 202.4 billion)	Chugoku Electric Power Company area (60.2 TWh)	-18.9 to -4.4%	-11.1 to -3.0%	-8.0 to -1.8%	-5.9 to -0.7%	-4.2 to 0.3%
[K3] Busan-Imari/Oita-Ikata (Construction cost: JPY 212.3 billion)	Kyushu Electric Power Company area (85.7 TWh)	-12.3 to -3.4%	-8.4 to -2.0%	-5.9 to -0.7%	-4.1 to 0.4%	-2.6 to 1.5%

*In the red frames, the IRR median value is positive.

Source：ASG Study Group Second Report, 2018, REI

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1. Business models for investment recovery and estimated results

3) Transmission rights sales model: Japan-Russia route and Japan-South Korea route

Assumptions

Payback period	25 years
O&M ratio	1 - 3% of initial investment cost
Amount of transmission right	2 GW per one-way
Set value of annual average transmission right prices	0.2, 0.4, 0.6, 0.8, 1.0 yen/kWh

Table 16: Japan-Russia route: Estimated results of transmission right sales models (Unit: IRR%)

Set value of annual average transmission right prices	0.2 yen /kWh	0.4 yen /kWh	0.6 yen /kWh	0.8 yen /kWh	1.0 yen /kWh
[R1] Sakhalin-Kashiwazaki (Construction cost: 430.5 billion JPY)	Max. -11.0%	-15.1 to -4.0%	-5.1 to 0.2%	-1.0 to 2.6%	2.0 to 5.1%
[R2] Sakhalin-Ishikari-Kashiwazaki (Construction cost: 461.9 billion JPY)	Max. -12.0%	Max. -4.6%	-6.3 to 0.9%	-1.9 to 1.9%	1.1 to 4.3%
[R3] Sakhalin-Wakkanai-Ishikari-Kashiwazaki (Construction cost: 573.0 billion JPY)	Max. -15.7%	Max. -6.7%	-10.7 to -2.9%	-5.1 to -0.2%	-1.8 to 2.0%
[R4] Sakhalin-Ishikari-Tomakomai-Fukushima (Construction cost: 526.4 billion JPY)	Max. -14.0%	Max. -5.9%	-8.7 to -2.1%	-3.8 to 0.6%	-0.7 to 2.9%

Table 17: Japan-South Korea route: Estimated results of transmission right selling models (Unit: IRR%)

Set value of annual average transmission right prices	0.2 yen /kWh	0.4 yen /kWh	0.6 yen /kWh	0.8 yen /kWh	1.0 yen /kWh
[K1] Busan-Maizuru (Construction cost: 246.5 billion JPY)	Max. -5.2%	-2.9 to 1.3%	2.7 to 5.6%	6.7 to 9.2%	10.2 to 12.5%
[K2] Busan-Matsue-Hino (Construction cost: 202.4 billion JPY)	-12.5 to -3.4%	-0.1 to 3.3%	5.4 to 8.0%	9.8 to 12.1%	13.7 to 15.9%
[K3] Busan-Imari/Oita-Ikata (Construction cost: 212.3 billion JPY)	-14.4 to -3.9%	-0.8 to 2.8%	4.7 to 7.4%	9.0 to 11.4%	12.8 to 15.0%

*In the red frames, the IRR median value is positive.

Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results

4) Congestion charge model for Japan-South Korea interconnector

The transmission operators obtain the congestion charge which is calculated as “multiplication of wholesale price difference and actual transmitted electricity amount” as a revenue at the time of market splitting in the interconnector between markets.

South Korea

Japan

Power flow

JPY a /kWh

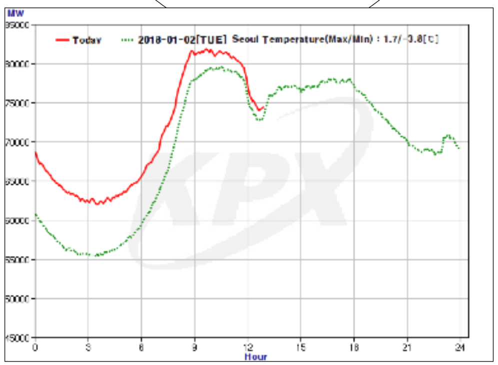
smart KPX

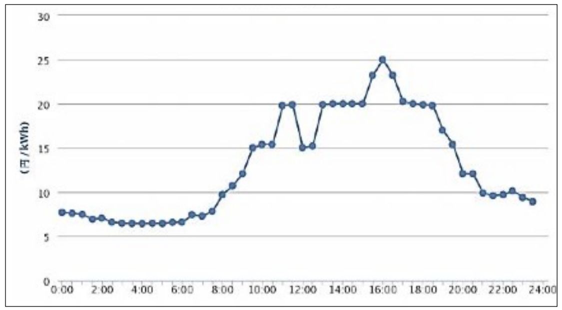
JEPX Japan Electric Power eXchange

JPY b /kWh

Electricity flows from lower-priced market to higher-priced market.

Amount of income;
|a - b| JPY/kWh X 2 GW



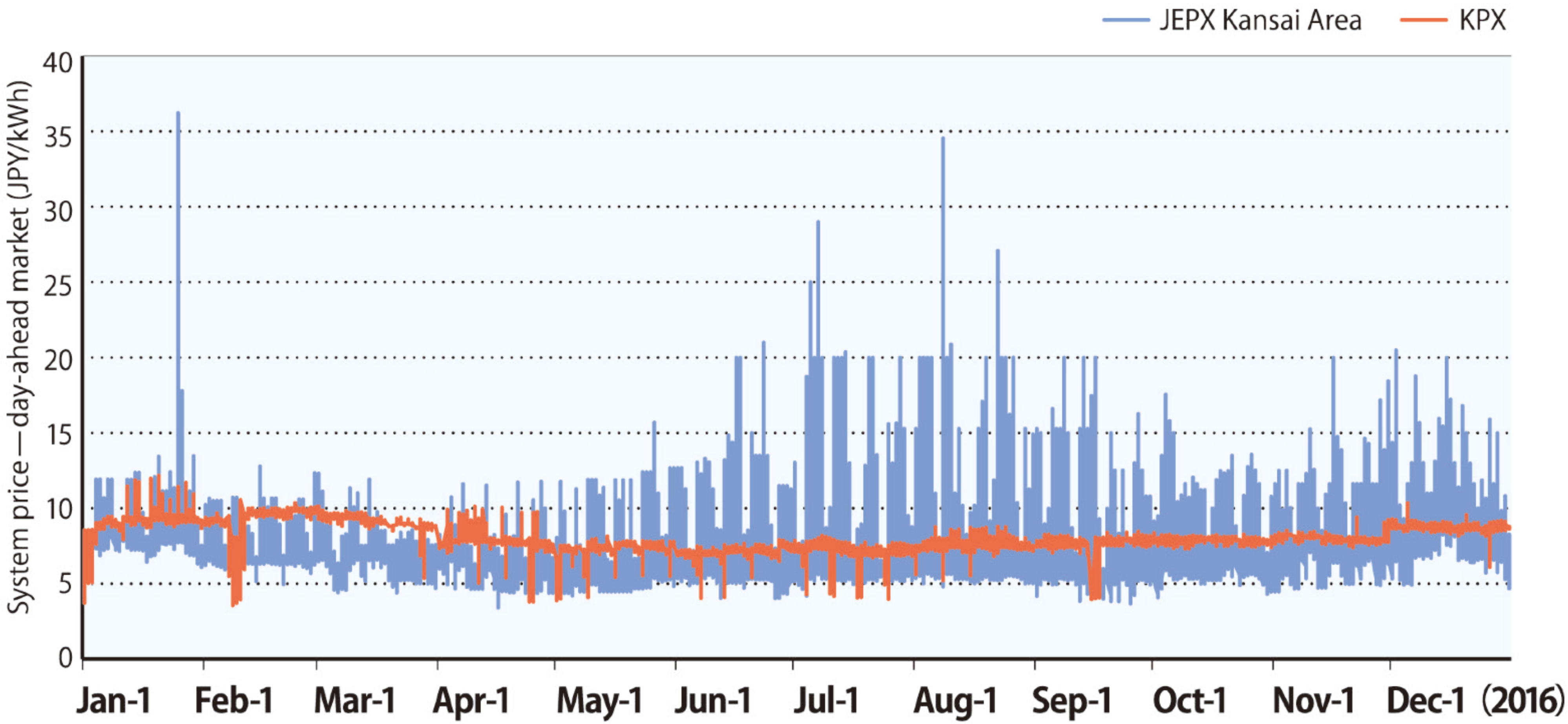


Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results

4) Congestion charge model for Japan-South Korea interconnector

Typical examples of Japanese and South Korean system prices in both day-ahead markets



Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results

4) Congestion charge model for Japan-South Korea interconnector

Assumptions

Payback period	25 years
O&M ratio	1 - 3% of initial investment cost
Annual average capacity factor	50%, 75%, 100%
Exchange conversion	Middle rate of the day prior to trading day
JEPX price	Each year of 2016 and 2017 (every 30 minutes)
Market prices in other countries	System prices at the same time on the same day of JEPX

Table 18: Japan-South Korea route: Estimated results of congestion charge model (Unit: IRR%)

Capacity factor	Japanese side market	50%	75%	100%
[K1] Busan-Maizuru (Construction cost: JPY 246.5 billion)	JEPX Kansai area	0.0 - 5.1%	5.5 - 10.2%	9.9 - 14.8%
[K2] Busan-Matsue-Hino (Construction cost: JPY 202.4 billion)	JEPX Chugoku area	2.6 - 7.4%	8.5 - 13.2%	13.4 - 18.5%
[K3] Busan-Imari/Oita-Ikata (Construction cost: JPY 212.3 billion)	JEPX Kyushu area	2.3 - 6.9%	8.1 - 12.5%	12.9 - 17.6%

*In the red frames, the IRR median value is positive.

Source：ASG Study Group Second Report, 2018, REI

1. Business models for investment recovery and estimated results: Conclusion

Four business models for interconnectors investment recovery estimated:

1) The low priced electricity is the key to recover the investments in interconnectors in the case of "generators/suppliers dedicated line model -selling electricity model“ to procure electricity from overseas power plants or suppliers and sell it in Japan.

- *the impact on the profitability could be significant by the power procurement prices and by the Japanese market frameworks.*

2) The consumers would pay less than 1% of current electricity tariff to recover the investments by existing incumbent utilities through grid tariff, in the case of "regulated grid tariff model"

3) It is uncertain whether investments can be recovered due to difficulty in forecasting the appropriate transmission price, in the case of "transmission right sales model" that sells transmission rights of interconnector to power producers or retailers for recovery of investments.

4) Investment can be recovered even with a relatively low capacity factor, in the case of “congestion charge model,” which market price differences in the consolidated market are the revenues,.

- *careful discussions should be conducted to adopt the congestion revenue income model by transmission system operators, market managers and governments including regulatory agencies, as the wholesale electricity trading price of the two countries approaches equilibrium and the profitability changes due to changes in the system.*

Source：ASG Study Group Second Report, 2018, REI

Recent developments in Northeast Asia and Japan

Renewable energy growth and the need for interconnectors

Renewable energy in Northeast Asia continues to expand. The situations in South Korea, China and Japan can be summarized as follows.

South Korea: Under the Moon Jae-in administration, which has committed to phasing out nuclear and coal-fired power, South Korea is promoting maximum expansion of renewable energy at the level of national energy policy with the expectation that International Grid Connection will be utilized. In the country's 3rd Energy Master Plan (June 2019), it set a new target of raising the country's renewable energy ratio to 30-35% by 2040.

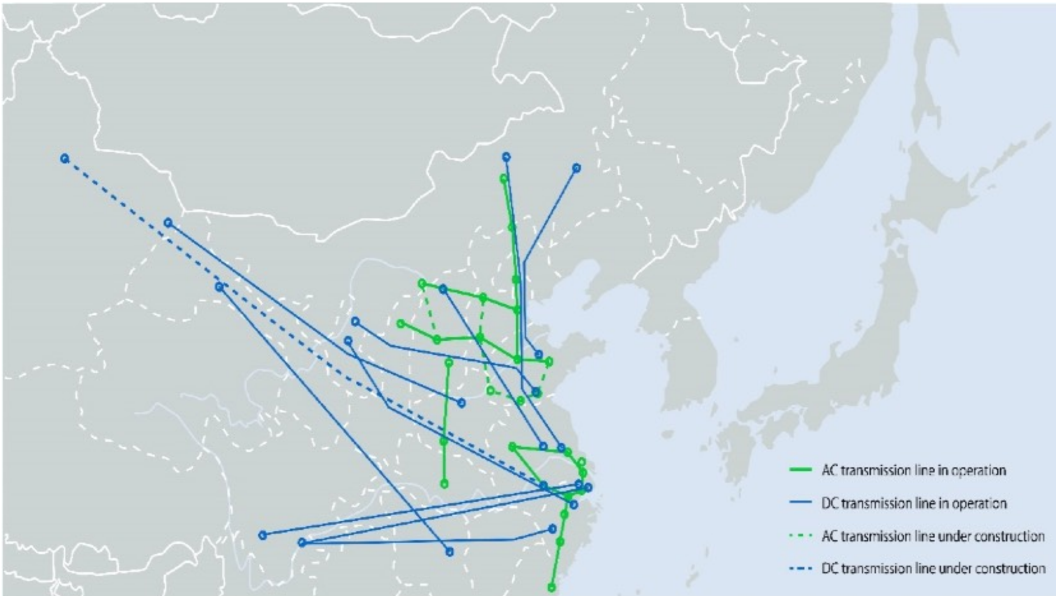
China: Installed capacity for renewable energy in China at the end of 2018 increased 12% year-on-year to 729 GW, accounting for roughly 38.4% of the total. Its total electricity generation increased 169 TWh to 1,867 TWh, or 26.7% of the total. The key 2020 targets for renewable energy deployment set by the Chinese government in 2018 have either been met or nearly met. The State Grid Corporation of China (SGCC) is currently constructing and operating a long-distance, ultra-high voltage transmission line project over 32,000 kilometers in 22 projects in preparation for further large-scale deployment.

Table 1: China's renewable energy deployment targets and results

	Installed capacity in 2020 (target) (GW)	Installed capacity in 2018 (GW)	Electricity generation in 2018 (TWh)
Hydropower	380	352	1,233
Wind	210	184	366
Solar PV	105	175	178
Bioenergy	15	18	91
Total	710	729	1,867

Source: Renewable Energy Institute based on National Development and Reform Commission and National Energy Administration (2016a, 2016b), and National Energy Administration (2019)

Figure 1: China SGCC's domestic ultra-high voltage transmission project



Source: Partially adapted by Renewable Energy Institute from SGCC (2019)

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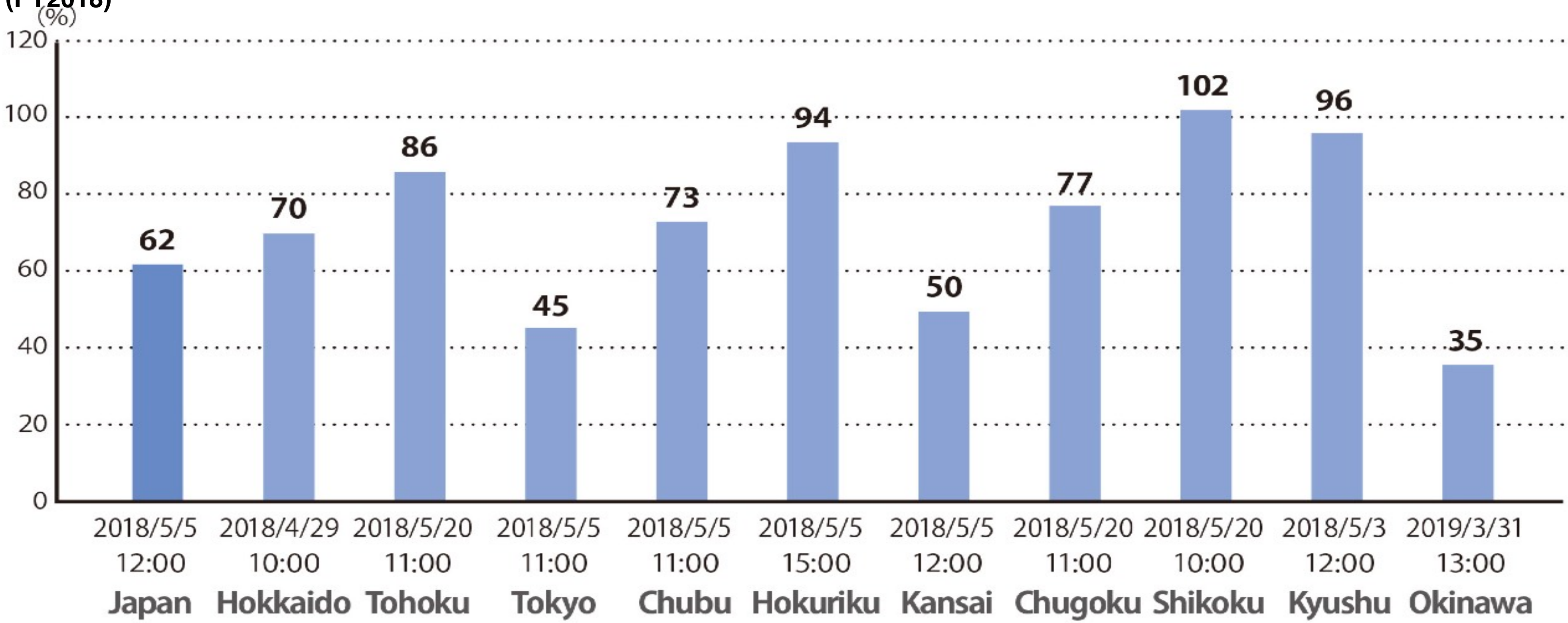
Recent developments in Northeast Asia and Japan

Renewable energy growth and the need for interconnectors

Japan: Installed capacity in 2018 included 6.5 GW of solar PV, for a cumulative total of 55.5 GW, and 261 MW of wind power, for a total of 3.6 GW (IRENA, 2019b). Growth in onshore wind installations has slowed, but with the Renewable Energy Sea Area Utilization Act (Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities Using Maritime Renewable Energy Resources) going into effect on April 1, 2019, Japan is poised to move forward with further deployment of offshore wind power, with related power grids expected to be enhanced and onshore wind power to expand. Within Japan's regional service areas, there are time periods when renewable energy's share of the power supply temporarily rises to a high level

Figure 2: Largest hourly renewable energy shares and time slots that were recorded in service areas across Japan (FY2018)



Source: Renewable Energy Institute based on data released by the general electricity transmission and distribution utilities

Recent developments in Northeast Asia and Japan

Changing political situation of Korean Peninsula and specific discussion of interconnectors

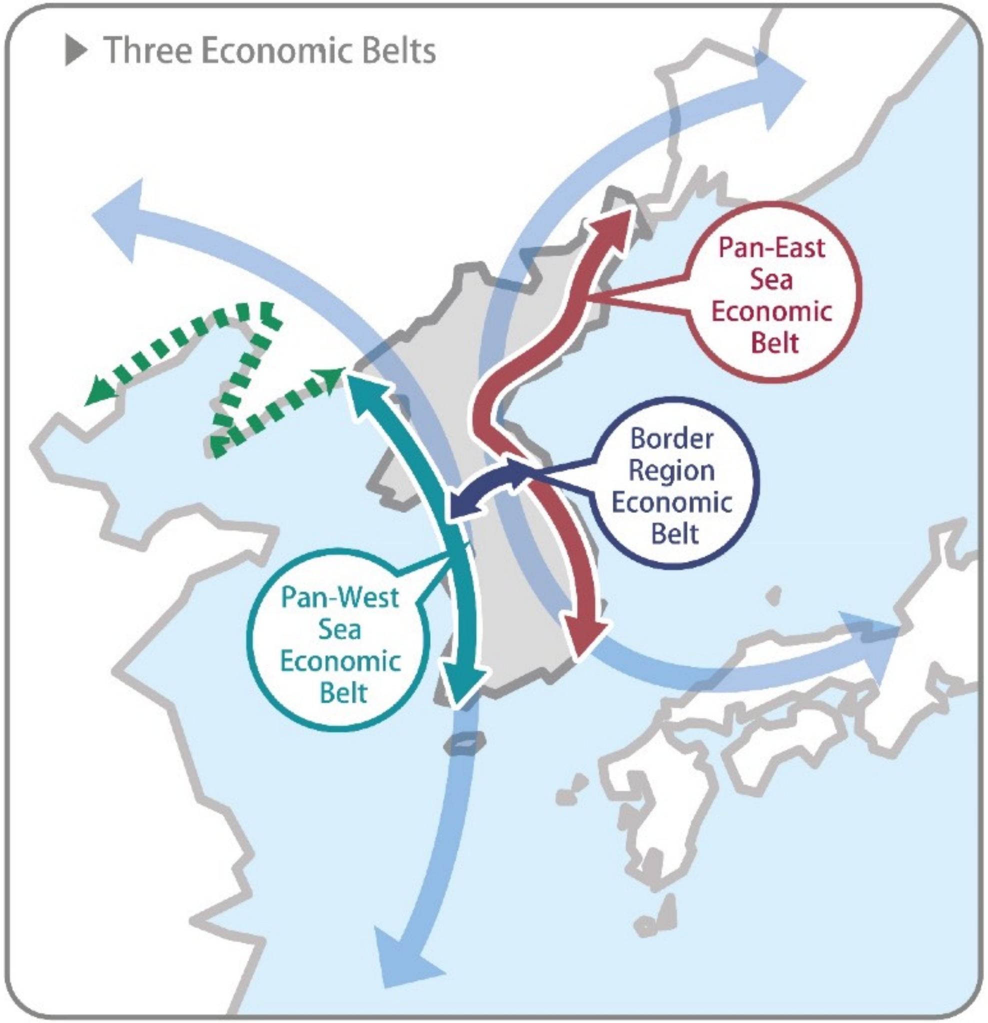
With the political situation on the Korean Peninsula improving, there have been multiple summits between the leaders of the Democratic People's Republic of Korea (North Korea) and South Korea, and the two countries have agreed to cooperate economically.

For the South Korean government, the economic integration of the Korean Peninsula is a first step toward securing direct routes with China and Russia and accessing a major economic zone.

Regarding energy cooperation in particular, there are substantial expectations for development and expansion of renewable energy and construction of interconnectors.

As this dialogue on economic cooperation deepens, construction plans for an international submarine transmission route between China and South Korea are expected to accelerate.

Figure 3: Moon Administration plan



Source: Extracted from the Ministry of Unification (n.d., p. 24)

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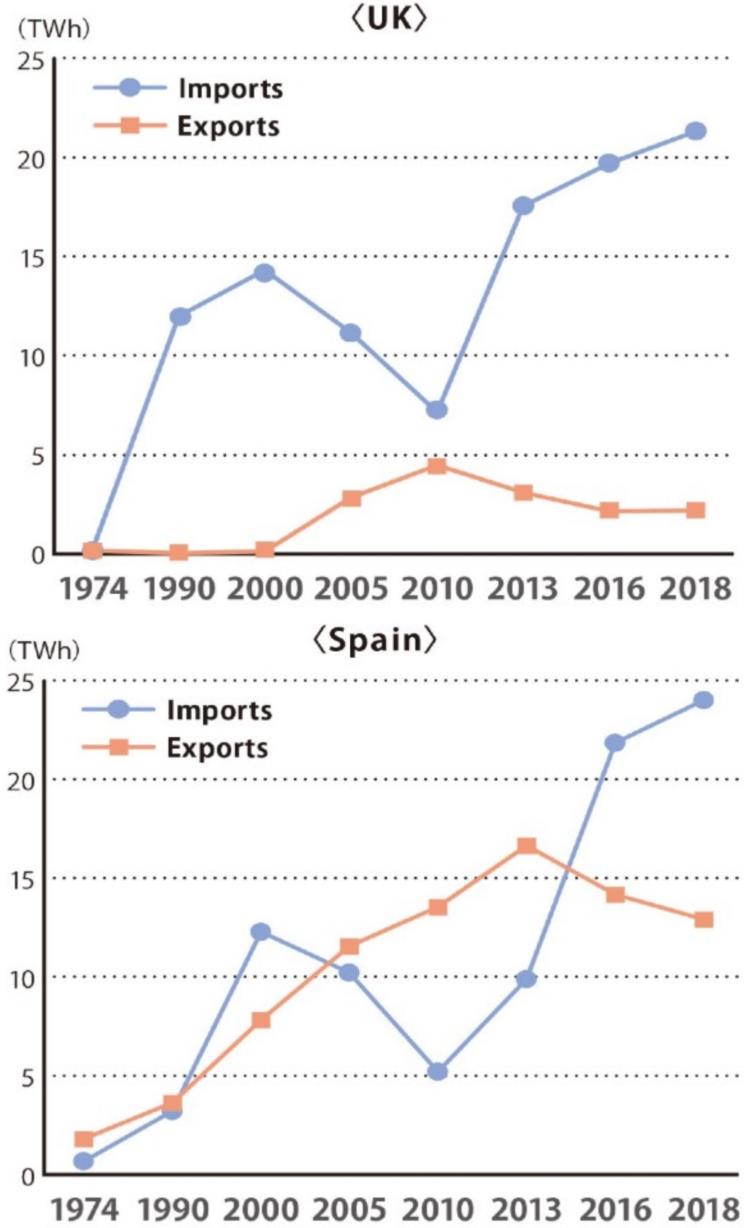
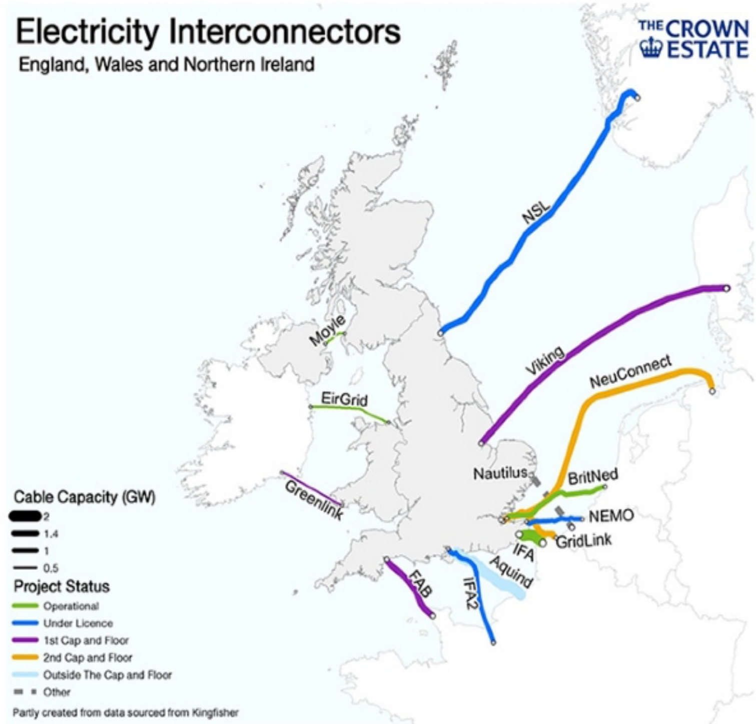
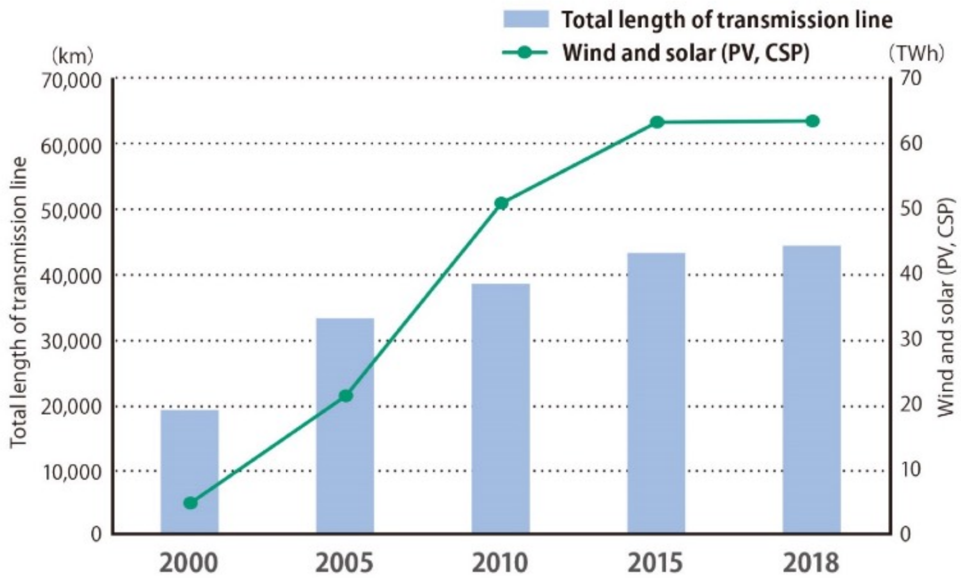
International grid initiatives in the UK and Spain

Figure 7: Electricity exports and imports in the UK and Spain







Source: Renewable Energy Institute based on IEA (2018), IEA (2019a), IEA (2019b)

Cost-benefit analysis of international grid connections

Approaches to the benefits of international grid connections

1) Characteristics of benefit analysis for international grid connections

- Differences in how benefits are set in cost-benefit analysis between domestic inter-connections and International Grid Connections (interconnectors):
  [Domestic inter-connections] Debate centers on increasing economic performance (increasing social welfare)
  [International Grid Connection (interconnectors)] Broad range of items are set, not just economic performance.

➢ Economic benefits increase for connected regions and the country overall, but the benefits and drawbacks differ depending on the region and country, so multiple benefit items are set and discussions are comprehensive.

➢ Cost-benefit analysis is utilized to discuss general future prospects, such as what situation would be most deficit for the overall region subject to the analysis from a medium/long-term perspective (after 2030, for example).

2) Prior cost-benefit analyses

- Summary and comparison of benefit items in three examples of cost-benefit analysis for International Grid Connection published since 2017 (Table 4).
- In all three cases, expansion of renewable energy and integration of energy markets (establishment of international grid connections), as a climate change policy, are included in assessment items, and region-specific phenomena are also considered.

Table 4: Examples of cost-benefit analysis for international grid connections

Assessment body (Year)	ENTSO-E CBA2.0 (2018)	Ofgem (2017)	ASEAN Centre for Energy / GEIDCO / U.N. ESCAP (2018)
Scope	European international interconnector (from 2030)	International interconnector connecting UK and other countries (from 2020's)	Southeast Asia international interconnector (2030 - 2050)
Assesment indicators/ categories (unit)	• Socio-economic welfare*1 (Euro) • CO_2 variation (ton) • RES integration (MW/MWh) • Variation in societal well-being as a result of variation in CO_2 emissions and RES integration. • Grid losses • Adequacy to meet demand • System flexibility • System stability (transient stability, voltage stability, frequency stability) • Costs (CAPEX/OPEX)(Euro) • Residual impact (environmental, social, other)	• Socio-economic welfare*2 (GBP) • Improvement of reserve securement • Improvement of supply stability • Contribution to decarbonization • Cost (CAPEX/OPEX)(GBP)	• R&D investment (USD) • New employment opportunities (number of people) • Number of people who do not have universal access to electricity (number of people) • Average power generation cost (USD/kWh) • Gas consumption at gas-fired power plants (m^3) • Coal consumption at coal power plants (ton) • Energy efficiency (%) • CO_2 emissions reduction (ton) • SOx emissions reduction (ton) • NOx emissions reduction (ton) • Total investment (USD)

Source: Renewable Energy Institute based on ENTSO-E (2018), Ofgem (2017), ACE, et al. (2018)

Cost-benefit analysis of international grid connections

How interconnectors generate benefits

1) Viewing a phenomenon flow chart

- A flow chart summarizing the general phenomena that can be thought to occur when an interconnector is built between Country A and Country B, with reference made to benefit items in preceding studies conducted in other countries.
- Horizontal axis (three timeframes): Short term (phenomena assumed to occur simultaneous with interconnector construction); Short-to-medium term (phenomena expected to occur within several years of construction); Medium-long term (phenomena that could occur after a certain period of time).
- Arrow (→): When a phenomenon causes another phenomenon; Dotted line (. . .): Essentially, the same phenomenon viewed from a different perspective.
- Phenomena: Divided into two categories (phenomena themselves explained on the next pages)
  - ➢ Physical phenomenon: Impact brought or developed directly by the power system and interconnector.
  - ➢ Economic phenomenon: Impact brought or developed by the interconnector.

2) Economic phenomena

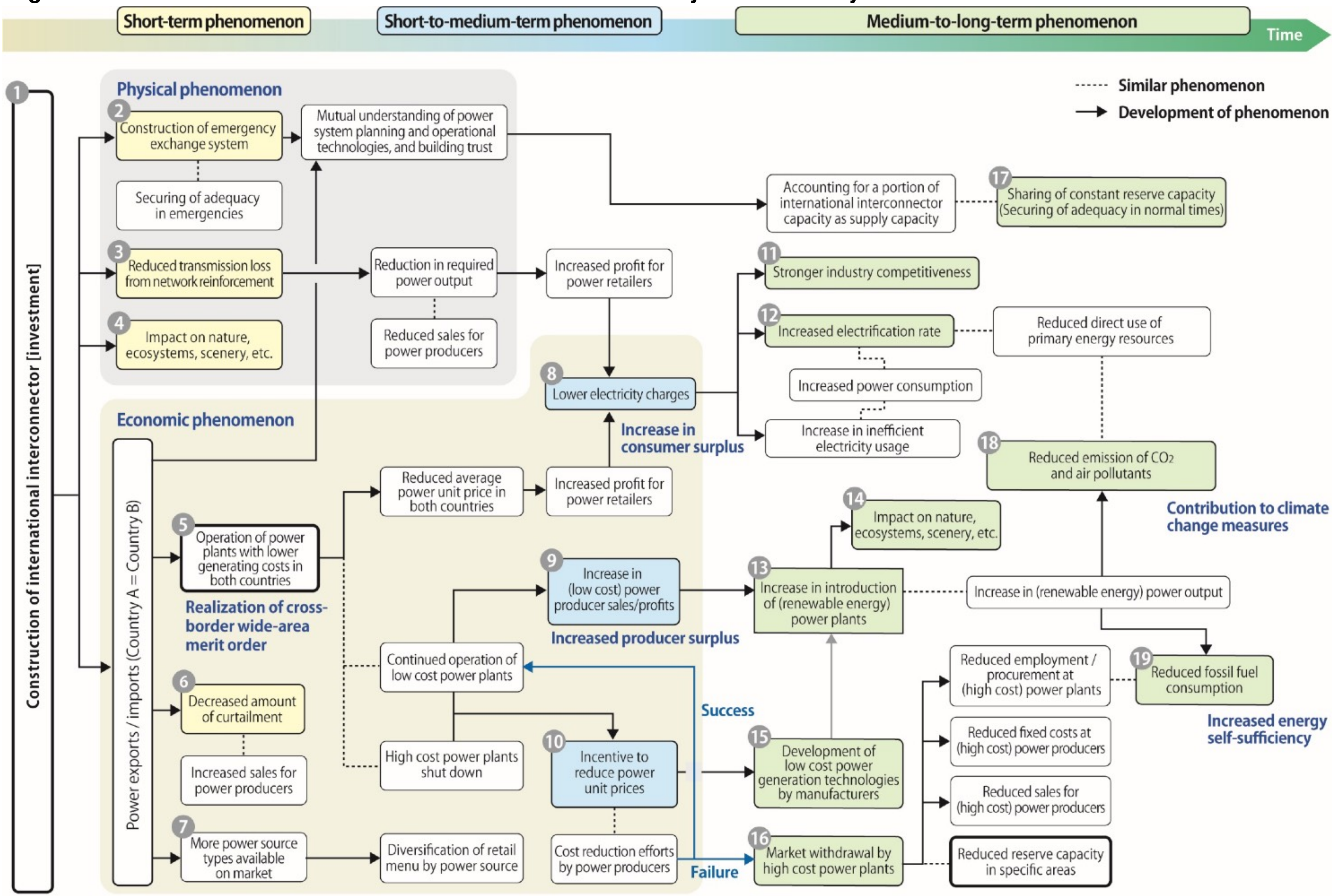
- Electricity transactions through an interconnector would create an inter-regional, cross-border merit order. As a result, electricity charges can be lowered and the competitiveness of renewables potentially increases.
- Power plants with high costs due to fuel costs, etc. will have a new incentive to reduce costs, but if high-cost plants fail to do so, it can be assumed they will shut down and a shift will take place to deployment of lower cost power plants.

3) Physical and other phenomena

- Building an emergency interchange measures system from outside the area would foster mutual understanding and trust regarding power system planning and operation technologies. As an extension of this, there is the potential for sharing power reserve through the interconnector.
- Other phenomena are those that are not caused by the interconnector alone but have the potential to develop as a result of the interconnector, either in terms of further quantitative expansion or shorter time periods, when there are certain other external factors. Increased industry competitiveness and an increased electrification rate are examples.

Cost-benefit analysis of international grid connections

Figure 11: Phenomenon flow for interconnector between Country A and Country B



Source: Renewable Energy Institute.

Cost-benefit analysis of international grid connections

Table 5: Explanation of phenomena for interconnector between Country A and Country B

Phenomenon	Phenomenon name	Content
❶	Construction of international interconnector	Investment is conducted in connection with construction of an international interconnector.
❷	Construction of emergency exchange system	System is constructed for securing adequacy in emergencies. For example, a system is developed in which both countries provide emergency assistance in disasters.
❸	Reduced transmission loss from network reinforcement	Building an international interconnector limits loop flow and reduces transmission loss.
❹	Impact (of transmission lines) on nature, ecosystems, scenery, etc.	Physical impact from construction of transmission lines and facilities occurs.
❺	Operation of power plants with lower generating costs in both countries	Creating a wide-area wholesale power market creates a situation in which power plants with lower generating costs go into operation first.
❻	Decreased amount of curtailment	When restrictions are placed on power plant output, power can be exported overseas via the international interconnector, so output restrictions are lessened.
❼	More power source types available on market	More power sources are made available on wholesale markets in both countries.
❽	Lower electricity charges	Electric power prices on wholesale power markets come down through wide-area merit order, so power retailer profits increase to create the resources for reducing electricity charges.
❾	Increase in (low cost) power producer sales/profits	Sales and profits of power producers with competitiveness in wholesale power markets increase.
❿	Incentive to reduce power unit prices	Power producers are incentivized to lower sales unit prices.
⓫	Stronger industry competitiveness	Companies' electricity-related costs are reduced, which raises the competitiveness of industry overall.
⓬	Increased electrification rate	There is a transition from direct use of city gas, LPG, kerosene, gasoline, diesel and other fossil fuels to services being received via electricity.
⓭	Increase in introduction of (renewable energy) power plants	Introduction of renewable energy power plants increase.
⓮	Impact (of renewable energy power plants) on nature, ecosystems, scenery, etc.	Physical impact from establishment of introduction of renewable energy power plants occurs.
⓯	Development of low cost power generation technologies by manufacturers	Generator manufacturers invest R&D resources into lower cost power generation technologies.
⓰	Market withdrawal by high cost power plants	It has been difficult to make a profit by operating high cost power plants, so these plants stop operating.
⓱	Sharing of constant reserve capacity	The power sources of the countries connected to the international interconnector are accounted for as the supply capacity of its own country in normal times. This makes it unnecessary to maintain surplus power facilities.
⓲	Reduced emission of CO_2 and air pollutants	Emission of pollutants from fossil fuels, including carbon dioxide (CO_2), nitrogen oxide (NO_x), and sulfur oxide (SO_x) are reduced.
⓳	Reduced fossil fuel consumption	Consumption of fossil fuels such as coal, petroleum and natural gas is reduced.

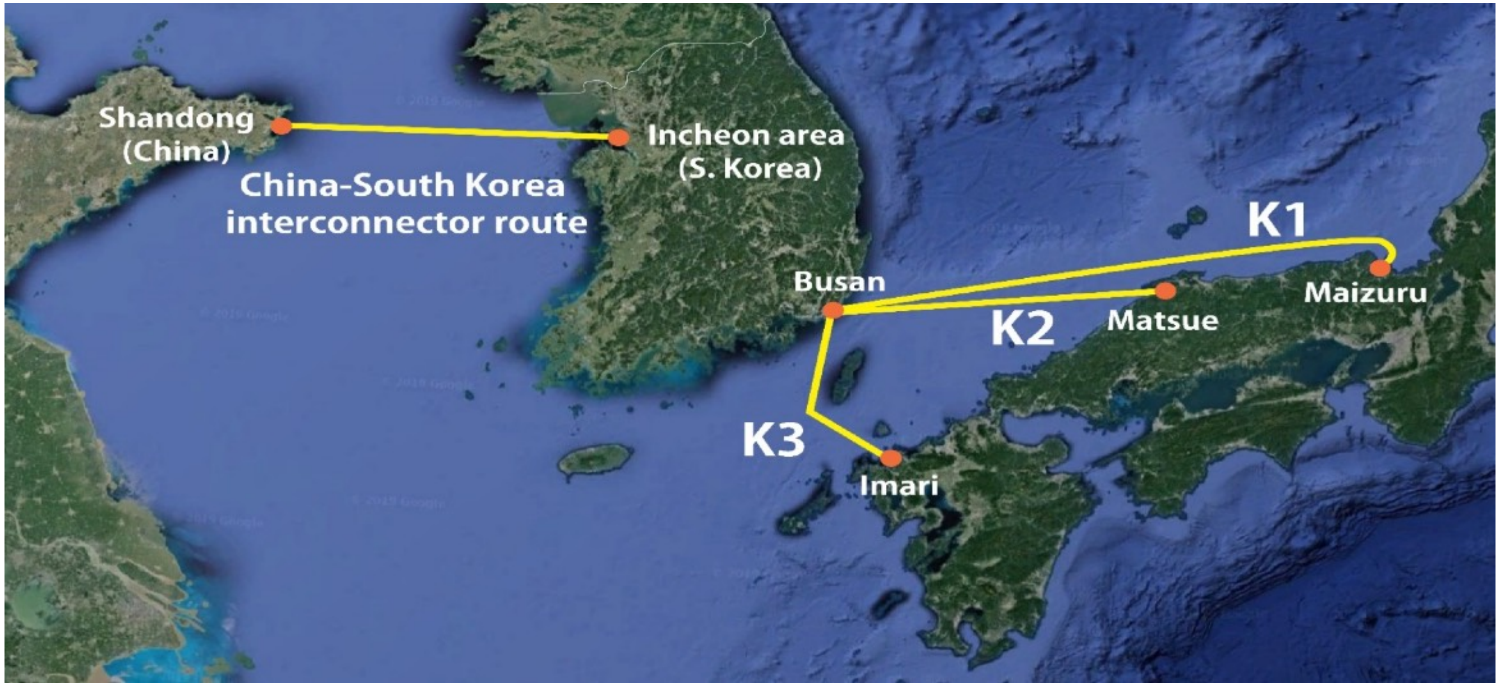
Source: Renewable Energy Institute based on ENTSO-E (2018), Ofgem (2017), ACE, et al. (2018)

Analysis of the benefits of a Japan-South Korea interconnector

1) Consideration of the phenomenon flow for a proposed specific route

- Of the four Japan-Russia interconnector routes and three Japan-South Korea routes considered in the Second Report, one route (K3 route) was selected for the sake of expedience, and the specific benefits assumed to result from the interconnector were considered.
- However, this does not mean that Japan-South Korea route candidates have been narrowed down; the same considerations could be made for the other routes as well. The K3 route was selected as an example in light of the following three points: 1) it is related to accelerated deployment of renewable energy in South Korea, 2) mutual transactions are possible because South Korea has a wholesale electricity market, and 3) it can be considered in connection with curtailment in the Kyushu service area.
- In making considerations, discussions were conducted on the premise that a China-South Korea interconnector has already been built.
- The considerations resulted in identifying the following three types of phenomena as specific to the K3 route: 1) phenomena connected with electricity flows from South Korea to Japan, 2) phenomena connected with electricity flows from Japan to South Korea, and 3) phenomena related to emergency interchange measures from outside the area.

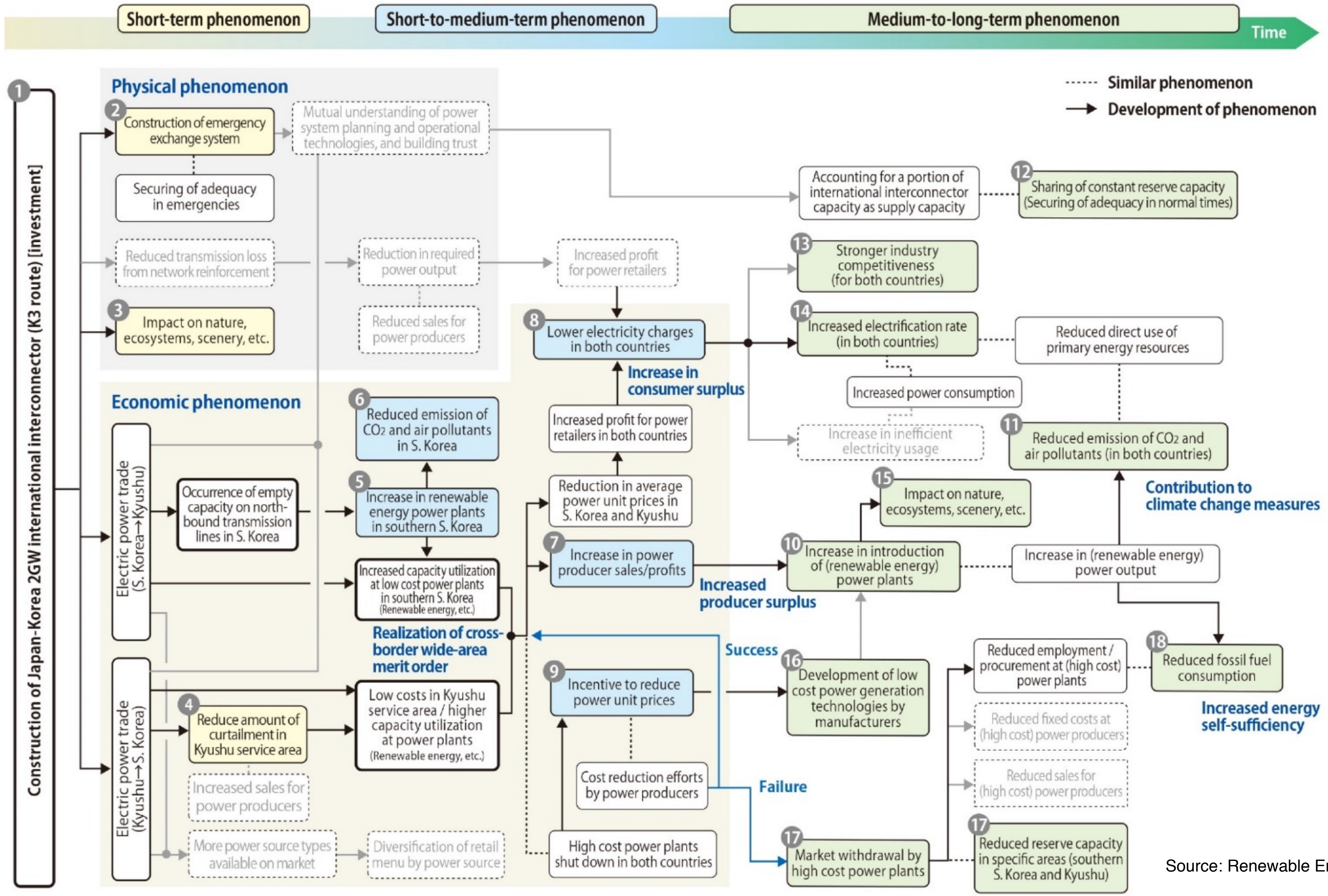
Figure 12: Three possible routes for Japan-South Korea interconnection from the Asia International Grid Connection Study Group Second Report, and China-South Korea interconnector



Source: Renewable Energy Institute.

Cost-benefit analysis of international grid connections

Figure 13: Phenomenon flow with construction of Japan-South Korea interconnector-K3 Route



Source: Renewable Energy Institute.

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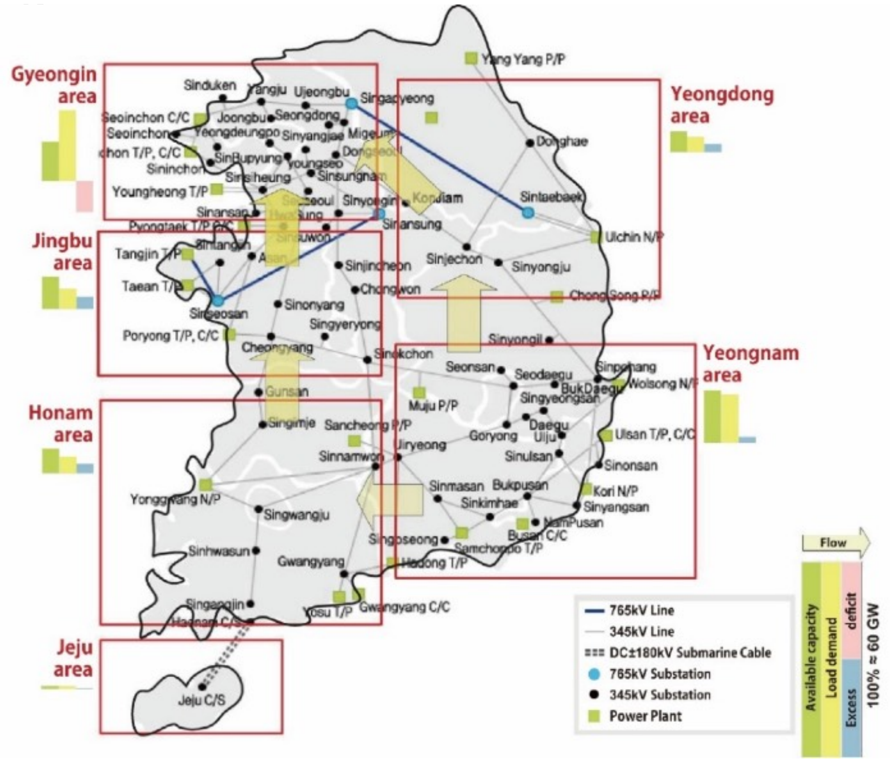
Analysis of the benefits of a Japan-South Korea interconnector

2) Phenomenon 1 specific to a Japan-South Korea interconnector-K3 Route (Expansion of renewable energy in South Korea)

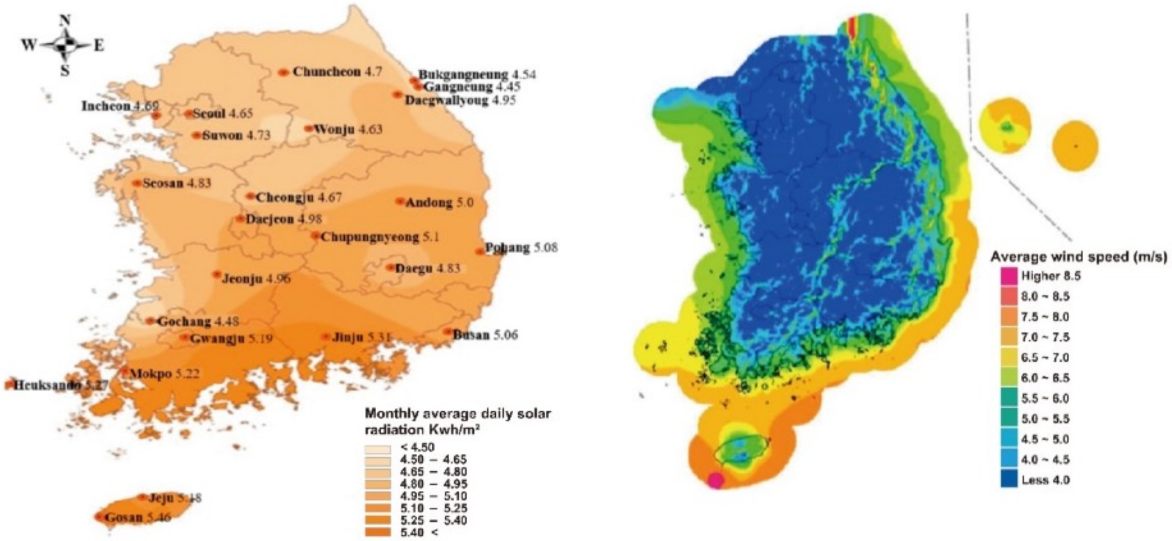
- It was suggested that when electricity flows from South Korea to Japan, there is the potential for expansion of renewable energy in South Korea domestically.
- This is related to electricity flows within South Korea. Within the country, electricity mainly flows from the southern region, where there are many power sources, to the northern region (toward Seoul), where demand is largest. Solar PV and wind power potential are concentrated in the southern region, but domestic south-north transmission routes are limited and transmission capacity does not have adequate availability, so to expand deployment of renewable energy, it is necessary to create available capacity on south-north transmission line. Electricity flows from South Korea to Japan on the K3 route have the potential to create this availability.

Figure 14: Electric power flows in South



Source: Partially adapted by
Renewable Energy Institute from Khan, et al. (2013, p.969), Figure 15

Figure 15: Map of average daily solar radiation in South Korea (left) and meteorological map of wind speeds in South Korea (right)



Source: M. H. Alsharif, et al. (2018). Figures 4 and 11.

Analysis of the benefits of a Japan-South Korea interconnector

3) Phenomenon 2 specific to a Japan-South Korea interconnector -K3 Route (reduced curtailment in Kyushu area)

- When electricity flows from Japan to South Korea, on the K3 route, surplus electricity is sent to South Korea and this could potentially help reduce curtailment in the Kyushu service area. This is brought about by wholesale electricity prices in Japan during curtailment timeslots dropping lower than prices in South Korea.

4) Phenomenon 3 specific to a Japan-South Korea interconnector -K3 Route (establishment of an emergency interchange system)

- A simulation was conducted based on a 2 GW-class accident (Case 6 of Figure 16) and margin during peak demand in Japan and South Korea in the summer of 2018, and how the accident would impact the other country was considered.
- If current reserve margin is maintained, it was suggested that the impact of the interconnector on the other country would be limited. Also, when an accident of 2 GW or more occurs, it was suggested there is the possibility of emergency interchange through the interconnector (Table 6).

Figure 16: Accident scenarios

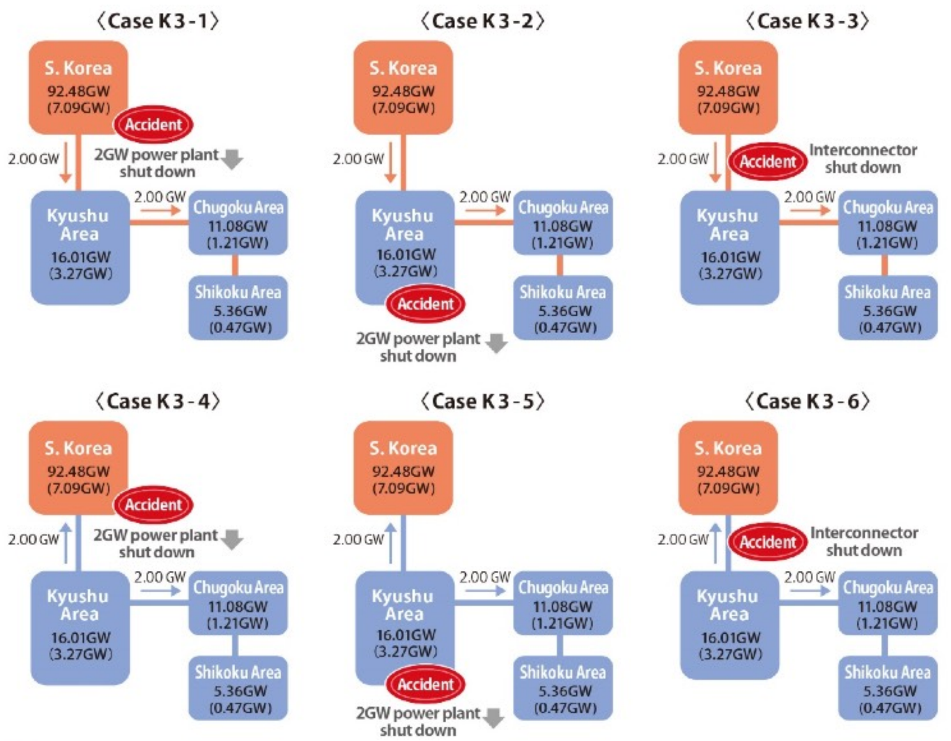


Table 6:
Consideration of responses to accidents occurring related to the K3 Route

Accident case	K3-1	K3-2	K3-3	K3-4	K3-5	K3-6
Current	S. Korea → Kyushu area			Kyushu area → S. Korea		
Area	In S. Korea	In Kyushu	Interconnector	In S. Korea	In Kyushu	Interconnector
In S. Korea	Activate reserve capacity	No change	Curtailment	Activate reserve capacity	In some cases, activate reserve capacity	Activate reserve capacity
In Kyushu	In some cases, activate reserve capacity	Activate reserve capacity	Activate reserve capacity	No change	Activate reserve capacity	Curtailment
Japan-S. Korea interconnector flow	In some cases, reduced	No change	Zero current	No change	In some cases, reduced	Zero current
Chugoku-Kyushu interconnector flow (Kyushu→Chugoku)	In some cases, reduced	In some cases, reduced	In some cases, reduced	No change	In some cases, reduced	No change

Source: Renewable Energy Institute.

Analysis of the benefits of a Japan-South Korea interconnector

5) Summary

Results of discusisons on interconnectors in general (when an interconnector connects Country A and Country)

- **Physical phenomena** in the short-to-medium-term timeframe include establishment of an emergency interchange system, reduced transmission loss, and impact on nature, ecosystems, and scenery.
- **Economic phenomena** in the short-to-medium-term timeframe include realization of a cross-border, wider area merit order, reduced amount of curtailment, and increased power source options available to both markets. Cross-regional merit order has been evaluated in prior studies as a social welfare.

Results of discussions on the K3 route

- If there are electricity flows from South Korea to Japan after construction of the China-South Korea interconnector, there is the potential for a certain amount of capacity surplus to occur on south-north transmission lines in South Korea and this would contribute to expansion of renewable energies such as solar PV and wind power in the southern part of the country.
- If power flows from Japan to South Korea in hours when wholesale electricity prices in Japan are inexpensive, it would potentially reduce the amount of curtailment in the Kyushu area and depending on the system also reduce FiT surcharge tariffs.
- Regarding establishment of an emergency interchange system through an interconnector, if there are power source stoppage accidents on the scale of 2 GW or an accident on an interconnector, it would be covered by reserve margin within the area, the amount of emergency transmission on an interconnector and cross-regional transmission lines would not be affected. However, if reserve margin is diminished in the future or a power plant larger than around 2 GW shuts down due to an accident, emergency interchange would be effective, and an interconnector would be useful as a means to more flexibly responding to the accident.

Section 4: Stakeholder analysis for a Japan-South Korea interconnector

1) Organizing phenomena with benefit incidence table

- A qualitative assessment of benefits and deficits was conducted using a benefit incidence table* to show how each phenomenon (1 to 18) in the phenomenon flow for the K3 route considered in Figure 13 would impact stakeholders (Table 7).

Table 7: Findings of benefit incidence evaluation (qualitative) for the K3

	K3 Route Assessment of benefits and losses when each stakeholder is directly connected to the respective phenomena	International transmission providers	Grid operators in areas connected by international interconnector		Consumers		(High cost) power producers	(Low cost) power producers	(Low cost) generator manufacturers	Residents near facilities	Policy makers (Policy targets)	
			Kyushu	S. Korea	Kyushu	S. Korea					Japan	S. Korea
	① Construction of international interconnector (investment)	−										
Short-term phenomenon	② Construction of emergency exchange system		+	+								
Short-term phenomenon	③ Impact (of transmission lines) on nature, ecosystems, scenery, etc.									−		
Short-term phenomenon	④ Reduce amount of curtailment in Kyushu service area		+		+			+				
Short-to-medium-term phenomenon	⑤ Increase in renewable energy power plants in southern S. Korea			+ / −		+	+ / −	+	+			+
Short-to-medium-term phenomenon	⑥ Reduced emission of CO_2 and air pollutants in S. Korea					+				+		+
Short-to-medium-term phenomenon	⑦ Increase in power producer sales/profits (Increased producer surplus)						−	+ / −				
Short-to-medium-term phenomenon	⑧ Lower electricity charges (Increase in consumer surplus)				+	+					+	+
Short-to-medium-term phenomenon	⑨ Incentive to reduce power unit prices						+ / −	+	+			
Medium-to-long-term phenomenon	⑩ Increase in introduction of (renewable energy) power plants		+ / −	+ / −	+	+	+ / −	+	+		+	+
Medium-to-long-term phenomenon	⑪ Reduced emission of CO_2 and air pollutants (Contribution to climate change measures)				+	+				+	+	+
Medium-to-long-term phenomenon	⑫ Sharing of reserve capacity	+	+	+			−	+ / −				
Medium-to-long-term phenomenon	⑬ Stronger industry competitiveness										+	+
Medium-to-long-term phenomenon	⑭ Increased electrification rate				+ / −	+ / −	+	+	+			
Medium-to-long-term phenomenon	⑮ Impact (of renewable energy power plants) on nature, ecosystems, scenery, etc.									−		
Medium-to-long-term phenomenon	⑯ Development of low cost power generation technologies by manufacturers						+	+	+ / −			
Medium-to-long-term phenomenon	⑰ Market withdrawal by high cost power plants (Reduced reserve capacity in specific areas)		+ / −	+ / −			−	+				
Medium-to-long-term phenomenon	⑱ Reduced fossil fuel consumption (Increased energy self-sufficiency)				+	+					+	+

(*) Benefit incidence tables organize the benefits to stakeholders of public works investment on a benefit-by-benefit basis (Morisugi, et al., 1988).

Source: Renewable Energy Institute.

Cost-benefit analysis of international grid connections

Stakeholder analysis for a Japan-South Korea interconnector

2) Summary

- Stakeholders that would be negatively impacted over the short-to-medium term by a Japan-South Korea interconnector include power producers and residents living in areas where facilities would be built.
- Among these, power producers operating with high cost power plants would need to convert their business. And even low cost producers would be subject to more pressure to further reduce costs. Accordingly, power producers will have to transit to generating technologies that further lower costs overall, and in some cases invest in and enter new business areas like the interconnector business.
- For people living where transmission lines and renewable power plants would be built, the facilities may have some impact on scenery and ecosystems, but existing thermal power plants would shut down, which would bring the benefit of reduced air pollutants like NOx, SOx, and particulate matter (PM). Based on these factors, when facilities are to be established, it will be important to take considerations based on a process that includes environmental assessments.
- Regarding stakeholders other than power producers and people living near the facilities, interconnectors generate many phenomena that are generally positive. Accordingly, in promoting interconnectors, it is important to have a sufficient understanding of stakeholders negatively affected and to take proactive initiatives with respect to stakeholders on whom the impact is positive.

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Summary of how environmental value handled when electricity traded via international transmission

1) National emission calculations

- GHG emissions of each country calculated and reported based on IPCC Guidelines.
- Emissions from the electricity generation sector counted are only those emitted from burning fuel in one's own country.
- Emissions from thermal power plants in Country A counted in full as the emissions of Country A even if the electricity is sent to Country B by international transmission and consumed in Country B. They are not counted as the emissions of Country B.

[Specific Example]

- ➢ Sweden report: Low emissions in 2003 when lower electricity generation from hydropower was supplemented primarily with imports, and high emissions in 1996 when supplemented with domestic oil-fired thermal power.
- ➢ Denmark report: Carbon dioxide emissions increase in years with high exports and decrease in years with high imports.
- ➢ In the emissions reports of both countries, carbon dioxide from coal-fired power exported from Denmark to Sweden is counted as the emissions of Denmark and not included in Sweden’s emissions, in accordance with the IPCC Inventory Guideline.

2) Corporate emission calculations

- When corporate emissions are calculated, the de facto international standard is the standards and guidance in the Greenhouse Gas Protocol.
- The GHG Protocol Scope 2 Guidance stipulates two methods for calculating emissions from consumption of electricity acquired or purchased from another entity.
- Market standard: Calculated with emissions factors for electricity the company has purposefully chosen
- Location standard: Calculated with the average emissions intensity of grids on which energy consumption occurs (covers a location).
- For CDP, SBT, RE100 and other programs, effectively, companies must calculate their emissions with the market standard.
- Example of method for calculating emissions factors with the market standard: Green Power Certificates, EU Guarantees of Origin, power purchase agreements (PPA), etc.

[Summary]

In current international electricity transactions, when Company X in Country A concludes a contract with Power Provider Y in Country B and purchases renewable power from Country B, the emissions of Company X are reduced.

International grid connections and energy security

Section 1: The concept of energy security in the fossil fuel era

- Generally, in Europe and elsewhere, international grid connections are thought to contribute to energy security.
  → "It positively affects supply stability from the standpoint of reserve capacity and also increases energy self-sufficiency because it helps mitigate the effects of output fluctuations from renewable power."
- In Japan, due to a lack of experience with international transmission, security concern is sometimes voiced that exports from neighboring countries could be arbitrarily suspended.
  → "Electricity exports being suspended for political reasons would not present much of a problem at all for Japan."

1) Energy security and three risks: Fossil fuels characterized by uneven geographical distribution (oil in particular)

Definition=Energy security refers to being able to secure energy in the 'quantity' necessary for people's lives, economic and social activities, and national defense at affordable 'prices.'

1. **Geopolitical risk:** When fossil fuels are imported, etc., it is affected by the political stability in the region and diplomatic relations.
   → This is especially important for Japan, which is highly reliant on imports; the diplomatic involvement of the government is indispensable.
2. **Geological risk:** Fossil fuels are a depletable resource; they will be gone some day. Geographic distribution is uneven and there are major price fluctuations.
   → There are various policies that address this, like oil field development domestically and overseas (and support for it), but renewable energy development is the fundamental measureas a purely domestic source.
3. **Domestic supply system risk:** : Risk of power outages, etc. depending on domestic supply infrastructure, level of operations technology, ability to respond to natural disasters, etc.
   → Wholly the responsibility of providers.

2) Fossil fuel security and the oil crisis

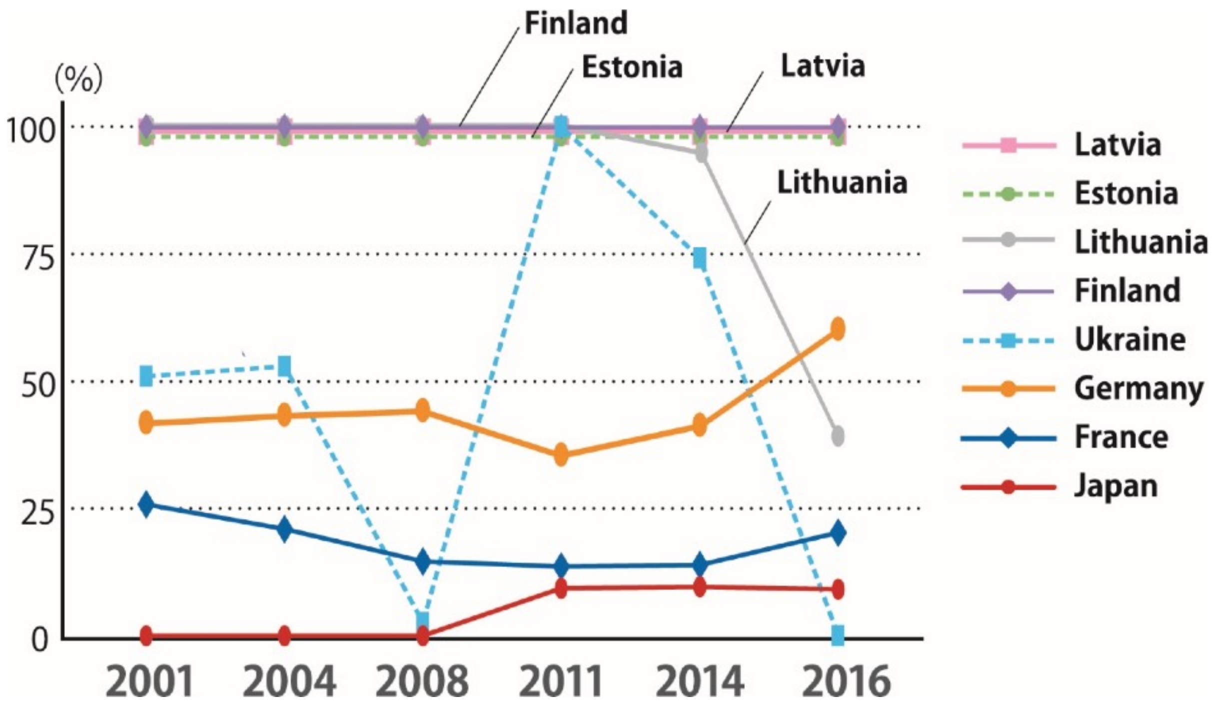
- Energy security as a concept has basically been a problem of fossil fuels. Oil in particular is concentrated in the Middle East, and geopolitical risk is high, so of these three risks, it was given highest priority.
- The oil crises of the 1970s are the typical example: Arab countries raised oil prices and restricted exports. The economic systems in developed countries were thrown into turmoil, and they responded by stockpiling and establishing the IEA.
- Thereafter, supply sources diversified and international market transactions increased, and because of this restrictions on exports to developed countries disappeared.

The concept of energy security in the fossil fuel era

3) Suspension of exports for political reasons

- In recent years in particular, Russia's suspension of natural gas exports has been regarded as problematic: Ukraine has strongly criticized Russia for inappropriately suspending exports for political reasons in connection with its new pro-Europe administration. Russia argues that the act is retaliation for unpaid gas charges and tapping pipelines without permission and that rate hikes apply to other countries as well.
- It has been pointed out that such an act, or threat, between Russia and major European countries did not even occur during the Cold War.
- Merits of suspending exports:
- Achieve political intentions through pressure
- Drawbacks of suspending exports:
- Reduced export revenue, international criticism
- In reality, limited to asymmetrical national relations between Russia and the former Soviet states due to special historical circumstances (Figure 18)
- How the risk is mitigated
  - ➢ Reduce reliance on imports from specific countries
  - ➢ Construct multiple pipelines and import from multiple countries
  - ➢ Transactions through the international market

Figure 18: Dependence on natural gas imports from Russia



Note: "Dependence on Russia" is imports from Russia divided by total imports. Latvia, Estonia and Finland continue 100% dependence.

Source: Renewable Energy Institute based on IEA (2006, 2013, 2018, 2019)

Electricity security and international grid connections

1) Electricity characteristics and security

From an energy security standpoint, electricity differs from fossil fuels.

1. Geopolitical risk: There is a fixed level of domestic supply, so the import ratio is not high (Table 8). Countries like Switzerland and Denmark with high import ratios are intermediary countries in electricity trading, so both their imports and exports are high (Figure 19). Europe has conducted international market integration, so suspending exports for political reasons is inconceivable. Lithuania, a former Soviet state, is an exception and its import ratio is high at 114%.
2. Geological risk: When fossil fuels are imported as the power source, the risk is high even with electricity. Deployment of renewable energy in recent years is improving energy security.
3. Supply system risk: Electricity is characterized by the fact that stable supply depends on operation of a transmission grid, it is difficult to store, and supply-demand balancing is important. With renewable energy, measures for output fluctuations are necessary.

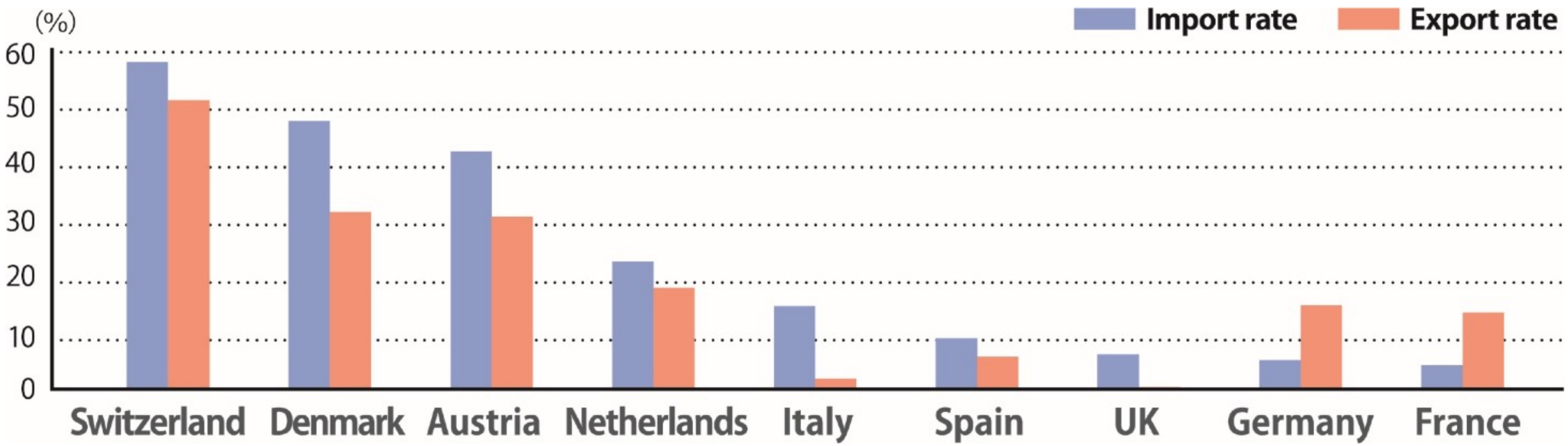
Table 8: Import rates by energy type and region (2016)

	Coal (World)	Oil (World)	Natural Gas (World)	Electricity (World)	Electricity (OECD)	Electricity (OECD Europe)
Imports	795 Mtoe	2,379 Mtoe	915 Mtoe	722 TWh	476 TWh	395 TWh
Area supply	3,657 Mtoe	4,473 Mtoe	3,032 Mtoe	25,082 TWh	11,007 TWh	3,630 TWh
Imports ratio	21.7%	53.2%	30.2%	2.9%	4.3%	10.9%

Note: Import rate = Imported amount / total area supply
Source: Renewable Energy Institute based on IEA (2019a)

Note: Import rate = Electricity imports / electricity consumed Export rate = Electricity exports / electricity consumed
Source: Renewable Energy Institute based on IEA (2019a)

Figure 19: Electricity import and export rates of European countries (2016)



Electricity security and international grid connections

2) Contribution of international grid connections to energy security

- If diverse export/import routes are established premised on a certain level of domestic supply capability, reserve supply capacity is supplemented and benefits are generated from mutual reliance.
- As a measure to address renewable energy output fluctuations, helps raise energy self-sufficiency.
- With electricity, the effects of suspending exports for political reasons are limited, and the risk is extremely low.
- Additional measures for reducing risk: Multiple interconnectors with multiple countries, limited import ratio, integration with international market, conclusion of international agreements.
- If Japan builds a 2 GW interconnector, it is only 1.1% of peak demand and only 10.4% in the Kyushu Electric Power service area.

3) Electricity export suspension and emergency interchange examples

1. **1976: Exports suspended between Uganda and Kenya**
   - Uganda's military government suspended electricity exports to Kenya, which accounted for 15-20% of Kenya's supply, due to a territorial dispute.
   - Relations between the two countries improved, the Eastern Africa Power Pool was formed (an international electricity market in the East Africa region established in 2005), and the countries both trade electricity through it.
2. **2017: Exports suspended within Ukraine to Eastern Ukraine**
   - Ukraine's TSO suspended supply to the Donbass in the eastern part of the country on the grounds of unpaid electricity charges.
   - This can be viewed as an act of retaliation against pro-Russia separatists. It was an act to check Russia in a de facto war situation.
3. **Emergency interchange in France during tight electricity supply-demand conditions**
   - 2012: As a result of record-high heating demand caused by severe winter weather, electricity supply-demand tightened and 8.3 GW was imported from all surrounding countries.
   - 2016-2017: As a result of suspending nuclear power operations due to safety issues, imported a total of 1 TWh in January 2017 alone.

Conclusion

- Suspending exports of electricity for political reasons is much less likely to occur than with fossil fuels.
- It is limited to special cases like regions at war or between countries in an authoritarian system. Inconceivable that exports would be suspended to politically stable countries with large economies like Japan.
- The benefits are far more numerous and include emergency interchange.

Electricity security and international grid connections

4) Addressing export suspension through international agreements

- General agreements related to trade and investment (WTO agreements/GATT, etc.) and Energy Charter Treaty severely limit import suspension and help facilitate electricity trade.
- There are further examples of strict conditions being set in individual agreements (Table 9 on next page).
- There are also various channels for dispute resolution (WTO Panel, investment arbitration, etc.).
- There is a legal framework to minimize arbitrary export suspension. Export suspension cannot be entirely prevented by international agreements alone, but if Japan establishes this kind of legal framework even when it is building an interconnector, it would serve as a deterrent and potentially prevent disputes in advance.

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Table 9: Examples of electricity and energy agreements related to export suspension

Examples of restrictions on measures	Name of agreements and summary of regulations
Limitation of force majeure	Agreement between the Republic of Turkey and Georgia concerning cross-border electricity trade via Borcka-Akhaltsikhe interconnection line (2012), Article 9, Paragraph 2 Force majeure shall be limited to: - Natural disasters - War between sovereign states where the relevant party has not initiated the war under the principles of international law, acts of terrorism, rebellion or insurrection - International embargoes against states other than the relevant party
Measures prohibited on grounds of disputes	Energy Charter Secretariat, Model Intergovernmental Electricity Agreement, Part 4 Each country agrees that its obligations under this agreement and its commitment to the project activities continue irrespective of disputes, requests, or changes, etc. related to border or territorial disputes (including now and in the future). Any border or territorial disputes must not interfere with the related projects. The obligations in this agreement and other related agreements must not be changed on the grounds of a border or territorial dispute or its resolution.
Specification and limitation of grounds for measures	Agreement between the Azerbaijan Republic and Georgia on oil pipeline (1996), Article 2, Paragraph 1 Based on the principle of the smooth distribution of goods and services, the governments of the countries must not discontinue or hinder oil distribution through facilities in their own territories. In addition, the governments of the countries must not hinder distribution in any way such as […] except to take reasonable measures when operation of facilities constitutes a threat to public health, safety, property or the environment. Even in this case, the measures must be limited to the degree and time period necessary to remove the threat.
Specification of quantities, price terms when measures taken	North American Free Trade Agreement (NAFTA), Chapter 6: Energy and Basic Petrochemicals, Article 605 Exports may be restricted only in the following cases, except as stipulated elsewhere. - Exports are not reduced relative to total exports for the most recent 36 month period - Prices are set equivalent to prices for domestic consumption (prices are not set at a high level by means of taxes or licensing fees, etc.) - The restriction does not disrupt the normal supply channels of the other country or normal proportions of export products
Limitations on grounds for measures and investigations of appropriateness	EU Directive 2009/72/EC (the third energy package), Article 42 - "In the event of a sudden crisis in the energy market and where the physical safety or security of persons, apparatus or installations or system integrity is threatened, a Member State may temporarily take the necessary safeguard measures." (however, the measures must be the minimum necessary.) - Member states have a duty to notify the other member states and the European Commission in advance. - The European Commission may decide that the member state who took such safeguard must amend or abolish such measures.

Source: Renewable Energy Institute based on various sources (provided below)

Energy security and international gird connections in the era of renewable energy

1) Transformation of the concept of energy security

- It should be emphasized that the discussion to this point is based on the traditional conception of energy security in the fossil fuel era.
- Fossil fuel era: There is a clear distinction between haves and have-nots, and the relationship is zero-sum. The concept is premised on unidirectional import of unevenly distributed fossil fuels, so it becomes important to defend sea lanes, and importers are at the mercy of fuel price fluctuations.
- Renewable energy: it is found in large quantities in many countries. If domestically produced, it does not need to be transported, and except for biomass, fuel costs are zero, and because it is not depleted, resources do not need to be contested. Both geopolitical risk and geological risk are eliminated.
- Major reduction in renewable energy costs in recent years and large-scale deployment, including in developing countries: China is strategically deploying renewable energy on a large scale for energy security reasons and has declared it will be building International Grid Connections a part of this.

2) Importance of international grid connections in the renewable energy era

- “A new world” is emerging that is not dependent on the scramble for fossil fuels. ：IRENA(2019a) “A New World”
- Plus-sum relationship in which all countries are haves and mutually exchange a portion of their electricity: With climate change a threat to all of humanity, international relations become mutually reliant.
- Renewable energy is the most powerful means to this end, and the international grid connections that contribute to its deployment promote both the independence of individual countries and the formation of relationships of mutual reliance.
- “The new threats” to energy security: the procurement of rare metals necessary to manufacture cutting-edge technologies related to solar panels and storage cells, and cyber attacks on international grid connections increasingly supported by information technologies (IRENA, 2019a).
- Remaining supply system risk: In Europe, output fluctuations are being addressed by increasing the flexibility of the power system, and International Grid Connection is one means of doing this.
- Japan, as a fossil fuel have-not, would benefit greatly.

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CONCLUSION

1) Conclusions of the report

- International grid connections increase economic transactions of electricity through trade, contribute to supply stability through the sharing of reserve capacity, and promote deployment of renewable energy because they mitigate output variability.
- International grid connections are being expanded even in geographically disadvantaged regions such as the UK and Spain. Rather, the only country in Northeast Asia not currently taking a proactive stance toward international grid connections is Japan, and we should acknowledge this fact with a sense of crisis.
- Concerns over energy security, can essentially be ignored by Japan. When electricity is exported and imported in limited amounts on the assumption of sufficient supply capacity domestically, the effects of exports being suspended by another country on political grounds is nearly nil and so the benefits to that country, too, are non-existent.

2) Recommendations for realizing international grid connections

1. The Japanese government should begin full-fledged, concrete discussions on international grid connections with the governments of neighboring countries, such as South Korea, Russia and China.
2. The Japanese government should reconsider the nature of energy security going forward based on large-scale deployment of renewable energy and position International Grid Connection within this conception.
3. The Japanese government and OCCTO should formulate a long-term master plan related to its domestic and international transmission grid with targets set for 2050.
4. Domestic power system reforms should be accelerated to the level of Europe by expanding cross-regional interconnectors, enhancing intra-regional transmission lines, creating inter-regional transmission companies, streamlining operating rules (a grid problem) and modernizing the electricity market.

With renewable energy expanding globally, the day is coming when it will no longer be necessary to assume that fossil fuels will be exported and imported unidirectionally. Japan, whose energy self-sufficiency is especially low, needs to actively respond to this by means of interconnectors. The fact that China and South Korea are actively pursuing International Grid Connection despite international relations in Northeast Asia not necessarily changing for the better can be considered in this same context. With the international situation in Northeast Asia changing significantly, now is the time for the Japanese government to move from consideration to action.

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Asia International Grid Connection Study Group the secretariat: Renewable Energy Institute

JUL 2016	Group creation
JAN 2017	Study tour in Europe
APR 2017	Interim Report published
SEP 2017	Study tour in the US
JUN 2018	Second Report published
OCT 2018	Study tour in Europe

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	Takeo Kikkawa	Professor, Graduate School of Management, Tokyo University of Science
	Tetsuo Saito	Project Researcher, Institute of Industrial Science, The University of Tokyo (Senior research fellow at REI since April 2019)
	Taku Niioka	Chairman, Energy Committee, European Business Council in Japan (Member until March 2019)
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