Asia International Grid Connection Study Group

Second Report Summary

June 2018

Asia International Grid Connection Study Group

自然エネルギー財団 RENEWABLE ENERGY INSTITUTE

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

Asia International Grid Connection Study Group

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1. Initiatives in Northeast Asia for international grid connections

Since 2016, the Asia international grid connection has entered a phase towards more specific business plans by energy companies representing the countries concerned; e.g., China, Japan, South Korea and Russia, from the stage of the research institutions' planning (April 2017 Interim Report). And progress to build cross-border grid connections are now gaining momentum.

1) The Moon Jae-in administration, which took office in May 2017, presented Korea's "energy turnaround" as a key issue of its agenda, and has since then been working hard to advance the Northeast Asia Super Grid Concept. This scheme aims at making best use of renewable energy throughout the region. In this regard, the administration has set up the Presidential Committee on Northern Economic Cooperation.

2) After the Japan-Russia summit held on 27 April 2017, President Putin emphasized the talks about a "Japan-Russia Power Bridge," that would connect the two countries through interconnector.

3) At the China-South Korea Business Forum, which was held on 13 December 2017, the Global Energy Interconnection Development and Cooperation Organization (GEIDCO) signed a cooperation agreement with State Grid Corporation of China (SGCC) and Korea Electric Power Corporation (KEPCO). This agreement aims at facilitating an international connection project between the two countries as a forerunner of international grid connections in Asia.

4) The agreement states the China-South Korea interconnector will be pursued under the framework of a Mongolia-China-South Korea-Japan project, which assumes the development of cross-border grid connections with Japan and other neighbors as next steps.

2. Developments of Electricity System Reform in Japan

1) Progress on unbundling

In April 2016, Tokyo Electric Power Compnay (TEPCO) implemented legal unbundling, spinning off its transmission and distribution business as an independent subsidiary; TEPCO Power Grid. Chubu Electric Power Company introduced an in-house company system as a preliminary step toward legal unbundling in the same month. The in-house company system was also introduced by Kyushu Electric Power Company (April 2017), Chugoku Electric Power Company (October 2017), and Tohoku, Shikoku, and Hokkaido Electric Power Companies (April 2018). In June 2017, Chubu, Hokuriku, and Kansai Electric Power Companies announced the partnership of their power grid business, which aims to optimize operational efficiency of grid system and its system development, as well as cooperation of power supplies and demand balances.

2) State of competitive retail market

Since the full competition was introduced in April 2016, 440 new electricity retailers registered as of December 2017, in addition to the incumbent utilities, those are still mostly vertically integrated. Their share in the entire retail market reached 12.6%, and 7.5% of low-voltage demand which is mainly households. As of March 2018, 7.1 million low-voltage contractors had switched electricity retailers nation-wide. These figures demonstrate a certain level of competition among power suppliers.

3) State of market system reform

The day-ahead (DA) spot market grew fast, more than double from the previous FY 2016. Nonetheless, less than 10% of the entire country’s electricity consumption is traded in the spot market, further growth is needed to achieve liquidity of the market.

In May 2018, the non-fossil value trading market started to auction non-fossil value certificates originating from FiT renewables. Other non-fossil value such as from nuclear will be introduced in 2019, but those will be treated separately from renewables. In the future, this should help to distinguish environmental values when trading electricity at the international level.

3. Cross-regional transmission operations in Japan, and grid connection issues

First-come-first-served rule in the grid: In Japan, power generation facilities that are already connected to electrical grids are guaranteed transmission capacity equivalent to their maximum generating output. And any new entrant applying for a new grid connection has to pay for increasing grid capacity when unallocated grid capacity are not sufficient for the new generating facility to connect to the existing grid. This is to ensure that existing power producers will not be hindered from the grid access. However, in the real supply-demand balances, power plants do not always operate at their maximum capacity. In order to use the grid system efficiently, the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) is considering to adopt a new rule; "connect & manage," which would allow new entrants to connect to a grid running short of unallocated capacity before work for increasing grid capacity is completed.

Table 1: Initiatives for Japanese version of "connect & manage"

Initiatives	Existing rules	New rules
rationalization of power flow forecast	Estimate unallocated grid capacity based on the rated capacity of generation facilities to be connected.	Simulate total power outputs that can be practically produced, and estimate unallocated grid capacities from the total expected outputs.
N-1 criteria	Develop an electric power system that can maintain power generation, transmission and distribution when a single component of the system fails.	Introduce a mechanism to control power sources when a grid accident occurs, in order to connect as many generation facilities as possible to the grid.
Non-firm access	Develop an electric power system with enough transmission capacity margin to prevent its grid capacity being exceeded by rated outputs of generation facilities when they all generate large amounts of electricity at the same time.	Allow a new power generating facility to connect to the grid before grid capacity is increased, in exchange of its agreement to have its output curtailed when existing power plants use all available transmission capacity.

Source: Renewable Energy Institute

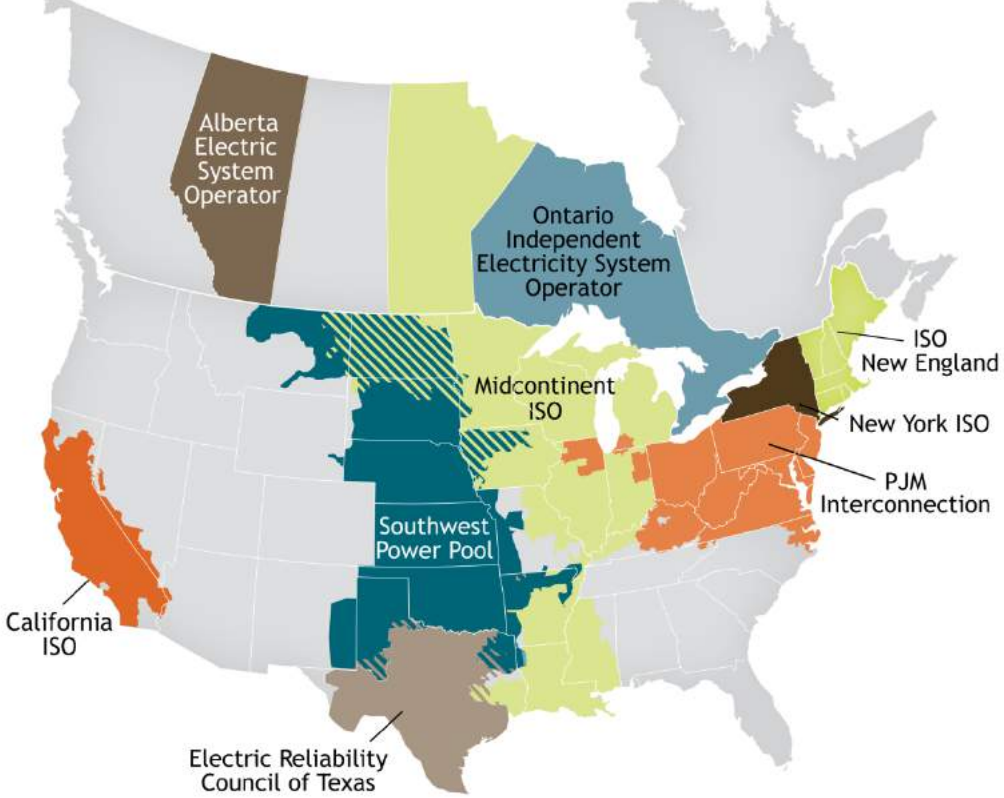
1. The electricity system and international grid connection in North America

The US and Canada have been trading electricity for more than a century. As of 2016, there were 37 routes of interconnectors running across the border. The two countries' electrical grids are implemented integrated system operation under the rules set by the North American Electric Reliability Corporation (NERC). In North America, state governments pursue policy programs for development of interconnectors. The federal government is responsible for inter-state and international transactions of electricity mainly from the standpoint of national energy security. A federal agency - the Department of Energy (DOE) for the US and the National Energy Board (NEB) for Canada - is authorized to review plans of interconnectors from a technical viewpoint and decide whether to approve it.

Canada: the 2nd hydropower producer in the world (59.4% in generation mix) Of its annual production of electricity, 11.3% is exported to the US (IEA, Electricity Information 2017).

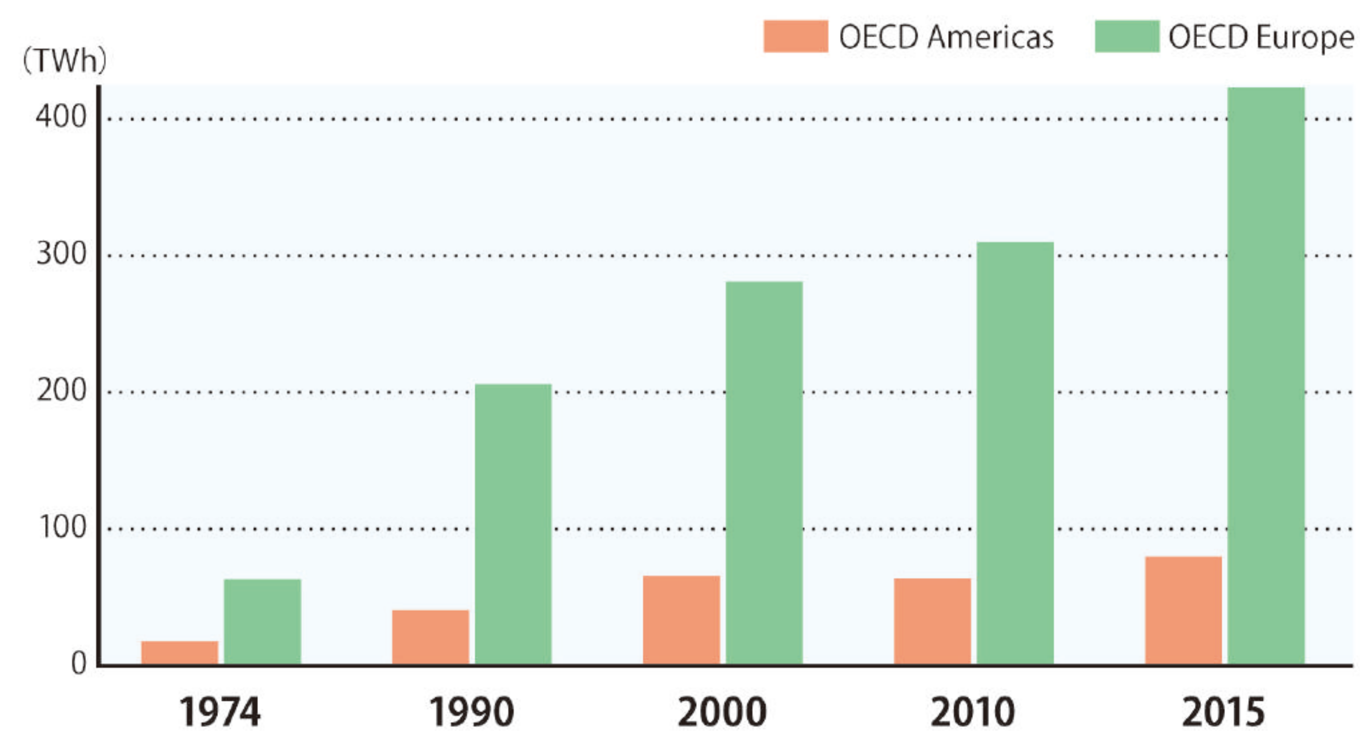
US: the 2nd installed wind & solar PV capacities in the world, leading the renewables market (BP Statistics, 2018)

ISOs in the US and Canada



Source: ISO/RTO Council website, 23 May 2018 http://www.isorto.org/about/default

Trend of exported electricity in North America and Europe



Source: Electricity Information 2017, IEA

2. Examples of interconnector projects in North America

Massachusetts: To achieve its greenhouse gases (GHGs) emission reduction target of 25% by 2020 from 1990 level, the state government, together with retail electricity businesses, made an open call in March 2017 for a project of procuring 9.45 TWh of electricity per year generated from clean energy. A total of 46 project proposals were submitted.

Adopted project: New England Clean Energy Connect (NECEC)
Proposes to supply 1.2 GW of hydroelectricity from Quebec to Massachusetts by Enhancement of overhead transmission line of 233 km and partial new installation (320 kV, HVDC) through Maine. The project cost is estimated as $950 million. The application for Presidential Permit was filed in September 2017.

New York State: To achieve its target of supplying 50% of electricity consumed in-state with renewables by 2030, an open call was made in June 2017 for a long-term contract for procuring renewable electricity. Tender results will be announced in Summer 2018.

Example of proposed projects: Champlain Hudson Power Express (CHPE)
Plans to deliver hydropower and other renewable electricity from Quebec through Lake Champlain and the Hudson, Harlem, and East Rivers over to Queens, New York City, through 1-GW HVDC cables. The line is designed to go underwater and underground, 315 km and 220 km, respectively. The project is operated by Transmission Developers Inc. (TDI), a subsidiary of Blackstone, as a primary contractor. Initial capital expenditure amounts to $2.2 billion. The project is estimated to supply 8.3 TWh of renewable electricity per year, and deliver almost 50 billion dollars of market value and economic benefits during a 30-year operational lifetime.

Insights from the North American case

1) International grid connections is quite common in North America just as it is in Europe

This may partly be because North America has a geographical advantage in terms of continuity as a single continent, however, some cables go through the under-sea, lakes, and/or rivers.

2) State, not federal, governments play critical roles, a difference with Europe

State governments themselves set targets for deploying renewables, and cross-border trade of electricity is growing as the environmental value of renewables attracts greater attention.

3) Many projects adopt a commercial scheme combined with power generation as an investment recovery model

That in part reflects the fact that Canada has historically a large supply capacity of renewable power, mainly hydro, but also the global cost reduction of renewables and progress in technology for long-distance transmission lines are a boost for recent projects.

1. Interconnector construction route

*2GW DC interconnectors for both Japan-Russia & Japan-South Korea.

Table 2: Scenario for Japan-Russia interconnector

	Power Source	Demand Center
Russia	・Existing hydropower stations along Amur River ・Newly-developed wind power in southern Sakhalin	・Sakhalin ・Continent part of Far East
Japan	・Newly-developed wind power in Hokkaido	・Kanto Area

Table 3: Scenario for Japan-South Korea interconnector

	Power Source	Demand Center
South Korea	・Newly-developed renewables in South Korea ・Assume renewables from Mongolia and China as future options	・Mainly in the southern part of South Korea and Seoul Metropolitan area
Japan	・Solar PV in Kyushu	・Kansai Area

Table 4: Reference data

Research Item	Study of Submarine Routes	Evaluation of Interconnection & Landing Points
Fishery rights, protected areas, etc.	Marine Cadastre	Marine Cadastre NEDO NeoWins
Geology	National Institute of Advanced Industrial Science and Technology (AIST) "GeomapNavi," etc.	National Institute of Advanced Industrial Science and Technology (AIST) "GeomapNavi," and other datas
Depth of sea	Japan Oceanographic Data Center, etc.	-
Land use	-	aerial photos, and other datas.
Grid capacity in Japan	-	power companies' grid maps

Source: Renewable Energy Institute

1. Interconnector construction route

Selection of connection points

Russia: surroundings of the Korsakov Substation, southern Sakhalin

South Korea: surroundings of Busan (selected based on grid capacity)

Several landing points in Japan

Japan-Russia: Wakkanai (Hokkaido), Ishikari (Hokkaido), Kashiwazaki (Niigata)

Japan-South Korea: Maizuru (Kyoto), Matsue (Shimane), Imari (Saga)

Table 5: Criteria for selecting connection points in Japan

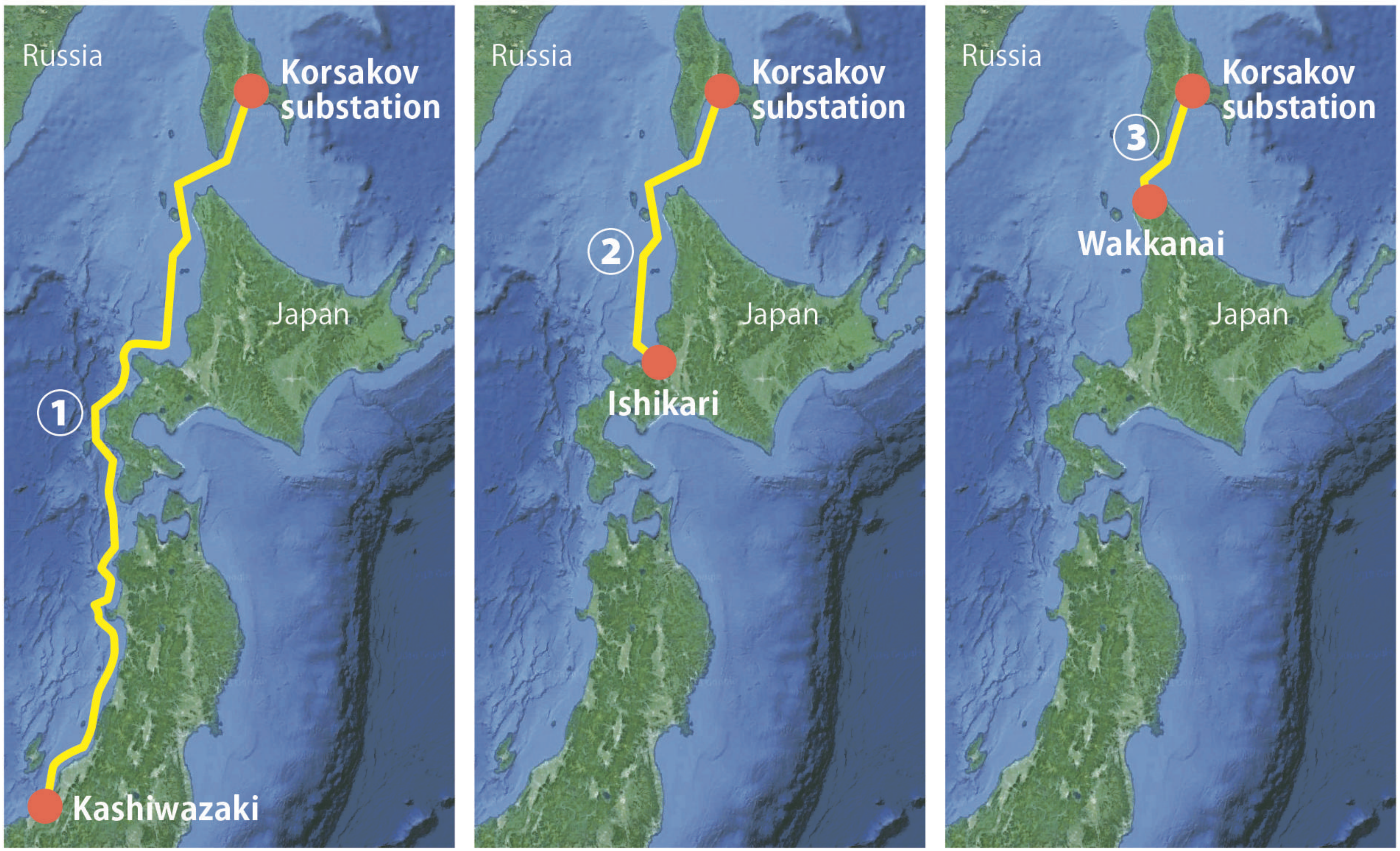
Criteria	Evaluation	Reference Data
1. Geological proximity to the connection points in Russia/South Korea	Shortest submarine transmission line	Google Earth, and other datas.
2. Geological proximity to demand centers in Japan (Tokyo Metropolitan/Kansai areas)	Power can be transported to demand centers through the shortest transmission lines	Maps by the Geospatial Information Authority of Japan, and other datas.
3. Transmission capacity to demand centers in Japan	Sufficient grid capacity can be secured to transport electricity to demand centers in Japan	Data of transmission capacity released by General Electricity Transmission and Distribution Utilities, and other datas.

Source: Renewable Energy Institute

1. Interconnector construction route

Route designs of Japan-Russia interconnector

- Routes are less than 400 meters deep (NorNed Interconnector in Europe: 410 meters at the deepest), and
- Avoid coastal areas with fishery rights and rocky seabed found on bathymetric charts.



[Russia—Honshu]

①Sakhalin—Kashiwazaki
Length: 1,255 km
Maximum sea depth: 300 m

[Russia—Hokkaido]

②Sakhalin—Ishikari
Length: 455 km
Maximum sea depth: 300 m

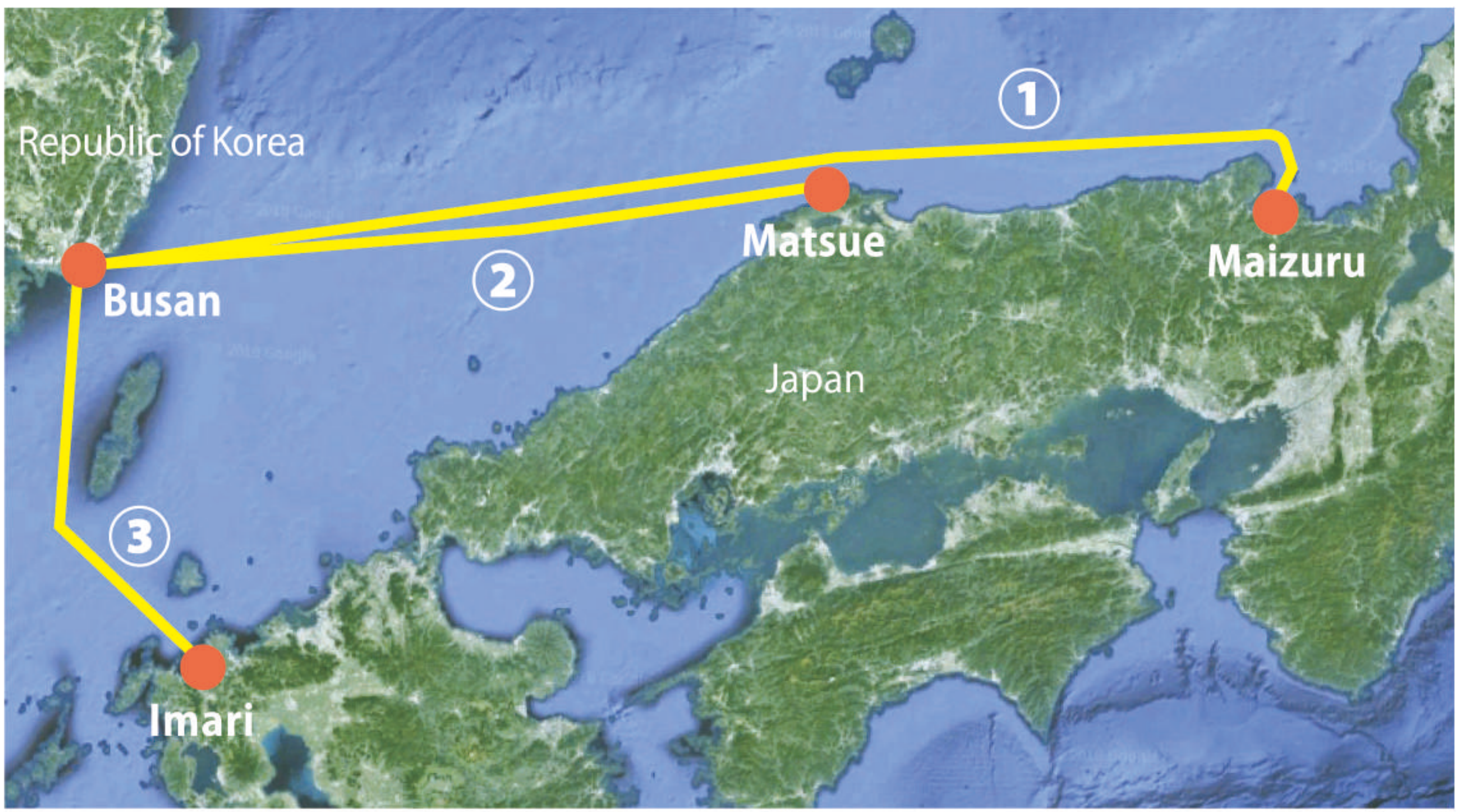
③Sakhalin—Wakkanai
Length: 161 km
Maximum sea depth: <100 m

Source: Renewable Energy Institute

1. Interconnector construction route

Route designs of Japan-South Korea interconnector

- Routes are less than 400 meters deep (NorNed Interconnector in Europe: 410 meters at the deepest), and
- Avoid coastal areas with fishery rights and rocky seabed found on bathymetric charts.



①Busan—Maizuru
Length: 627 km
Maximum sea depth: 200 m

②Busan—Matsue
Length: 372 km
Maximum sea depth: 150 m

③Busan—Imari
Length: 226 km
Maximum sea depth: 120 m

Source: Renewable Energy Institute

1. Interconnector construction route

Results of route designs

- The shortest routes for Japan-Russia and Japan-South Korea interconnectors are 161 km and 226 km, respectively, and each goes less than 300 meters deep into sea.
- In Europe, for instance, NorNed, a more than 500 km long submarine transmission cable going deeper than 400 meters into the sea, has been in service for ten years. As well as SAPEI, a Mediterranean project for submarine transmission cable which interconnects the mainland of Italy and Sardinia, cables are laid more than 1,500 meters at the deepest.
- The longest route in this report, Sakhalin-Kashiwazaki, is 1,255 km. Europe has a plan to construct a 1,070 km submarine transmission cable connecting Iceland and Scotland (IceLink).
- With reference to these precedents, the results of the Japan-Russia and Japan-South Korea interconnectors route designs are physically possible and do not have any certain conditions that may make their construction especially difficult.

Table 6: Japan-Russia & Japan-South Korea interconnectors: Overview

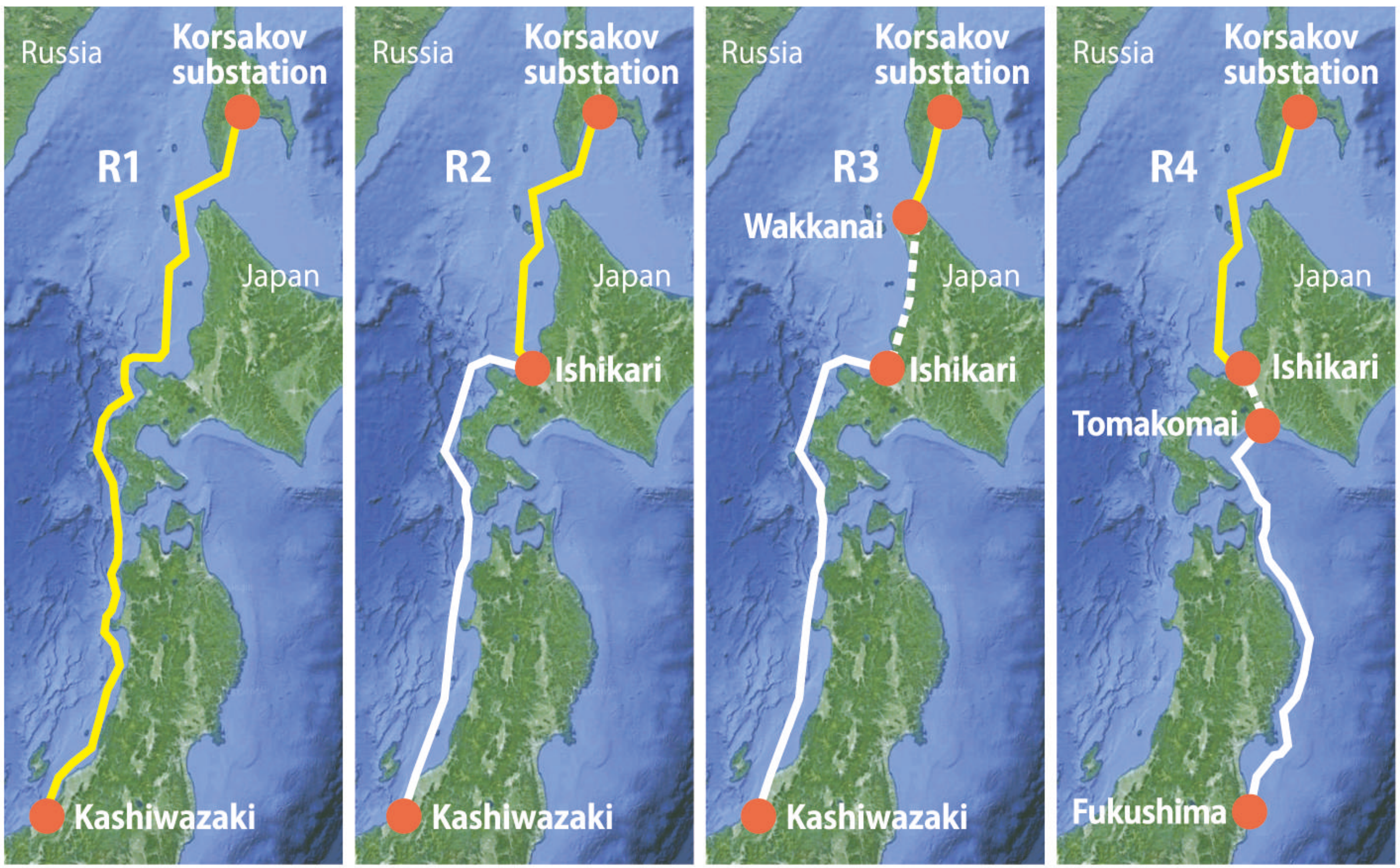
Japan-Russia			Japan-South Korea		
Route	Length	Max. Depth	Route	Length	Max. Depth
Sakhalin-Kashiwazaki	1,255 km	300 m	Busan-Maizuru	627 km	200 m
Sakhalin-Ishikari	455 km	300 m	Busan-Matsue	372 km	150 m
Sakhalin-Wakkanai	161 km	≤ 100 m	Busan-Imari	226 km	120 m

Source: Renewable Energy Institute

1. Interconnector construction route

Routes between Russia and demand centers in Japan: Overall views

- Four routes are selected including three reaching the Kanto area after cables make a first landfall in Hokkaido
- R2, R3, and R4 come ashore in Hokkaido, with AC/DC converters installed to integrate electricity generated from wind power in the prefecture.



R1 Sakhalin－Kashiwazaki
Length: 1,255 km

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

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

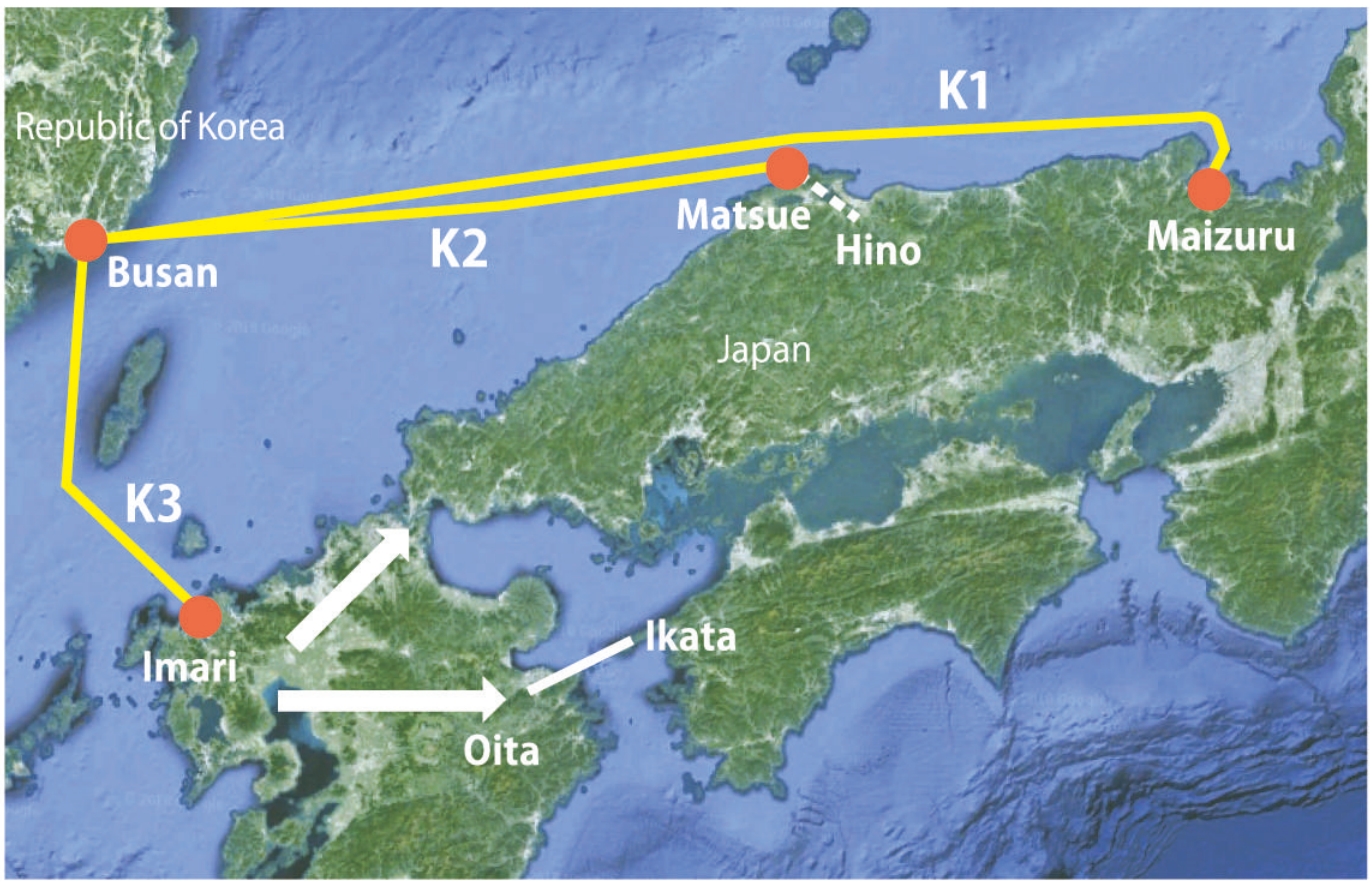
R4 Sakhalin－Ishikari－Tomakomai－Fukushima
Length: 1,246 km
(455+108+683 km)

Source: Renewable Energy Institute

1. Interconnector construction route

Routes between South Korea and demand centers in Japan: Overall views

- Three routes are selected including one reaching the Kansai area after cables make a firs landfall in Kyushu.
- Once K3 is connected in Kyushu, 1 GW of power is transferred through Chugoku to Kansai, and the remaining 1 GW goes through Shikoku to Kansai. A new interconnector need to be developed between Kyushu and Shikoku.



K1 Busan—Maizuru
Length: 627km

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

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

Source: Renewable Energy Institute

2. Estimated construction costs

Table 7: Examination of per-km construction cost

Item	Specifications/ References	Description
Main circuit configuration	Bipole/one circuit, metallic return method	• The bipole system, which uses two cables for the main line, 1GW each in this estimation, is adopted for resilience in case of failures with cable. This is also because a single cable with large capacity of 2GW cannot be manufactured at present. • Although ground is usually used in Europe as returning route, the metallic return method is adopted in line with existing facilities in Japan (Hokkaido-Honshu HVDC Link and Anan-Kihoku DC Trunk Line).
Submarine cables	Cost data from European cases, MI cable	• “Electricity Ten Year Statement 2015,” National Grid (2015) is referred as the publicly available recent cost data source. • MI (Mass Impregnated) cable is adopted. MI is commonly used for long-distance submarine cables globally. • In order to have the possibility to use the return line as a main line, the three cables of the same specifications are adopted. The price of 1.5 times that of 2 cable-case is applied.
AC/DC converter	ENTSO-E	• AC/DC converters were calculated to be placed at both ends of interconnectors, since the power lines transmit AC electricity in each area. • The voltage-source converter (VSC), which is generally used in recent years, is adopted to use. VSC is the self-commutated type of AC/DC converters, that can make an entire system easier to simplify, compared to the current-source converter (CSC) that has been commonly used so far. The cost data of ENTSO-E (2011) is referred. • Since the bipole system is adopted as the main circuit configuration, two 1 GW converters are installed at the site supporting 2 GW of transmission capacity.
Overhead lines	Tohmatsu	• "Study on the Cost and Period for Construction of Transmission Lines," Tohmatsu (2012) is referred as the construction cost for Japan’s domestic overhead lines. The report was submitted to a METI’s experts’ study group on transmission line expansion in March 2012. • The unit cost of DC ±500 kV overhead lines was calculated based on the cost of DC ±250 kV lines by assuming the cost of pylons for DC ±500 kV should increase.
Underground cables	OCCTO	• For the per-kilometer cost for underground cables, including civil work, the "Standard Per-kilometer Cost of Transmission and Conversion Facilities,” OCCTO (2016) is referred. • Calculation of per-kilometer construction cost for DC ±500 kV cables is based on data on AC 33 kV to 275 kV cables.

Source: Renewable Energy Institute

2. Estimated construction costs

The unit cost of the submarine cable is less than half of the overhead line and less than one-third of the underground cable, which is the cheapest. It is also considered that price competition has been occurring due to the fact that long-distance direct current submarine cables are being actively laid in Europe in recent years. The unit cost of Japan's overhead line is more than twice that of Europe and the US, and it can be conjectured that unique circumstances peculiar to Japan are working.

Table 8: Examination of per-km construction cost, etc.

Item	Cost	Reference	Remarks
Submarine cables	293 mn. JPY/km	DC submarine transmission line projects in Europe (SAPEI, MON.ITA, NordLink, North Sea Link)	DC ±500 kV; transmission capacity: 2 GW; MI cable; 3 cables; cables laid separately
AC/DC converter	15.7 bn. JPY/unit	ENTSO-E 2011	VSC 1,250 MW; Lowest value at 500 kV
Overhead lines	664 mn. JPY/km	Data from Tohmatsu on construction cost for transmission lines (2012)	Estimated cost for DC 500 kV
Underground cables	915 mn. JPY/km	Standard cost estimated by OCCTO (March 29, 2016)	Estimated cost for DC 500 kV

Source: Renewable Energy Institute

2. Estimated construction costs- summary

The construction cost of 2 GW capacity interconnector between Japan-Russia and Japan-South Korea would cost JPY 431 -573 billion and JPY 202 - 247 billion, respectively, including the domestic reinforcement part in Japan. Among the possible Japan-Russia routes, the one that connects to a location near demand center though long undersea cable, the construction cost turns out to be the lowest. On the other hand, the multiple benefits can be expected, if a cable makes a first landfall in Hokkaido to be connected with renewable energy sources available in the prefecture, the transmission line part in Japan can be also used as an cross regional transmission system.

Table 9: Construction cost for Japan-Russia interconnector (incl. transmission lines in Japan)

Routes	Specifications	AC/DC converter	Interconnector	Domestic lines	Total
R1: Sakhalin-Kashiwazaki	Submarine cables	4 units	JPY 430.5 bn.	-	JPY 430.5 bn.
R2: Sakhalin-Ishikari-Kashiwazaki	Submarine cables	6 units	JPY 196.1 bn.	JPY 265.8 bn.	JPY 461.9 bn.
R3: Sakhalin-Wakkanai-Ishikari-Kashiwazaki	Onshore; Overhead lines	6 units	JPY 110.0 bn.	JPY 463.0 bn.	JPY 573.0 bn.
R4: Sakhalin-Ishikari-Tomakomai-Fukushima	Onshore; Underground cables	6 units	JPY 196.1 bn.	JPY 330.3 bn.	JPY 526.4 bn.

Table 10: Construction cost for Japan-South Korea interconnector (incl. transmission lines in Japan)

Routes	Specifications	AC/DC converter	Interconnector	Domestic lines	Total
K1: Busan-Maizuru	Submarine cables	4 units	JPY 246.5 bn.	-	JPY 246.5 bn.
K2: Busan-Matsue-Hino	Matsue-Hino to be reinforced	4 units	JPY 171.8 bn.	30.6 bn. JPY	JPY 202.4 bn.
K3: Busan-Imari/Oita-Ikata	Submarine cables	8 units	JPY 129.0 bn.	83.3 bn. JPY	JPY 212.3 bn.

Despite their limited possible impact, among necessary additional cost items that should be examined are; (1) Other expenses for laying cables (mobilizing/demobilizing of cable laying vessels, etc.), (2) O&M (generally 1 to 3% of total construction cost per year), (3) Route survey (more than billions of JPY in some cases, depending on items of the survey and the length of a route), (4) Fluctuation of material prices (prices of copper, conductor for cables, and other materials may change along with market fluctuations), (5) Possibility of compensation for fishing industry (for anyone engaged in the fishing industry around a landing point), and (6) Environmental impact assessment.

Source: Renewable Energy Institute

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.

Table 11: Business models for interconnector investment recovery

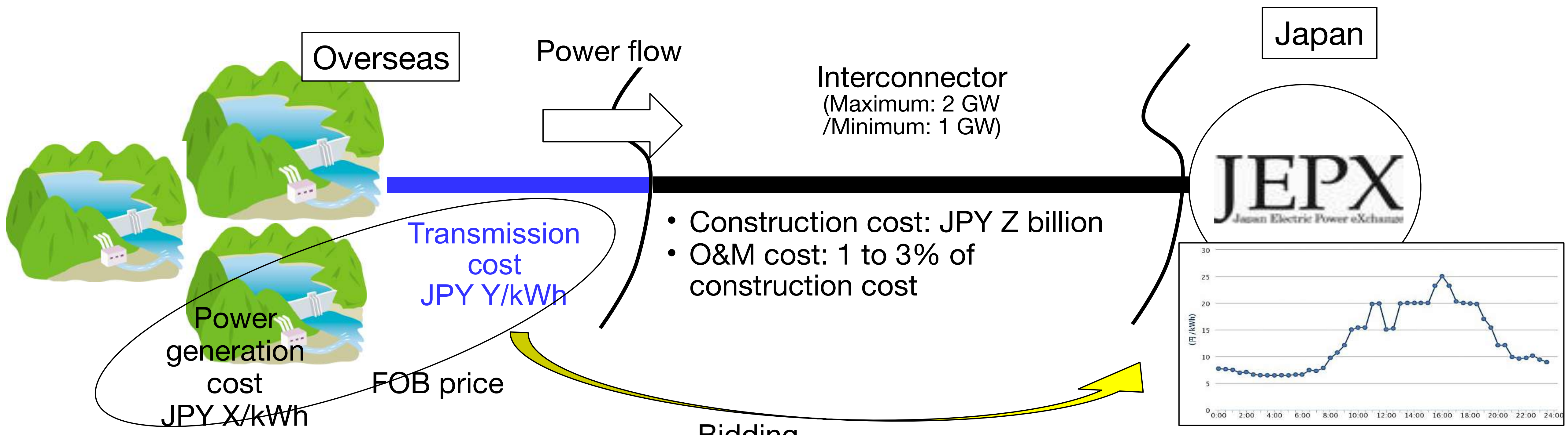
Business model	Contents	Examples
1) Generators/ suppliers dedicated line model	Interconnector is laid as a part of a power supply project to specific customers or markets from specific generators or suppliers, and investment is carried out by power sales income.	Russia - China Canada - US
2) Regulated 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.	European markets, North American markets (e.g. PJM)
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.	

Source: Renewable Energy Institute

1. Business models for investment recovery and estimated results

1) Generators/suppliers dedicated line model

One-way power supply and sales from overseas power plants or suppliers to the Japanese market. Investment recovery is based on income obtained by electricity sales.



example of system prices data

1. Business models for investment recovery and estimated results

1) Generators/suppliers dedicated line model: Japan-Russia 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-Russia 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
[R1] Sakhalin-Kashiwazaki (Electricity market: JEPX Tokyo area; Construction cost: JPY 431 billion)					
1 GW	2.3% to 7.1%	-1.3% to 4.3%	-5.6% to 1.2%	-11.4% to -2.3%	Max. -5.2%
2 GW	12.9% to 18.0%	8.4% to 13.7%	4.1% to 9.1%	0.3% to 4.6%	-3.9% to 1.3%
[R2] Sakhalin-Ishikari-Kashiwazaki (Electricity market: JEPX Tokyo area; Construction cost: JPY 462 billion)					
1 GW	1.3% to 6.2%	-2.3% to 3.6%	-6.8% to 0.5%	-13.9% to -3.0%	Max. -5.9%
2 GW	11.7% to 16.6%	7.3% to 12.5%	3.1% to 8.2%	-0.7% to 3.8%	-4.9% to 0.6%
[R3] Sakhalin-Wakkanai-Ishikari-Kashiwazaki (Electricity market: JEPX Tokyo area; Construction cost: JPY 573 billion)					
1 GW	-1.6% to 3.8%	-5.5% to 1.3%	-11.6% to -1.6%	Max. -4.9%	Max. -8.0%
2 GW	8.1% to 12.8%	4.2% to 9.3%	0.2% to 5.5%	-3.7% to 1.6%	-8.8% to -1.4%
[R4] Sakhalin-Ishikari-Tomakomai-Fukushima (Electricity market: JEPX Tokyo area; Construction cost: JPY 526 billion)					
1 GW	-0.4% to 4.7%	-4.2% to 2.2%	-9.4% to -0.8%	Max. -4.2%	Max. -7.1%
2 GW	9.5% to 14.3%	5.4% to 10.5%	1.4% to 6.5%	-2.5% to 2.5%	-7.1% to -0.6%

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

Source: Renewable Energy Institute

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%

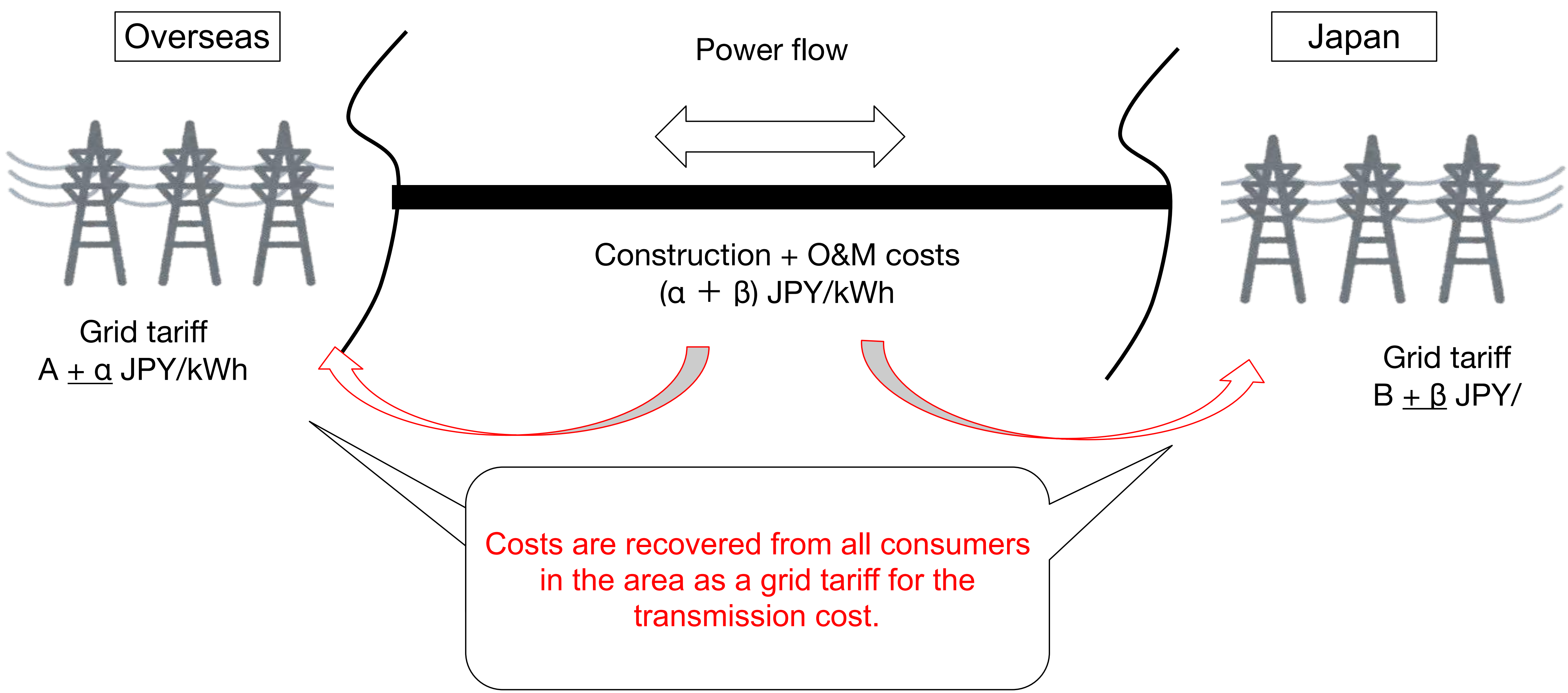
*In the red frames, the IRR median value is positive.

Source: Renewable Energy Institute

1. Business models for investment recovery and estimated results

2) Regulated grid tariff model

Overseas and Japanese power transmission operators (assuming General Electricity Transmission and Distribution Utility) bear the construction and O & M cost of interconnector. Investment is recovered by adding to the transmission fee for transmission cost in each area.



Source: Renewable Energy Institute

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%**

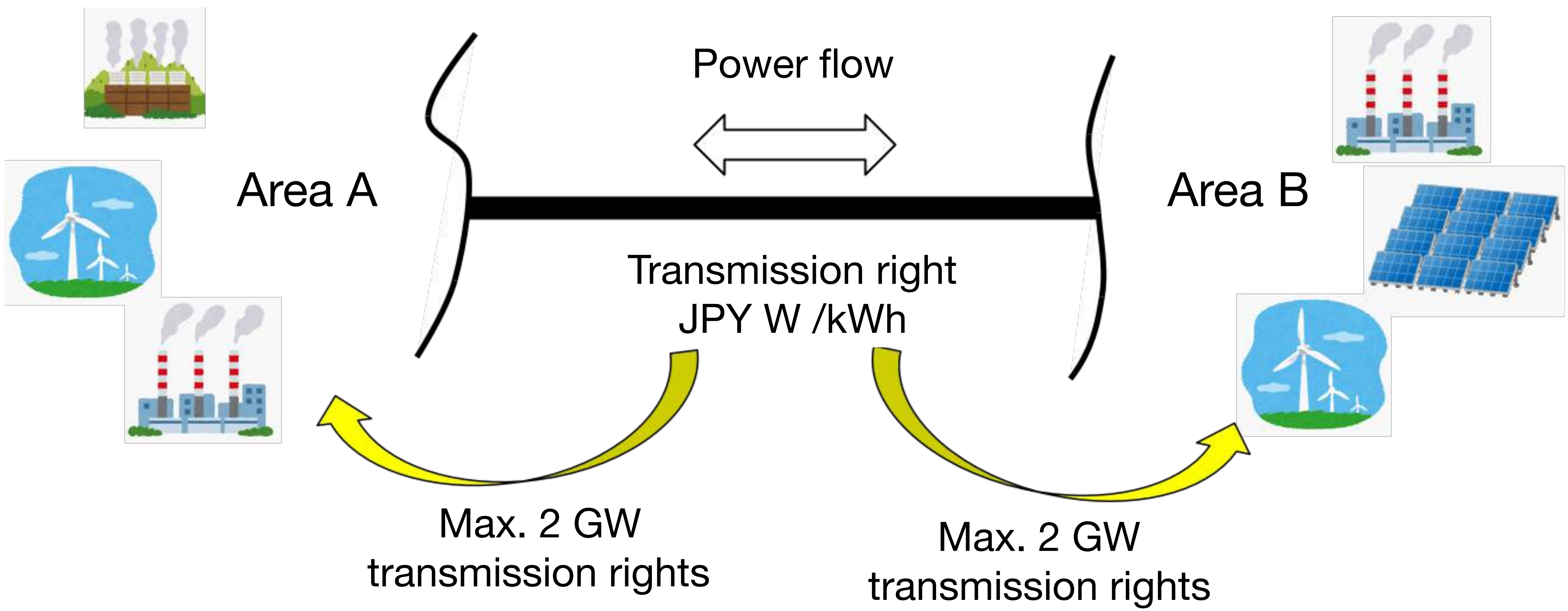
*In the red frames, the IRR median value is positive.

Source: Renewable Energy Institute

1. Business models for investment recovery and estimated results

3) Transmission rights sales model

The power transmission rights are sold to power producers and/or electricity retailers. The investment is recovered by the sales income of the power transmission right.



Source: Renewable Energy Institute

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%

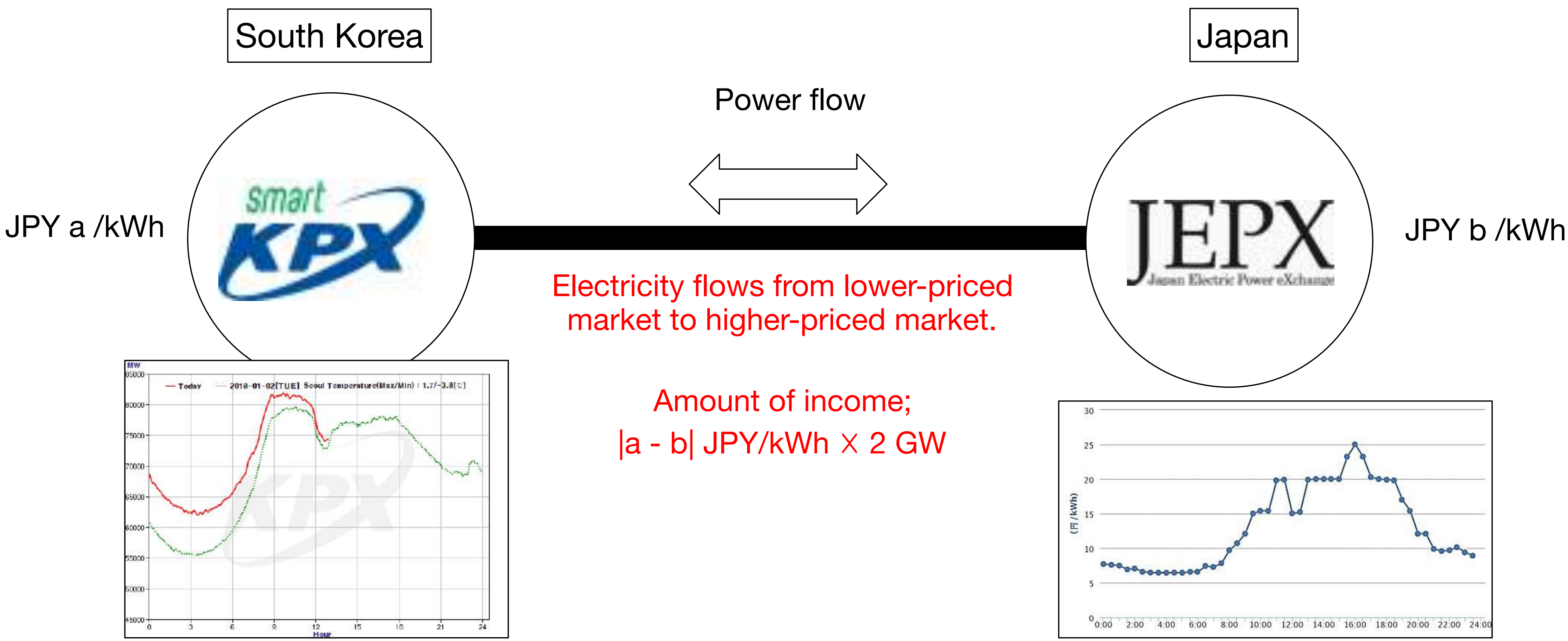
*In the red frames, the IRR median value is positive.

Source: Renewable Energy Institute

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.

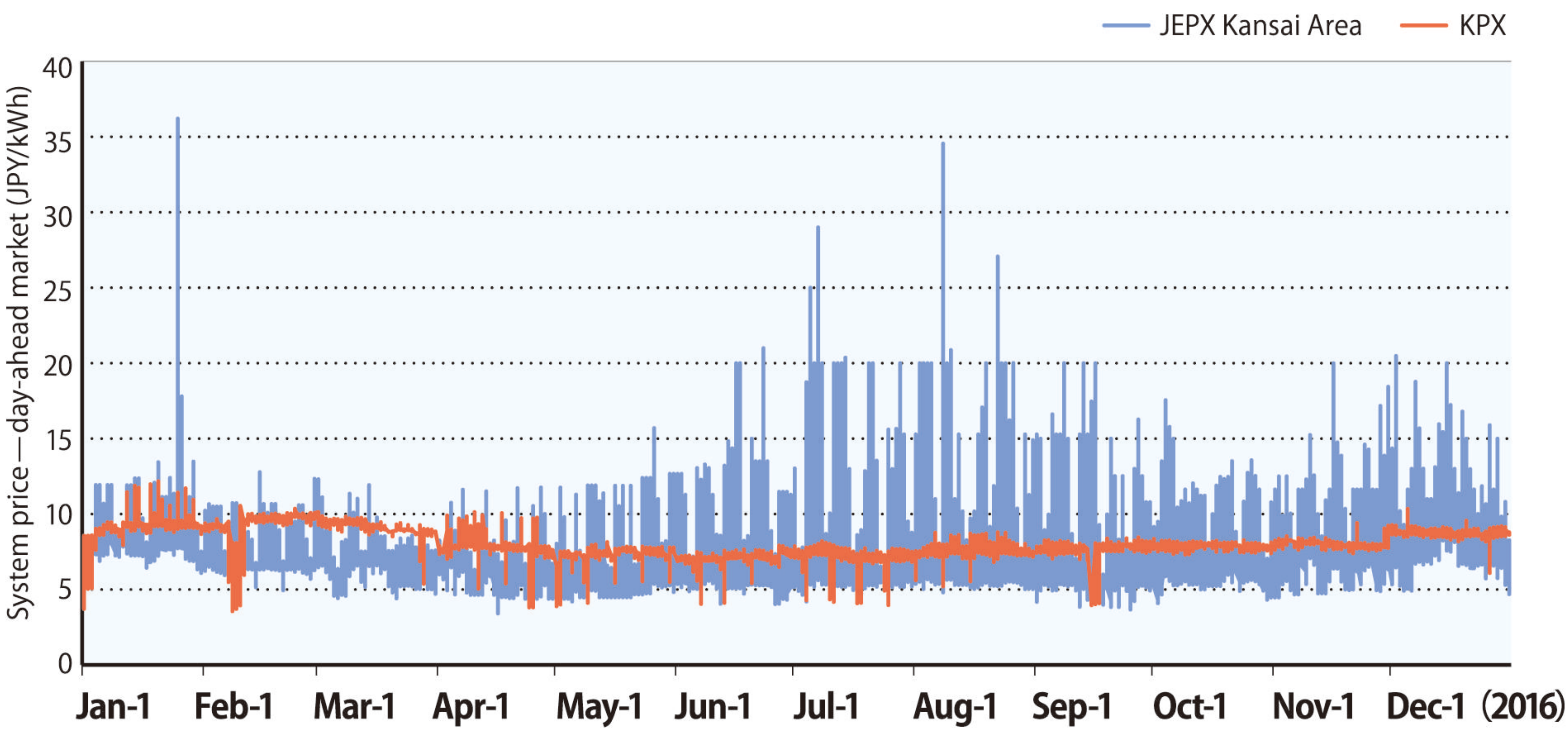


Source: Renewable Energy Institute

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: Renewable Energy Institute

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: Renewable Energy Institute

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

Four business models for interconnectors investment recovery estimated:

1) In the case of "generators/suppliers dedicated line model" to procure electricity from overseas power plants or suppliers and sell it in Japan, it was shown that investment for interconnector could be recovered if low-priced electric power can be procured.

- *it is important to note that the impact on the profitability could be significant by the power procurement prices and by the Japanese market frameworks.*

2) In the case of "regulated grid tariff model" in which General Electricity Transmission and Distribution Utility invests to construct interconnector and recovers the investment through grid tariff, the consumers need to pay around 0.1 yen /kWh.

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

4) In the case of “congestion charge model" in which market price differences in the consolidated market are the revenues, investment is recovered even with a relatively low capacity factor.

- *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.*

2. Assessment of social benefits

Table 19: Preceding studies on cost benefit analyses in the energy field with consideration of benefits other than investment recovery

Benefits	METI (2015)	OCCTO (2017)	MOE/Mitsubishi Research Institute (2015)	METI/Mizuho Information & Research Institute (2016)	Research Institute of Innovative Technology for the Earth (2014)	Central Research Institute of Electric Power Industry (2015)	Otsuki (2017)	(Reference) ENTSO-E CBA 1.0
1. Reduction in fuel costs of thermal power plants		○	○	○	○	○	○	○
2. Reduction in equipment costs of existing power plants					○	○		△
3. Economic effects (GDP & employment)			○	○				
4. GHG reduction			○	○	○	○	○	○
5. Improvement of energy security (self-sufficiency rate/ effect of stockpiling cost reduction)			○	○	△			
6. Reduction in nuclear power risk costs					○			
7. Reduction in nuclear power plant siting grants					○			
8. Expansion of renewables	○						○	○
9. Toughness/flexibility against transmission accidents and unimplemented planned transmission lines								○
10. Reduction of overall transmission line loss								○
Costs	**METI (2015)**	**OCCTO (2017)**	**MOE/Mitsubishi Research Institute (2015)**	**METI/Mizuho Information & Research Institute (2016)**	**Research Institute of Innovative Technology for the Earth (2014)**	**Central Research Institute of Electric Power Industry (2015)**	**Otsuki (2017)**	**(Reference) ENTSO-E CBA 1.0**
1. Fuel cost increase owing to degraded power generation efficiency in thermal power plants	○		○					
2. Fuel cost increase associated with increased frequency of start-stop in thermal power plants	○		○					
3. Cost to improve pumped-storage hydropower plants	○							
4. Grid reinforcement cost	○	○	○				○	○
5. Cost to deploy storage batteries	○		○					
6. Investment cost for new energy source (including cost of purchase from renewable energy power plants)				○	○	○	○	

Source: Renewable Energy Institute

2. Assessment of social benefits

According to the preceding studies and the Interim Report (2017), social benefits were summarized as follows;

Main benefit 1: Electric power rate decrease owing to lower wholesale power price

Main benefit 2: Improvement of power supply security and reduction in ancillary costs by reserve capacity sharing

Main benefit 3: Expansion of flexibility favoring integration of variable renewable energy

Secondary benefit 1:

- Shutdown of thermal power plants owing to increased renewable energy, and subsequently fuel cost reduction, equipment maintenance cost reduction, CO2 emissions reduction, improvement of energy self-sufficiency rate.
- Increase of GDP, improvement of industrial competitiveness and expansion of employment are also expected.

Secondary benefit 2:

- Improvement and deepening of international relations

3. Legal frameworks of international connections

1) Cross-border transmission businesses and licenses

In order to realize the investment recovery model proposed, consider necessary business licenses in Japan.

1. Applicability of current business licenses: General Electricity Transmission and Distribution Business License and Electricity Transmission Business License may allow cross-border transmission business. Either "Regulated grid tariff model" or "Generators/suppliers dedicated line model" can be adopted.
2. Possibility of establishing a new license: In cases where international connection is not applicable to the definition of "wheeling service," or imposes special regulations (e.g., restriction on foreign investment), establishment of a new licenses would be a logical step.

Table 20: Business models and licenses

Investment recovery model		General Electricity Transmission and Distribution Business License	Electricity Transmission Business License	Reference system
Regulated Grid Tariff model	Directly	• Main General Electricity Transmission and Distribution Utility recovers the investments from grid tariff.	×	General burden in cross-regional grid development
	Indirectly	• Main General Electricity Transmission and Distribution Utility recovers the investments from other General Electricity Transmission and Distribution Utilities. • Other General Electricity Transmission and Distribution Utilities recovers the investments from grid tariff.	• Main Electricity Transmission Utility recovers the investments from General Electricity Transmission and Distribution Utilities. • General Electricity Transmission and Distribution Utilities recover the investments from grid tariff.	
Generators /suppliers dedicated line model	Directly	▲	▲	Wholesale supply in the Act on Special Measures Concerning Procurement of Electricity From Renewable Energy Sources by Electricity Utilities
	Indirectly	• Main General Electricity Transmission and Distribution Utility recovers the investments from interconnector users. • Interconnector users recovers investments from electricity sales income.	• Main Electricity Transmission Utility recovers the investments from interconnector users. • Interconnector users recover the investments from electricity sales income.	Specified burden in cross-regional grid development

Source: Renewable Energy Institute

3. Legal frameworks of international connections

2) Interconnector frameworks between two countries

The global investment frameworks for the construction of the interconnectors are determined taking into consideration of the electric industry laws, the foreign investments regulations, the taxation system of the two connecting countries.

Table 21: Examples of frameworks of international connections and related countries

		Interconnector name **"( )" means in planning**		**Interconnector operator (Investor)**
Country of one side	**One company**	East West Interconnector	Sea	Eirgrid Interconnector DAC (Ireland)
		Skagerrak 1 - 3	Sea	Statnett (Norway)*
Two countries	**One joint company**	BritNed	Sea	BritNed Development Ltd. (UK/Netherlands joint)
		(Le Golfe de Gascogne) (Baixas-Santa Llogaia)	Sea Land	INELFE (France/Spain joint)
	Two companies	Skagerrak 4	Sea	Statnett (Norway) Northern half of cable Energinet (Denmark) Southern half of cable
		China/Russia	Land	FGC (Russia) In the territory of Russia SGCC (China) In the territory of China
		(Hertel-New York Interconnector) (Champlain Hudson Power Express)	Lake and Land	Hydro-Québec (Canada) In the territory of Canada TDI New England (US) In the territory of US

*Denmark pays a lease fee for Skagerrak 1 to 3 and bears half of the operating and maintenance costs.

Source: Renewable Energy Institute

Points to consider concerning the frameworks of Japan-Russia and Japan-South Korea international connections

Russia:
- Having actual results ininterconnectors and a framework of Federal Law on international connections.
- Since exceptional rules are applied to Sakhalin, the direction of legal development in Sakhalin will influence the framework of Japan-Russia international connection.

South Korea:
- South Korea has no legal system for international connection. The discussion will be required along with legal development in the country.

CONCLUSION

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- Installation of interconnector by Japan is physically and technically feasible, and there are no major problems in connecting with Japan's domestic power grids after landfall.
- The cost for constructing 2 GW interconnectors will be within the range of a little over JPY 200 billion (for Japan-South Korea route) to a little less than JPY 600 billion (for Japan-Russia route), even including the cost for grid expansion in Japan. Cost can be recovered.
- Though legal frameworks should be further examined, even an existing transmission system operation-related license is applicable to a certain level. There is also an option to establish new international transmission system operation licenses.
- Various social benefits are expected, among which; improvement of diplomatic relations, and developments of more flexible and stronger Japan's electric power system.

- Dramatic cost reduction and massive integration of renewables show a cross section of global energy transition and inevitable future for Japan as well. International grid connections are key to accompany these developments.
- In the discussions on future energy scenarios, e.g. "Basic Energy Plan," announced by the Agency for Natural Resources and Energy in 2018, a "strategy of renewable energy expansion utilizing interconnectors" is stated. Amid the rapidly changing political situation in Northeast Asia, Japan now also needs to translate words into action.