Asia International Grid Connection Study Group

Second Report

June 2018

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Introduction

The Asia International Grid Connection Study Group, established in July 2016, released an Interim Report in April 2017 that reviewed the basics and global trends relating to international grid connections (often referred to as "interconnectors").

The Interim Report also pointed out that trading electricity through interconnectors is extremely rational from an economic perspective, and could be a powerful tool for ensuring reliable energy supply in an era when renewables will be adopted on a large scale. In Europe, such prospects have brought about what may be called a construction boom for interconnectors. In contrast, interconnectors are still uncommon in Northeast Asia, apart from a few exceptions. The Interim Report examined various factors to explain what lay behind the current situation and what challenges Japan should address.

The Study Group then extended its research, focusing on North America, and discussed what specific routes Japan could select when constructing interconnectors, as well as their associated costs. The findings have been compiled in this Second Report.

Chapter 1 outlines developments in international grid connections from early 2017 to May 2018. Expansion of international grid connections is an aspect of the global energy transition, and is regarded as one means of reforming electricity systems. Accordingly, the chapter surveys recent initiatives by China and South Korea to develop international grid connections and the progress of Japan in its electricity system reform.

Chapter 2 examines developments with regard to international grid connections in North America. Such grid connections between the United States and Canada have been in operation for over a century, with 37 major interconnectors running across the border as of 2016.[1] In contrast with Europe, where supranational institutions and national or federal governments play a key role in facilitating development of interconnectors, in the United States and Canada these initiatives have recently been advanced on a commercial basis by state or provincial governments and businesses other than transmission companies. Such setups and the way they are structured are useful points of reference for Northeast Asia.

Chapter 3 examines what specific routes Japan could choose for interconnectors to be developed with South Korea and Russia. However, it is likely to be difficult for Japanese people to understand the significance of interconnectors without specific examples and numerical estimates indicating where grids would be laid and their associated construction costs. This chapter therefore suggests and simulates several possible routes between Japan and Russia, and between Japan and South Korea, and estimates the associated construction costs, with reference to some overseas examples.

Chapter 4 examines several business models based on the findings of the previous chapter that could be adopted to recover construction costs (e.g., via grid tariffs [the regulated grid tariff model] or via electricity sales [the generators/suppliers dedicated line model]). Finally, analysis is performed to examine what benefits international grid connections could bring to society, and ascertain the necessary legal framework (e.g., a licensing scheme) for international transmission business.

The Study Group has now entered a new phase focused on detailed, practical analysis of international grid connections in Northeast Asia. We hope this report, together with the Interim Report released in 2017, will serve as material that fosters constructive discussion.

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1 Canadian Electricity Association, *The North American Grid* (2016).

Chapter 1:
Recent Developments in International Grid Connections and Electricity System Reform

The Study Group released its Interim Report in April 2017. Since then, some progress has been made, including initiatives in Northeast Asia to develop international grid connections, and reform of Japan's electricity system. This chapter reviews such developments inside and outside Japan during the period covered in this Second Report, from early 2017 to May 2018.

Section 1: Initiatives in Northeast Asia to develop international grid connections

As stated in the Interim Report, prior to 2016 research institutions were addressing the concept of international grid connections in Asia, but it was only from 2016 onward that major energy companies in the countries concerned (China, Japan, South Korea, and Russia) started to develop more specific business plans. In March 2016, a memorandum of understanding for research and planning was concluded between Japan's SoftBank Group, China's State Grid (SGCC), Korea Electric Power (KEPCO), and Russia's state-run transmission company Rosseti to facilitate development of international grid connections.

Amid these developments, more support and decision-making than ever before are needed from governments. Since the conclusion of the memorandum mentioned above, the countries concerned have been working even harder to build international grid connections in Asia; the initiatives undertaken in each country since 2017 are reviewed below.

Since he took office in May 2017, South Korean President Moon has presented the nation's energy transition as a main issue of his agenda, announcing an energy policy aimed at increasing the share of renewable energy in the country's energy mix. Accordingly, he has been working hard to advance the Northeast Asia Super Grid concept, the aim of which is to share renewable energy throughout the region.

At the Eastern Economic Forum, held in Vladivostok, Russia, in September 2017, President Moon called on the heads of the countries concerned to start discussions on developing international grid connections around Northeast Asia. He also set up the Presidential Committee on Northern Economic Cooperation to facilitate economic cooperation in the region. One of the top priorities on the committee's agenda was pursuing international grid connections among the countries of Northeast Asia via transmission lines.

In response to South Korea's proposals, Russia has also started working hard to develop interconnectors. Far East Development Minister Galushka visited South Korea in November 2017 to talk with KEPCO about a Power Bridge project. This is a project to connect the power systems of the two countries through high-capacity transmission lines and supply electricity from Russia.

Russia has also repeatedly suggested developing an interconnector between itself and Japan. At the joint press conference after the Japan–Russia summit held on April 27, 2017, President Putin emphasized that one of the topics discussed during the summit was a Japan-Russia Power Bridge that would connect the two countries via transmission lines. In October that year, when Deputy Prime Minister Dvorkovich visited Japan, he also referred to the project as feasible.[2]

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[2] A comment he made on October 1, 2017, when attending the Science and Technology in Society Forum in Kyoto. "A power bridge could benefit both Russia and Japan" [in Russian], *Rueconomics*, October 1, 2017, https://rueconomics.ru/278903-vice-premera-energomost-mozhet-byt-vygoden-i-yaponii-i-rossii.

The Global Energy Interconnection Development and Cooperation Organization (GEIDCO) is another entity working on projects to accelerate the development of interconnectors in Asia. Founded in March 2016 as a nonprofit organization and chaired by former SGCC President Liu, it works to get all parts of the world connected via high-voltage direct current (HVDC) grids to share renewable energy across borders.

At the China-South Korea Business Forum, held on December 13, 2017, during President Moon's visit to China, GEIDCO signed a cooperation agreement with SGCC and KEPCO for a China–South Korea interconnector project. The agreement aims to implement the project between the two countries as a precursor to international grid connections across Asia. To this end, the three entities will work together on decision-making, research, business planning, and project coordination.[3] The agreement states that they will pursue the China–South Korea interconnector under the framework of a Mongolia–China–South Korea–Japan project, which assumes development of interconnectors with Japan and other neighbors as the next steps.

Section 2: Progress with electricity system reform in Japan

As the Interim Report pointed out, Japan needs to make further progress in reforming its domestic electricity system as the first step toward developing international grid connections. Work to reform the electricity system of Japan, started in 2012, is still underway. This section reviews progress with the reform from early 2017 to May 2018.

1) Progress in unbundling transmission and distribution operations

In Europe, international grid connections are spearheaded by transmission system operators (TSOs) as neutral entities. In Japan, to ensure neutrality of the transmission and distribution sector, the Electricity Business Act was revised in 2015, obliging electricity companies to unbundle their power grid operations from their power generation and retail operations to form independent legal entities by 2020. Accordingly, Tokyo Electric Power (TEPCO), the first among the utilities to do so, implemented legal unbundling in April 2016, spinning off its transmission and distribution operations as a separate subsidiary, TEPCO Power Grid. In the same month, Chubu Electric Power introduced an in-house company system as a preliminary step toward legal unbundling. The same system was also adopted by Kyushu Electric Power in April 2017, by Chugoku Electric Power in October 2017, and by Tohoku Electric Power, Shikoku Electric Power, and Hokkaido Electric Power in April 2018.

In addition, in June 2017, Chubu Electric Power, Hokuriku Electric Power, and Kansai Electric Power announced the creation of a partnership for their power transmission and distribution operations. Since then, these companies have collaborated to optimize operational efficiency and development of grid infrastructure, and to balance power supply and demand. Likewise, in its Revised Comprehensive Special Business Plan released in May 2017, TEPCO stated that it would set up joint ventures with outside partners in the early 2020s, although such partnerships were intended to stop short of the reorganization and integration of transmission and distribution businesses proposed in our Interim Report. We hope that these developments will enable power to be transmitted over a broader area and in a more neutral manner.

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[3] GEIDCO, "GEIDCO Signed Cooperation Agreement for China-South Korea Grid Interconnection Project with SGCC and KEPCO," press release, December 18, 2017, http://www.geidco.org/html/qqnyhlwen/col2017080776/2017-12/18/20171218140633784710541_1.html.

2) Achievements in the fully liberalized electricity retail business

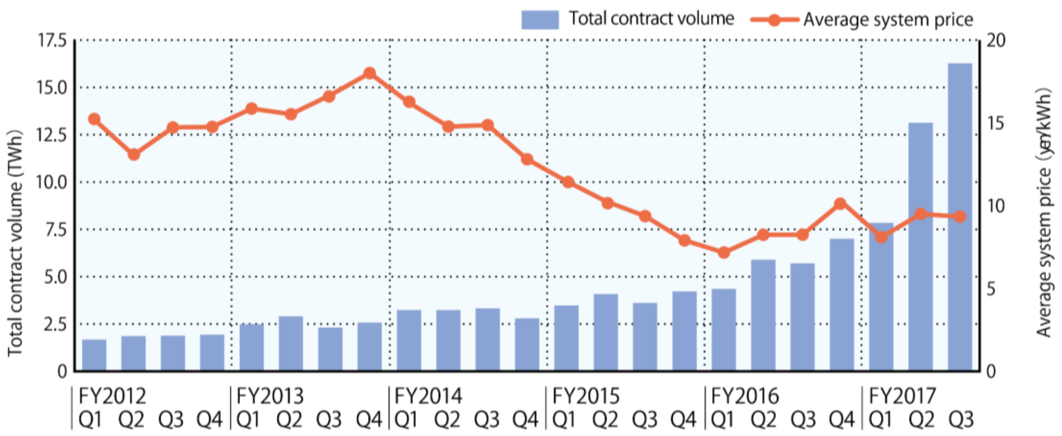
Full liberalization of the electricity retail business, another pillar of the electricity system reform, was achieved in April 2016. The *Surveys and Statistics of Electricity* released by Japan's Ministry of Economy, Trade and Industry (METI) show that, in addition to the former general electricity utilities (GEUs), which spanned power generation, transmission, and distribution, there were 440 electricity retailers registered as of December 2017, of which 345 had some sales recorded in that month. Their share of the electricity retail market as a whole amounted to 12.6%, while their share of low-voltage demand (mainly households) was 7.5%.[4] As of March 31,[5] 2018, about 7.1 million low-voltage consumers across Japan had switched to electricity retailers. About 3.5 million, or half, of such switches had taken place in TEPCO's service area, amounting to more than double the number recorded for March 31, 2017.[6] These figures demonstrate some degree of progress in terms of competition among power suppliers, while it appears that former GEUs are also embarking on price-based competition in an effort to get their customers back. It is truly expected that the government to adopt relevant policy programs promoting greater competition.

3) Progress with market system reform

One initiative for promoting competition is stimulation of wholesale electricity trading, as suggested in the Interim Report. It is encouraging in this regard that the day-ahead spot market more than doubled in size during FY2017 on a year on year basis (Figure 1). That seems to reflect, in part, the effects of gross bidding[7] by former GEUs launched in FY2017, as well as purchases of renewable energy by transmission and distribution utilities. Nevertheless, under 10% of the entire country's electricity consumption is traded on the spot market; further growth would therefore be beneficial.

Transaction prices on the spot market started to decrease in FY2014 with the inflow of solar electricity working as a main downward pressure, before picking up in FY2016 as prices of fossil fuels started rising fast. Meanwhile, differences between regions can be observed as a result of market splitting, and this appears to have also impacted competition in the retail market.

Figure 1: Quarterly contract volumes and average system prices at Japan Electric Power Exchange (JEPX)



Source: Created by Renewable Energy Institute from the Spot Market Trading Results on JEPX's website.

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4 The shares represent sales of electricity retailers plus those of specified electricity transmission and distribution utilities.

5 Note that fiscal years (FY) in Japan run from April 1 to March 31 for the public sector and most private sector companies.

6 According to the Organization for Cross-regional Coordination of Transmission Operators (OCCTO).

7 Under the gross bidding system, a former GEU sells electricity it has produced itself to the wholesale market, before buying back the amount it needs. Since FY2017 former GEUs have voluntarily engaged in gross bidding, which is believed to be effective for stimulating wholesale electricity trading.

At the same time, discussions are underway on new initiatives for market system reform. In May 2018, the non-fossil value trading market started to auction non-fossil value certificates derived from either renewable energy or non-renewable (nuclear) energy. The scheme is significant in that it gives explicit environmental value to renewable electricity, making it available to consumers and businesses. Potential categories of renewable energy sources are to be discussed going forward; hopefully they will be established soon. In the future, this will have a bearing on trading of environmental value as part of international electricity trading.

Some expected that the "Baseload Market"[8] would allow newcomers in the electricity retail business to buy electricity at lower prices. However, it has to be admitted that it is still unclear whether such a market would prove effective in that regard. In current discussions of the market system's design, the selling price of electricity put up to auction by former GEUs can be capped at the average generation cost among their power stations, including those not yet in operation, minus proceeds from the capacity market. This raises concerns that the former GEUs could keep their price offers high, reducing volumes traded. In fact, Europe and some other parts of the world now see the concept of baseload power sources as increasingly irrelevant anyway, given that renewable power is being deployed on a massive scale. How helpful this distinctive form of market design is for promoting competition should therefore be carefully monitored.

Section 3:
Inter-regional transmission operations and grid connection issues in Japan

In Japan, as electricity system reform has proceeded in recent years, a number of problems related to inter-regional transmission operations and grid connections have appeared. With an increasing number of facilities generating renewable energy, grid operators in many parts of Japan are reporting that, when receiving applications for grid connection, they have no available capacity in high-voltage transmission lines. Before considering international grid connection, therefore, it is possible that existing grid capacity may need to be reinforced, and that the reinforcement work required could result in long delays before international grid connections are established. On the other hand, it has been pointed out that the actual capacity factors of high-voltage transmission lines are in fact low across Japan, and that the real need is to improve the procedures employed for grid connection. This section therefore describes current grid connection issues and possible solutions.

1) Problems with the existing first-come-first-served rule

Behind the lack of available capacity in Japan's high-voltage transmission lines lies the first-come-first-served rule for grid users. Under this rule, power generating facilities that are already connected to the electrical grid are guaranteed transmission capacity equivalent to their maximum generating output. At the same time, if a new entrant applies for an initial grid connection when available grid capacity is insufficient, grid capacity must be reinforced so that existing power producers will not be hindered from accessing the grid. Some of the expenses for reinforcing the grid capacity must be borne by the applicant, who must wait until the work is completed to get connected.

However, given the realities of the supply-demand balance, an increase in output from solar photovoltaic (PV) facilities, for instance, would lead to a corresponding reduction in output from thermal power plants, which would therefore not reach maximum output. Consequently, when existing generating facilities are guaranteed grid connection capacity equivalent to their maximum output while grid capacity is reinforced for new entrants, not only do new entrants find it difficult to get connected to the grid, but also surplus grid capacity is developed, risking further decreased capacity factors.

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8 The Baseload Market is a special forward market where the utilities sell baseload electricity such as coal, large hydro and nuclear. The aim of this new scheme is to ensure newcomers to procure "low-marginal-cost" electricity via a wholesale market. METI plans to open it in 2019.

2) Japanese version of "Connect and Manage"

As a solution, OCCTO is considering adopting a new rule for grid access called "Connect and Manage." Already introduced in the United Kingdom, this approach to grid connections allows new entrants to get connected to a grid running short of available capacity before work to reinforce grid capacity is completed. Germany has also introduced a similar approach based on a combination of priority dispatch and redispatch. Using these examples for reference, a set of initiatives referred to as the Japanese version of Connect and Manage is being discussed (Table 1).

The solution, once adopted, is expected to mitigate grid connection issues. However, it assumes that in the case of a failure or a surge of power on the grid, adjustment of power flows would involve curtailing outputs from generating facilities to be connected to the grid in future, rather than curtailing outputs from thermal or renewable energy facilities that are already connected. As a result, the approach risks limiting the grid's capacity to adjust, while it could also impose excessive output curtailments exclusively on newly connecting facilities.

Table 1: Initiatives for Japanese version of Connect and Manage

Initiatives	Existing rules	New rules
More practical estimating of power flow	Estimate available grid capacity based on the total installed capacity of generating facilities due to be connected	Simulate power outputs that can actually be produced and use total predicted outputs to estimate available grid capacity
N–1 (N minus one) power control	Develop an electric power system that can maintain power generation and transmission even when a single component of the system fails (i.e., in "N minus one" conditions)	Develop a mechanism to control outputs from generating facilities when a power system failure occurs so that as many generating facilities as possible can be connected to the grid
Non-firm (flexible) connection	Develop an electric power system with enough transmission capacity margin to prevent its transmission capacity from being exceeded when all power plants generate large outputs at the same time	Allow a new power generating facility to connect to the electrical grid before grid capacity is reinforced in exchange for its agreement to have its output curtailed when already-connected generating facilities produce large outputs

Source: Created by Renewable Energy Institute.

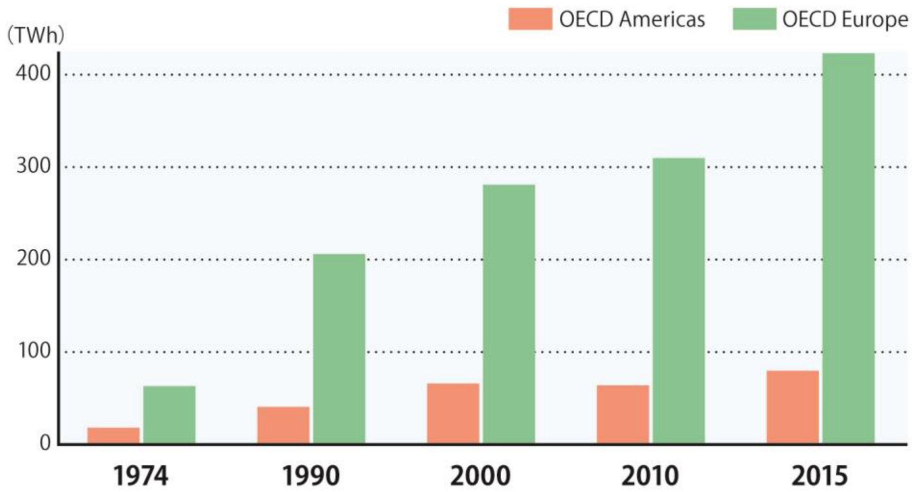
In the United Kingdom and Germany, which have already adopted Connect and Manage or a similar scheme, adjustment of power flows is also required of already-connected generating facilities to control power flows in a more flexible and economical manner. The Japanese version should also include existing generating facilities in the scope of its power flow control rules. Furthermore, any future mechanism designed with interconnectors in mind should avoid treating existing and new generating facilities differently, and should instead enable electric power to flow through the system in an economical manner in each time period. To achieve this, ways to encourage already-connected generating facilities to participate in controlling power flow should be considered, such as compensation for the economic losses incurred.

As described above, efficient use of the existing grid for inter-regional transmission operations is critical. At the same time, as pointed out in the Interim Report, more investments should be made in grid connections both within and outside Japan. Based on the cost-benefit analysis in Chapter 4, grid connections should be reinforced inside and outside Japan in a rational manner to enable inter-regional transmission operations. International grid connections are one of the pillars that will support such inter-regional operations.

Chapter 2:
Initiatives in North America to Develop International Grid Connections

Electricity trading through international grid connections has been growing globally in recent years. After Europe, North America is the next largest trader (Figure 2). The United States and Canada, in particular, have been trading electricity between them for a century: as of 2016, there were 37 interconnectors linking the two countries.[9] At the same time, some differences are observed compared with Europe. This chapter examines progress with initiatives to develop international grid connections in North America based on a field survey which the study group conducted in September 2017.[10]

Figure 2: Electricity trading volumes in North America and Europe



Source: Created by Renewable Energy Institute from International Energy Agency (IEA), *Electricity Information 2017*.

Section 1:
The electricity system and international grid connections in North America

1) Electricity system and trade in North America

North America, consisting of just three countries—the United States, Canada, and Mexico—is nevertheless a very large electricity market. Canada is the world's second largest generator of electricity from hydropower, which accounts for 59.4% of the country's generation mix, making it a renewable energy superpower. In the United States, renewables account for a smaller portion of the electricity mix, but the country ranks second in the world in installed capacity for both wind and solar PV generation, leading the renewable energy market.[11]

Having concluded a free trade agreement in 1994, North America's markets are already internationally integrated. It makes complete sense for the United States and Canada to trade electricity through interconnectors because they share a border of almost 9,000 kilometers, the longest in the world, and most of Canada's electricity demand comes from places located along the border anyway. Compared to the United States, Canada has some margin in its capacity for supplying electricity, especially in hydropower generation, and exports to its neighbor 11.3% of the power it produces annually, making

9 Canadian Electricity Association, *The North American Grid* (2016).

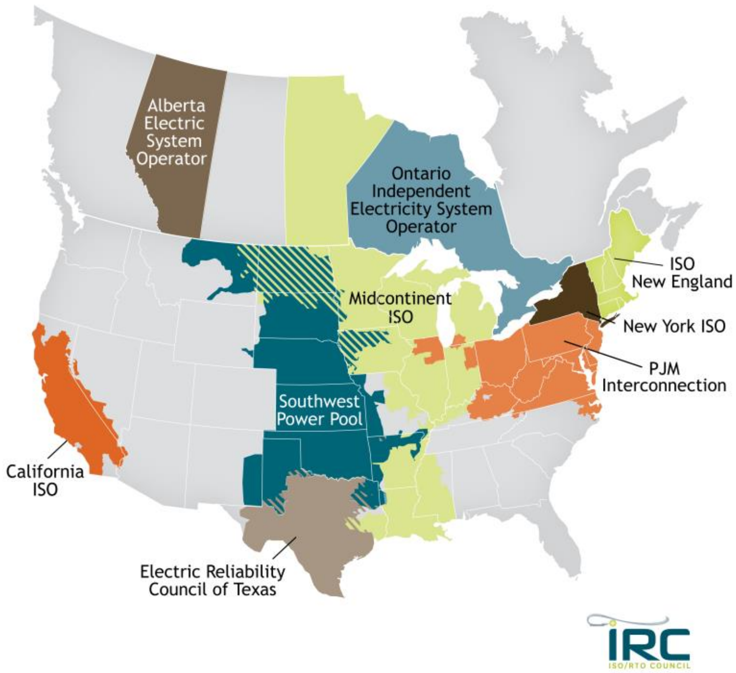
10 The study visits were made at Canadian operators including the Independent Electricity System Operator, Hydro One, and Emera Energy (Boston Office), as well as US entities such as ISO New England, New York ISO, the US Department of Energy, and the Federal Energy Regulatory Commission (FERC), to exchange opinions.

11 IEA, *Electricity Information 2017*; and BP, *Statistical Review of World Energy* (2018).

it one of the largest exporters of electricity in the world.[12] In contrast, the United States is the world's largest importer of electricity, though imported electricity accounts for only 1.9% of the power it consumes as it is the second largest electricity market in the world. Nevertheless, electricity trading between these two countries has been increasing steadily.

The United States and Canada have adopted similar market systems, and their grids are operated in an integrated manner under the rules set by the North American Electric Reliability Corporation. In many states and provinces, transmission business is functionally unbundled from generation business and independent system operators (ISOs) are in charge of grid operations and markets (Figure 3), while some avoid unbundling, instead retaining the integration of their generation and transmission sectors. In any case, the two countries have much in common as both have federal systems, great diversity in their electricity businesses, and component states and provinces that exercise great power. A number of close cross-border connections have been formed: Ontario (Independent Electricity System Operator), for example, is connected to New York State (New York ISO) and the Midwest (Midcontinent ISO); and Quebec (Hydro-Québec, a vertically integrated utility) is connected to New England (ISO New England) and elsewhere. Moreover, Midcontinent ISO could be called a cross-border ISO as it also covers the Canadian province of Manitoba as part of its business area.

Figure 3: ISOs in the United States and Canada



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

Meanwhile, Mexico exported 7.31 terawatt-hours (TWh) of electricity to, and imported 0.39 TWh from, the United States in 2015, much less than between the United States and Canada. Both imports from and exports to the US accounted for less than 1% of the electricity produced in Mexico, indicating limited progress with market integration between the two nations.[13] The only exception is the Mexican state of Baja California, where the US's California ISO is directly responsible for grid operations across the border.

[12] IEA, *Electricity Information 2017*.

[13] This is partly because the system Mexico had long maintained for integrated operation of generation and transmission kept deployment of variable renewable energy at a low level (10.8 TWh, or 3.4% of electricity generated). However, that is expected to change as the government of Mexico decided in 2014 to reform its electricity system.

2) Procedures for construction of interconnectors between the United States and Canada, and roles of state and provincial governments

In Europe, the European Commission and national governments have set ambitious targets for deployment of renewable energy, carrying out policy programs to promote construction of interconnectors as an integral component of such deployment. In North America, on the other hand, similar initiatives are led mainly by state and provincial governments (Table 2). For instance, the state of New York has set a target of raising the share of renewable energy within its electricity consumption to 50% by 2030. Meanwhile, the province of Ontario, where hydropower already accounted for more than half of electricity generation, decided to shut down all its coal-fired power plants, and plans to increase electricity generation from wind power and other renewable energy.

Table 2: Electricity systems in Europe and North America, and status of interconnectors (in generalized terms)

	Type of generation-transmission unbundling	Grid operators	Investors in interconnectors	Renewable energy policymakers
N. America	Functional	ISOs	Commercial entities	State and provincial governments
Europe	Ownership	TSOs	TSOs	National governments

Source: Created by Renewable Energy Institute.

In the United States, many state governments have particularly high expectations regarding Canada's massive capacity to supply renewable energy. For instance, the state governments of Massachusetts and New York, near Canada, intend to import hydropower and wind power electricity produced by their neighbor and thus raise the share of renewable energy in their electricity consumption. To that end, they are progressing several plans to develop interconnectors and combine electricity generation and transmission services for import. The next section introduces some of these plans.

In both countries, the federal governments in principle avoid interfering in the market by setting targets, such as targets for the electricity mix. A well-established division of roles between the federal and state or provincial governments dictates that such targets should be decided by state and provincial governments. Meanwhile, the federal government is responsible for interstate, interprovincial, and international electricity trading mainly from the standpoint of national energy security. Before any interconnector is developed, a federal agency—the Department of Energy for the United States and the National Energy Board for Canada—is authorized to review the plan from a technical perspective and decide whether to approve it.

That leads to the difference between Europe and North America with regard to the entities that develop interconnectors. In Europe, many countries have adopted ownership unbundling, and TSOs, state-owned or not, are working actively to build interconnectors in line with each national government's policy of renewable energy deployment. By contrast, in North America, where functional unbundling has been adopted, ISOs avoid taking the lead in development of interconnectors as they own no grids themselves. Meanwhile, the transmission companies that own the grids are relatively cautious about investing as they are not allowed to operate interconnectors themselves. Overall, the reluctance to develop interconnectors may reflect the fact that, compared with Europe, North America finds less need for inter-regional transmission operations and other solutions to power supply fluctuations in the first place. The share of variable renewable energy is still small in North America, while in Canada hydropower—the outputs of which are easy to control—accounts for a substantial proportion of the energy mix. Under these circumstances, interconnectors are often developed on a purely commercial basis today.

In addition to the approval from the federal government mentioned above, an entity planning to develop an interconnector must obtain approval from the relevant state or provincial government with regard to environmental assessment and other requirements. The prospective developer must also coordinate with the ISO responsible for grid operation in the area in question. Once an interconnector is in place, in principle, both ownership and responsibility for operation of the grid are divided between the two countries at the border.

Section 2: Examples of interconnector projects in North America

This section introduces some distinctive examples of recent interconnector projects between the United States and Canada comprising renewable electricity procurement projects for the states of Massachusetts and New York. The outlines and purposes of the projects described below are based mainly on materials released online by the state governments and the parties that responded to their requests for proposals.

1) Renewable electricity procurement projects for Massachusetts

Massachusetts aims to reduce its greenhouse gas emissions by 25% from their 1990 level by 2020 (as stated in its Climate Protection and Green Economy Act). As part of its effort to achieve this target, in March 2017 the state government joined with retail electricity businesses to request proposals for a project to procure about 9.45 TWh of electricity per year generated from clean energy in accordance with the Act to Promote Energy Diversity, revised in 2016. The request for proposals asked prospective bidders to propose a long-term contract for supplying electricity generated from cost-effective clean energy (renewable energy sources, such as hydropower, solar PV, or wind power, individually or combined) including relevant transmission expenses. A total of 46 project proposals were submitted before the deadline in July 2017.

The state announced the tender result on January 25, 2018, and the Northern Pass Hydro project, proposed by Eversource Energy, was selected. Northern Pass planned to construct an about 309-kilometer (192-mile) transmission line, composed of direct current (DC) and alternating current (AC) sections, between Québec and New Hampshire to supply 1,090 megawatts (MW) of hydropower electricity to Massachusetts. Under the plan, at least 80% of the new transmission line would have been laid under public roads or constructed by reinforcing existing overhead transmission lines. In November 2017, Eversource Energy had obtained a Presidential Permit from the US Department of Energy.

The transmission line was designed to go through New Hampshire. However, after the tender process was completed, the New Hampshire Site Evaluation Committee, authorized to review and approve the location, planning, and operation of energy facilities, unanimously rejected the project because of concerns about a possible negative impact on tourism and other business activities in the state. Accordingly, Massachusetts decided on March 28, 2018, to start negotiations for the runner-up project, New England Clean Energy Connect (NECEC).

Two projects for Massachusetts are explained in detail below: one is the NECEC project, which plans to construct an overhead transmission line in Maine to supply hydropower electricity from Québec, and the other is the Atlantic Link project, which connects Massachusetts with New Brunswick, Canada, through submarine HVDC cables to supply electricity generated from a combination of wind and hydro power. The latter is described based in part on an interview we had with Emera Energy, the company that proposed it, in September 2017.

2) New England Clean Energy Connect (NECEC) project

The NECEC project was proposed by Central Maine Power, a subsidiary of Avangrid, which operates electricity and gas businesses in New England and New York State. Avangrid, a member of the Iberdrola Group, a global electricity company based in Spain, owns 6.5 gigawatts (GW) of renewable power generation capacity in the United States. For the project, Central Maine Power is proposing to use a 233-kilometer (145-mile) overhead transmission line going through Maine to supply up to 1.2 GW of hydropower from Québec to Massachusetts. Most parts of the line will be constructed by reinforcing existing overhead transmission lines, and some will be newly constructed (320 kilovolts [kV], HVDC). The reinforcement work is estimated to cost 950 million dollars.[14] Central Maine Power applied for a Presidential Permit for this project in September 2017.

What distinguishes the NECEC project is its proposal of the shortest possible route to connect Québec and Massachusetts. The project also makes the most of the existing grid to reduce the need for reinforcement work, thereby mitigating the associated environmental impact. A substation in Lewiston, the connection point for the project, has already been upgraded at a cost of 1.4 billion dollars to make the grid more reliable when taking on a greater amount of renewable electricity. The partnership with Hydro-Québec, a Canadian electric utility with substantial hydropower assets, will help keep down the price of electricity to be supplied to Massachusetts.

In addition to the NECEC project, Hydro-Québec was also involved as a partner in two of the other projects submitted in response to the request for proposals by Massachusetts: the Northern Pass Hydro project and the New England Clean Power Link project proposed by TDI New England.[15]

3) Atlantic Link project

The Atlantic Link project (Figure 4) was proposed by Emera, a gas and electricity company based in Nova Scotia, Canada. The project proposes laying about 604 kilometers (375 miles) of submarine HVDC cables from Coleson Cove, New Brunswick, to Plymouth, Massachusetts, and supplying about 5.69 TWh of wind and hydroelectricity annually from the end of 2022 at rates fixed for 20 years.

A key characteristic of this project is the substantial use of wind power planned to supply electricity to Massachusetts. In January 2017, before presenting its proposal in July, Emera sought generating facilities in Canada from which it could procure power, and selected wind farms with a combined capacity of about 1.2 GW in the provinces of New Brunswick and Nova Scotia. These wind farms would account for about 70% of the electricity the project plans to supply. Emera also plans to supply electricity from hydropower stations in the province of Newfoundland and Labrador, and the province of New Brunswick, which would provide 1.1 TWh and 0.46 TWh per year, respectively.

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[14] "Prospects Improve for CMP's $950 Million Power Line Plan," *Portland Press Herald*, March 13, 2018, https://www.pressherald.com/2018/03/13/1-billion-cmp-transmission-project-ready-to-go-forward.

[15] "Hydro-Québec Dominates Mass. Clean Energy Bids," *RTO Insider*, July 27, 2017, https://www.rtoinsider.com/hydro-quebec-clean-energy-46741.

Figure 4: Atlantic Link project: Overview

Source: Emera, "About the Atlantic Link," accessed May 23, 2018, https://www.atlanticlink.com/the-project.

A second characteristic of this project is the plan to transmit electricity through long submarine HVDC cables extending more than 600 kilometers. At an interview we had with Emera Energy, a subsidiary of Emera, the company said that they had considered all aspects of the project, including the transmission distance and how they might build consensus with stakeholders. As a result of that assessment, they judged that submarine cables would be more economically rational than overhead lines laid onshore, mainly because the former could be completed in a shorter time. They plan to make use of available capacity in the existing grid by bringing the submarine cables ashore near the Pilgrim Nuclear Power Station in Massachusetts, which is set to cease operation in June 2019. In addition, the proposal estimates that the submarine cables will operate at a capacity factor of 65%, leaving surplus capacity available for such purposes as procuring more renewable electricity from Canada or making the grids in both regions more reliable.

Estimated initial expenditure for the Atlantic Link project amounts to two billion dollars, including expenses for constructing wind and hydropower stations and laying submarine cables. The electricity rates (fixed for 20 years) that Emera proposed to Massachusetts to recover its investment were higher than if the power were produced by gas-fired power plants, but were said to have been competitive. Before offering a bid to Massachusetts, in December 2017 Emera applied for a Presidential Permit to build the interconnector. Emera eventually lost the tender, as mentioned above, but the company has declared they will continue pursuing the project.

4) New York State's project for procuring renewable electricity

Guided by the Reforming the Energy Vision, a plan prepared under the leadership of Governor Cuomo, in 2014 the state of New York set the Clean Energy Standard, an ambitious target of supplying 50% of electricity consumed in-state with renewable energy by 2030. To achieve this target, in June 2017 the New York State Energy Research and Development Authority (NYSERDA) and the New York Power Authority (NYPA) requested proposals for long-term contracts to procure renewable electricity.

In the same month the governor announced that, through these requests for proposals, the state would invest 1.5 billion dollars and procure a large amount of renewable electricity, 2.5 TWh per year. Specifically, NYSERDA called for proposals aimed at producing renewable electricity in-state, while the NYPA requested proposals for a broader scheme that would cover transmission and procurement from sources out of state. More than 200 project proposals were received in response. In March 2018, NYSERDA announced the results of its tender process. It chose a total of 26 projects based in the state: 22 solar PV, three wind power, and one hydropower. The NYPA is set to announce its tender results in summer 2018.

Champlain Hudson Power Express is a project proposed in response to the NYPA's request for proposals. It plans to deliver hydropower and other renewable electricity from Québec through Lake Champlain and the Hudson, Harlem, and East Rivers over to Queens, New York City, through a 1 GW HVDC cable. The transmission line is designed to extend 315 kilometers underwater and 220 kilometers underground. The business entity operating the project is Transmission Developers (TDI), a subsidiary of Blackstone. According to a research report published by PA Consulting Group in 2017, the Champlain Hudson Power Express will require an initial project investment of 2.2 billion dollars, in return for which the project can supply 8.3 TWh of renewable electricity per year, delivering almost 50 billion dollars of benefits during a 30-year period of operation.[16] The project had been under review even before the state of New York set its target for deployment of renewable energy by 2030; a Presidential Permit and other approval and authorization necessary for construction have already been obtained.

In conclusion, the North American examples mentioned above provide some insights. First, international grid connections are quite common in North America just as in Europe. This may be partly because North America has a geographical advantage in terms of continuity as a single landmass, although lines that go through the sea, lakes, or rivers have also appeared of late. Second, behind the recent growth in interconnectors lie the critical roles played by state and provincial—not federal—governments, a difference with Europe. State and provincial governments themselves set targets for deploying renewable energy, and cross-border trading of electricity focusing on the environmental value of renewable energy is increasing. Third, many projects adopt an investment recovery model resembling a merchant scheme combined with power generation (the generators/suppliers dedicated line model, described in Chapter 4). This is partly because Canada historically has a larger surplus capacity of renewable power supply, although the global reduction in costs for renewables and progress in technology enabling long-distance transmission may also play a part.

[16] TDI website, accessed May 23, 2018, http://www.chpexpress.com/pa_analysis.php.

Chapter 3:
Interconnectors between Japan and Russia and between Japan and South Korea: Possible Routes and Costs

As highlighted in the Interim Report, Japan has a relatively favorable geographical position for building interconnectors with its neighbors, South Korea and Russia. In Europe, NorNed, an almost 600-kilometer submarine transmission line that connects Norway and the Netherlands, has been in service for 10 years. By comparison, Cape Soya in Hokkaido, Japan, is a mere 43 kilometers or so from Sakhalin in Russia, and the distance between Fukuoka City in Japan and Busan City in South Korea is only about 200 kilometers.

The first section of this chapter examines what routes could be planned for constructing interconnectors between Japan and Russia, and between Japan and South Korea, to suggest several candidates for the best route. Section 2 estimates how much capital expenditure would be needed for each route planned, including costs for submarine cables and AC-DC converters.

Section 1: Construction routes for interconnectors

1) Principles for construction routes

When examining possible interconnector routes between Japan and Russia and between Japan and South Korea, the purposes of the construction must be defined. In other words, scenarios must be envisaged to establish which power sources in each country would be used, which demand centers electricity would be supplied to, and what benefits would be derived. The Study Group prepared scenarios for Japan–Russia and Japan–South Korea interconnectors, shown in Tables 3 and 4, prior to examining some possible routes.

Table 3: Scenarios for Japan–Russia interconnector

	Power sources	Demand centers
Russia	· Existing hydropower along Amur River · Newly developed wind power in southern Sakhalin	· Sakhalin · Continental Russian Far East
Japan	· Newly developed wind power in Hokkaido	· Kanto region

Source: Created by Renewable Energy Institute.

An interconnector between Japan and Russia would primarily be intended to make use of abundant renewable energy in the Russian Far East to supply electricity to demand centers in Japan at reasonable prices. Specifically, one scenario envisages existing hydropower stations along the Amur River[17] being used to supply clean electricity to the Kanto region, a demand center located in Honshu, the main island of Japan. Another plan calls for development of new wind power plants in the southern part of Sakhalin, which is regarded as an optimal location for wind power generation.[18] The interconnector could be used to export wind power electricity produced in Hokkaido to Russia. If the line was extended through Hokkaido over to Honshu, it could also serve as an inter-regional connection and supply electricity produced in Hokkaido by wind power and other means to demand centers in Honshu.

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17 Amur Oblast has several large-scale hydropower plants in service, such as Zeya (1,330 MW) and Bureya (2,010 MW). Their capacity factor in recent years is below 50%. Construction of another nearly 2 GW of hydropower capacity is planned.

18 According to a document released by the Russian Energy Agency, there are plans for construction of wind power stations with a capacity of 3 GW around the southern part of Sakhalin. See Russian Energy Agency, “Igor Kozhukhovsky spoke at the conference ‘Integration of Energy Systems in the Eurasian Space’” [in Russian], press release, April 18, 2017, http://www.rosenergo.gov.ru/cur_news/2017-04-18/338/.

Table 4: Scenarios for Japan–South Korea interconnector

	Power sources	Demand centers
South Korea	· Newly developed renewable energy in South Korea · Assume renewable energy from Mongolia and China as future options	· Mainly in southern part of South Korea and Seoul Metropolitan area
Japan	· Solar PV in Kyushu region, etc.	· Kansai region

Source: Created by Renewable Energy Institute.

With regard to an interconnector between Japan and South Korea, unlike with the Japan–Russia interconnector, the Study Group considers no specific existing power sources as a given in South Korea. However, in view of the fact that South Korea may develop new renewable power sources, while interconnectors between China and South Korea, and China and Mongolia, are now under development, we do also assume a medium- to long-term scenario whereby Mongolia, China, and South Korea may be connected through transmission lines, enabling Japan to use South Korea as a conduit to import renewable energy produced in China and/or Mongolia (primarily solar PV and wind power electricity generated in Mongolia). We see the export of electricity from Japan to South Korea—especially solar PV electricity generated in the Kyushu region—as one of the main purposes of the interconnector as well. South Korea has a relatively large electricity market: the IEA reports the country consumed 495 TWh of electricity in 2015. Thus, Japan, South Korea, and China together could form the largest electricity market in the world. That is another main purpose of the Japan–South Korea interconnector.

We estimate that the capacity of the interconnectors during the initial stage of the projects would be 2 GW of direct current both for Japan–Russia and Japan–South Korea, mainly in view of the countries' supply capacities of renewable energy and the impact on the supply-demand balance in Japan.[19]

2) Methodology and reference data for desk research on route planning

Routes are planned under the scenarios described above by determining connection points in both countries and drawing up routes connecting them with submarine transmission lines.

For this report, the Russian connection point for the Japan–Russia interconnector is located near the Korsakov Substation in southern Sakhalin (Figure 7).[20] For the Japan–South Korea interconnector, we have defined the candidate connection point in South Korea broadly as somewhere around Busan (Figure 8). In the southern part of South Korea, some power stations, including the Samcheonpo Thermal Power Plant and the Kori Nuclear Power Plant, are expected to be shut down. The specific connection point in South Korea could be determined based in part on examination of whether and how transmission facilities and substations used for those power plants could be efficiently converted for the interconnector.[21]

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19 As the Interim Report pointed out, "In fact, usual interconnection has a capacity of around 1 GW. Several interconnection systems built for Japan would not supply more than two or three percent of the maximum demand, unlikely to compromise stability of supply."

20 There is currently no transmission line in place connecting Sakhalin and the continental Russian Far East. However, since the 1990s, discussions have been going on about construction of a transmission line connecting Japan and continental Russia through Sakhalin.

21 The Kori Nuclear Power Plant has a total capacity of around 2.4 GW at its Units 2, 3, and 4 (the decommissioning of Unit 1 has already been decided). The Samcheonpo Thermal Power Plant has a capacity of around 3.2 GW. Once these power plants shut down, a large amount of transmission capacity would become available.

In principle, a transmission line should go through the shortest route to hold down construction costs. However, connection points cannot always be linked with a straight route between them. For instance, locating the Russian connection point at the southernmost tip of Sakhalin, 43 kilometers away from Cape Soya, would enable the Japan–Russia interconnector to be built with a shorter submarine transmission line. However, this report assumes a connection point around the Korsakov Substation, both because of its locational advantages and the area near the cape ahead is unsuitable for construction of a connection point due to rough waves and ice floes around it. Based on those assumption, a location was determined as inside the bay, where the waves are weaker, should be chosen for the connection point.

As stated above, connection points should be determined and routes between them should be planned based on multiple factors, including the geographical conditions of surrounding areas, the depth of the sea where cables are laid, and any environmental reserves or fishing areas along the route. For this report, these factors[22] were taken into account as much as possible by reviewing publicly available data (Table 5). For instance, data from the NeoWins offshore wind conditions map and the Japan Coast Guard's Marine Cadastre, shown in Figure 5, can be used to check whether there are any designated fishing areas, where any reserves are located, how deep the surrounding sea is, and whether any communication cables have already been laid, around a proposed connection point.

Table 5: Reference data used for desk research

Research topics	Consideration of potential submarine routes	Evaluation of potential connection and landing points
Fishery rights, reserves, etc.	Marine Cadastre	Marine Cadastre; and the New Energy and Industrial Technology Development Organization (NEDO)'s NeoWins
Geology	National Institute of Advanced Industrial Science and Technology's GeomapNavi, etc.	GeomapNavi, etc.
Depth of sea	Japan Oceanographic Data Center, etc.	—
Land use	—	Aerial photos, etc.
Transmission grid capacity in Japan	—	Power companies' grid maps

Source: Created by Renewable Energy Institute.

Figure 5: Reference data used for desk research: Example 1

Source: Adapted by the Renewable Energy Institute from NEDO, "NeoWins" [in Japanese], http://app10.infoc.nedo.go.jp/Nedo_Webgis/index.html; and the Japan Coast Guard, "Marine Cadastre" [in Japanese], http://www.kaiyoudaichou.go.jp/KaiyowebGIS.

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22 Before the work of determining a definitive route gets fully underway, a submarine transmission line installer needs to survey the seabed, which may cost hundreds of millions, or even billions, of yen.

3) Determining connection points in Japan

Connection points in Russia and South Korea were determined as stated above. However, the routes taken by interconnectors would differ entirely depending on where in Japan they would connect to. Connection points in Japan were determined through much more detailed analysis than those in Russia (southern Sakhalin) and South Korea (Busan area). For the purposes of this research, the three criteria were used for planning the best route, shown below in Table 6, to determine three possible connection points each for Japan–Russia and Japan–South Korea interconnectors. For Japan–Russia, these were Wakkanai (Hokkaido), Ishikari (Hokkaido), and Kashiwazaki (Niigata). For Japan–South Korea, they were Maizuru (Kyoto),[23] Matsue (Shimane), and Imari (Saga).

Table 6: Criteria for selecting connection points in Japan

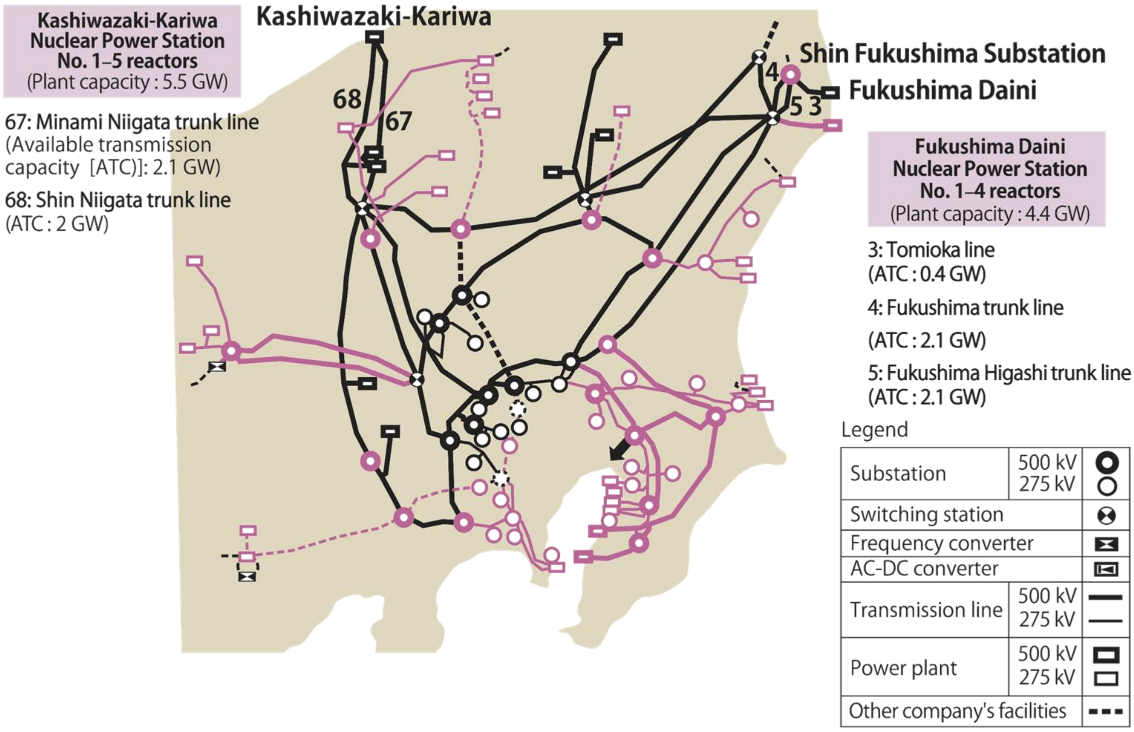
Criteria	Issues to be evaluated	Reference data
1) Proximity to the connection point in Russia or South Korea	Whether the submarine transmission line linking the two connection points is the shortest possible	Google Earth, etc.
2) Proximity to demand centers in Japan (Kanto and Kansai regions)	Whether power can be transported to demand centers in Japan through the shortest possible transmission line	Maps of the Geospatial Information Authority of Japan, etc.
3) Availability of transmission capacity to supply demand centers in Japan	Whether sufficient grid capacity can be secured to transport electricity to demand centers in Japan once a 2 GW interconnector has been established	Transmission capacity data held by general electricity transmission and distribution utilities, etc.

Source: Created by Renewable Energy Institute.

None of the potential connection points are rated highest in all three criteria in Table 6. For instance, Imari, Wakkanai, and Ishikari are rated higher in criterion 1, while rated lower in criteria 2 and 3 because they are far away from the Kanto and Kansai regions, which are the demand centers in Honshu. By contrast, Kashiwazaki and Maizuru are rated higher in criteria 2 and 3 because they are relatively near to demand centers and because a certain amount of available capacity is found in existing transmission lines linking them with demand centers (Figure 6). However, they are disadvantaged by longer transmission lines running underwater from their respective counterpart countries.

[23] For a Japan–South Korea interconnector, a connection point near the Reinan Substation in Fukui Prefecture, for instance, would have been near to demand centers in the Kansai region and could have made efficient use of existing transmission lines. However, the coastal area around the substation covers part of a quasi-national park and cliffs, so to avoid these we instead selected Maizuru as the connection point for this report.

Figure 6: Reference data used for desk research: Example 2



Source: Adapted by Renewable Energy Institute from TEPCO Power Grid, "Available transfer capacities mapping: Electric power systems for 275 kV or more" [in Japanese], accessed October 2, 2017, http://www.tepco.co.jp/pg/consignment/system/index-j.html.

For each of the connection points, potential landing points are reviewed and evaluated according to several criteria.[24] Such criteria include whether their geographical conditions allow cables to come ashore there, whether any site is available for installing AC-DC converters, and whether they are located in any national park or reserve.

4) Construction routes for Japan–Russia and Japan–South Korea interconnectors

After the desk research to determine connection points in Japan as well as the two counterpart countries, the routes were planned to link them. For planning routes, several factors were considered, for instance, submarine topography charts were referred to avoid areas where submarine cables are difficult to lay, such as rocky or deep seabeds and fishing grounds, whenever possible.

For the Japan–Russia interconnector, three possible routes were selected (Figure 7). The longest is the Sakhalin–Kashiwazaki route (1 in the figure), which is 1,255 kilometers in length. Whilst the route needs the longest submarine transmission line, it has the advantage of being directly connected to a location near to demand centers in Honshu. The sea off the coast of Hokkaido is more than 1,000 meters deep in some places, but for this research, routes up to 400 meters deep were examined.[25] The Marine Cadastre shows that in Hokkaido fishery rights exist for broad swathes of the sea along the coast. Therefore, routes were looked for that circumvent these areas as far as possible (Along Honshu, the areas subject to fishery rights are smaller). Investigations resulted in all the routes being up to 300 meters deep.

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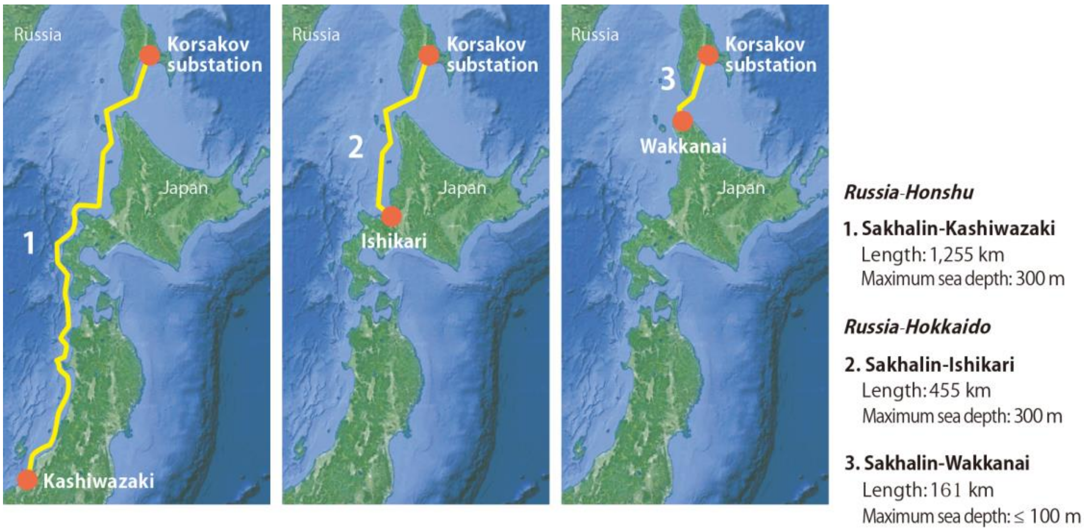
[24] Our references when setting the criteria for reviewing and evaluating landing points were interviews with experts and the requirements taken into account when communication cables are laid. Among the criteria adopted for the offshore zones of landing points were geological and topographic conditions, and fishing areas, while the criteria for onshore zones included tsunami risk and road access. Potential landing points were reviewed and evaluated comprehensively according to these criteria.

[25] NorNed, the aforementioned submarine transmission line that connects Norway and the Netherlands, reaches its deepest point near Norway at 410 meters underwater.

Figure 7: Japan–Russia interconnector routes

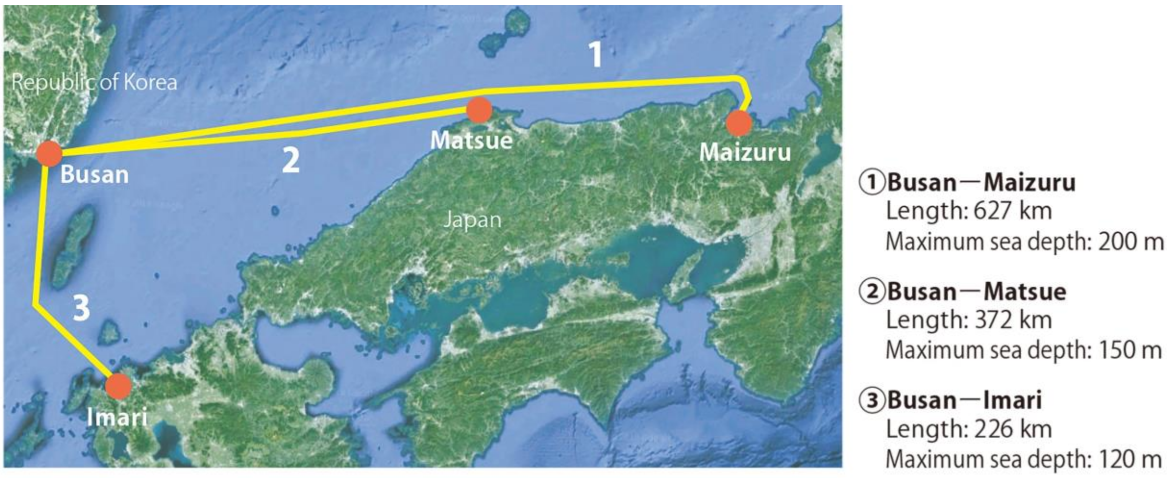


Source: Adapted by Renewable Energy Institute from Google Earth.

The Sakhalin–Ishikari (2 above) and Sakhalin–Wakkanai (3 above) routes are shorter, at 455 kilometers and 161 kilometers, respectively. However, both needed additional transmission lines within Japan, extending from their landing points in Hokkaido through the prefecture and all the way to Honshu. This issue will be discussed later.

For the Japan–South Korea interconnector too, three possible routes were selected (Figure 8). None of these goes as deep undersea as any of the Japan–Russia routes, the deepest being located at about 200 meters. When planning the routes between connection points, therefore prioritization was made to avoid areas with established fishery rights and rocky seabeds, among other factors, rather than deep waters.

Figure 8: Japan–South Korea interconnector routes



Source: Adapted by Renewable Energy Institute from Google Earth.

The Busan–Maizuru route (1 above) is the longest at 627 kilometers. However, it offers an advantage in that the cables can be connected to a point near demand centers in the Kansai region. The Busan–Matsue route (2 above) extends over a shorter distance of 372 kilometers undersea and comes ashore at a point with good access to demand centers in Kansai, as well. The Busan–Imari route (3 above) is the shortest at 226 kilometers, but access to demand centers in Kansai is a challenge. Further study will be needed on what route a transmission line should take in Japan once it comes ashore in the Kyushu region.

Thus, the shortest potential routes for Japan–Russia and Japan–South Korea interconnectors are 161 kilometers and 226 kilometers, respectively, while all routes are located at maximum depths of 300 meters or less (Table 7). In Europe, the NorNed submarine transmission line, which is more than 500 kilometers long and more than 400 meters undersea at its deepest point, has been in service for 10 years. The longest route identified in this report—the Sakhalin–Kashiwazaki route—may be longer, at 1,255 kilometers, but Europe also plans to construct a 1,070-kilometer submarine transmission line connecting Iceland and Scotland, dubbed "IceLink." Meanwhile, for SAPEI, a Mediterranean project comprising submarine transmission lines that connect the mainland of Italy to Sardinia, cables are laid more than 1,500 meters undersea at the deepest point. With reference to these cases, the conclusion was delivered that Japan–Russia and Japan–South Korea interconnector routes discussed here present no particularly difficult challenges from a technical perspective.

Table 7: Japan–Russia and Japan–South Korea interconnector routes: 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: Created by Renewable Energy Institute.

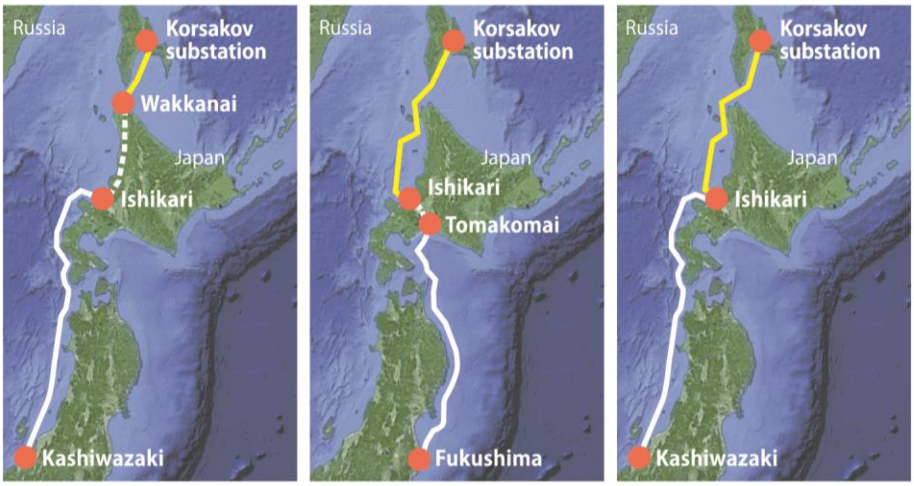
2) Examination of domestic routes after cables reach Japan

Among the interconnector routes planned above, the Hokkaido- and Kyushu-connected routes need another route going further through the country to reach the demand centers of the Kanto and Kansai regions. In such cases, the domestic routes chosen may in turn influence the length of the interconnectors themselves. Meanwhile, some additional benefit would be derived from cables that come ashore in Hokkaido or Kyushu and are connected to high-voltage transmission lines there, helping to mitigate fluctuations in the supply of renewable energy in those regions. It is assumed that domestic routes would all transmit DC electricity.

First, for the Japan–Russia interconnector, possible routes were examined to reach the Kanto region after cables come ashore in Hokkaido. The route connecting to Wakkanai (3 in Figure 7 above) is the shortest in terms of the section linking the two countries, but it requires a transmission line from the landing point through the prefecture all the way to Kashiwazaki (left map in Figure 9 below). From Wakkanai to Ishikari, cables would be installed overhead, with two AC-DC converters set up on the way to transport electricity generated from wind farms and other sources in northern Hokkaido. Beyond Ishikari, cables would be laid underwater to Kashiwazaki.

For the route connecting to Ishikari (2 in Figure 7), two options were examined to beyond Ishikari, one going to Fukushima (middle map in Figure 9) and the other to Kashiwazaki (right map in Figure 9). For the Ishikari-Fukushima option, underground cables would be laid through Hokkaido to the vicinity of Tomakomai, with AC-DC converters installed on the way to connect them to the high-voltage transmission system for the prefecture. At Tomakomai, they would be connected to submarine transmission lines going to Fukushima. What is characteristic of this option is that it requires only a short land section in Hokkaido and allows the cables to be connected to the high-voltage transmission system between Fukushima and Tokyo. The Ishikari-Kashiwazaki option almost traces the route going from Sakhalin directly to Kashiwazaki (1 in Figure 7), except that it comes ashore at Ishikari to be connected with the high-voltage transmission system for Hokkaido, before going back underwater to reach Kashiwazaki.

Figure 9: Japan–Russia interconnector routes: Sections in Japan



Source: Adapted by Renewable Energy Institute from Google Earth.

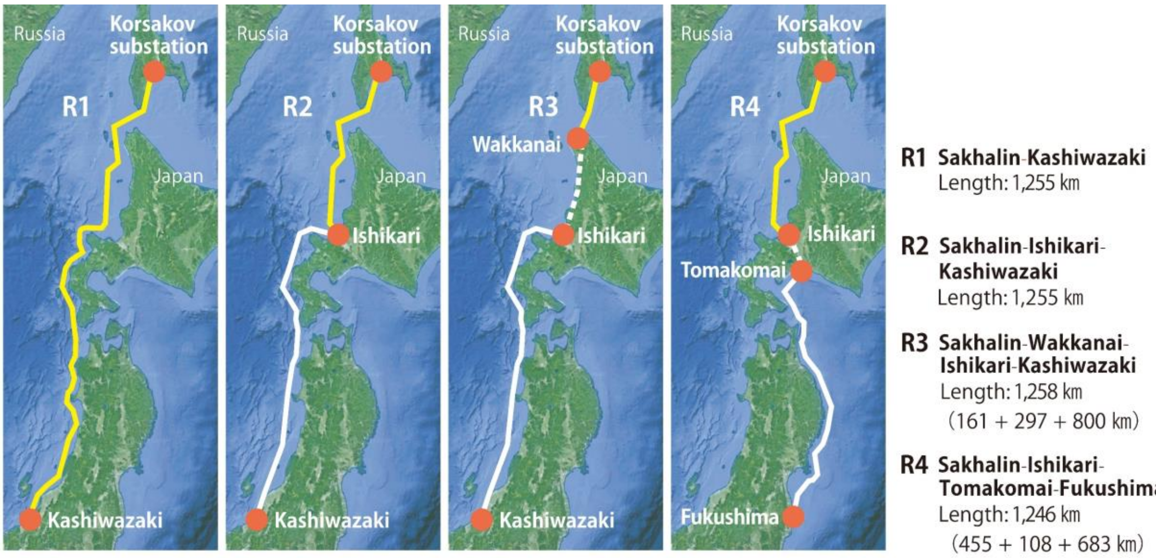
Table 8 below provides an overview of the possible routes in Japan. Through the examination process described above, four routes were determined (including sections in Japan) that start at Sakhalin to reach demand centers in Honshu (R1 through R4 in Figure 10).

Table 8: Japan–Russia interconnector routes: Characteristics of sections in Japan

Transmission Lines	Sections		Length (km)	Type
Land transmission lines in Hokkaido	Wakkanai	Ishikari	297	Overhead lines or underground cables
	Ishikari	Tomakomai	108	Overhead lines or underground cables
Submarine transmission lines from Hokkaido to Honshu	Ishikari	Kashiwazaki	800	Submarine cables
	Tomakomai	Fukushima	683	Submarine cables

Source: Created by Renewable Energy Institute.

Figure 10: Routes between Russia and demand centers in Honshu: Overview



Source: Adapted by Renewable Energy Institute from Google Earth.

Second, for the Japan–South Korea interconnector, possible routes were examined in Japan to supply electricity from the Kyushu or Chugoku region, where international cables first reach Japan, to the Kansai region, a demand center. When planning routes, it was ensured that transmission capacity available in each region would be used fully and that grids would in principle be reinforced only in sections where sufficient capacity is not available. Furthermore, for inter-regional connections, it was assumed that transmission capacity would be secured under an implicit auction scheme.[26]

There would, however, be a problem with the route within Japan for transporting electricity from Kyushu to Kansai once cables with a capacity of 2 GW coming from South Korea reached Kyushu (3 in Figure 8 above). This route has a bottleneck in interconnector capacity between the Kyushu and Chugoku regions. The Study Group assumed that the inter-regional connection between Kyushu and Chugoku (with a total capacity of about 2.7 GW) would be operated under an implicit auction scheme, and that at least 1 GW of the power imported from South Korea through Kyushu could be transported to Chugoku, a neighboring region, because, having reviewed the transmission capacity at present in Chugoku, the capacity available in the region for electricity coming from Kyushu would be around 1 GW at most.[27] Thus another 1 GW of transmission capacity would be needed for 2 GW of power imported from South Korea through Kyushu.

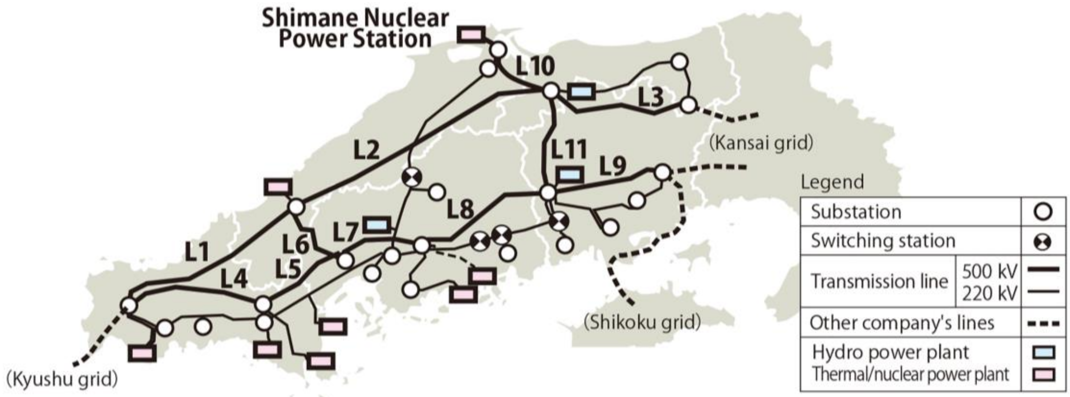
For that reason, it was considered another route incorporating the construction of an inter-regional connection between the Kyushu and Shikoku regions to supply 1 GW of power through Shikoku to the Kansai region. Our review of the transmission capacity within Shikoku, as well as the capacity of the inter-regional connection between Shikoku and Kansai, allowed us to conclude that only an inter-regional connection between Kyushu and Shikoku is required to supply 1 GW of power from Kyushu through Shikoku to Kansai (Figure 11).

[26] Inter-regional connections operated under an implicit auction scheme should allow one to assume that renewable electricity, with close to zero marginal cost, would be prioritized on a grid in accordance with the merit order.

[27] As indicated on the map of individual power companies' transmission line capacities (Figure 11), the Chugoku and Shikoku regions each have 1 GW of available transmission capacity in their 500 kV transmission lines.

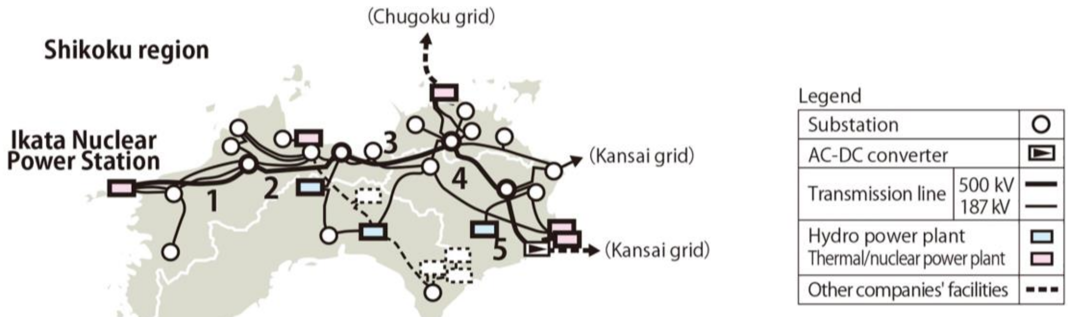
Figure 11: Existing transmission capacities in the Chugoku and Shikoku regions

Chugoku region



	Names of trunk lines	available transmission capacities		Names of trunk lines	available transmission capacities
L1+L4	Chugoku-Nishi & Shin-Yamaguchi	948 MW	L10	Kita-Matsue	1,155 MW
L1+L5	Chugoku-Nishi & Higashi-Yamaguchi	1,227 MW	L11	Hino	3,206 MW
L2+L7	Chugoku-Naka & Shin-Nishi Hiroshima	1,287 MW	L6	Nishi-Shimane	4,027 MW
L2+L8	Chugoku-Naka & Shin-Hiroshima	1,376 MW	L3, L9	Chugoku-Higashi Kansen, Shin-Okayama	–

Shikoku region

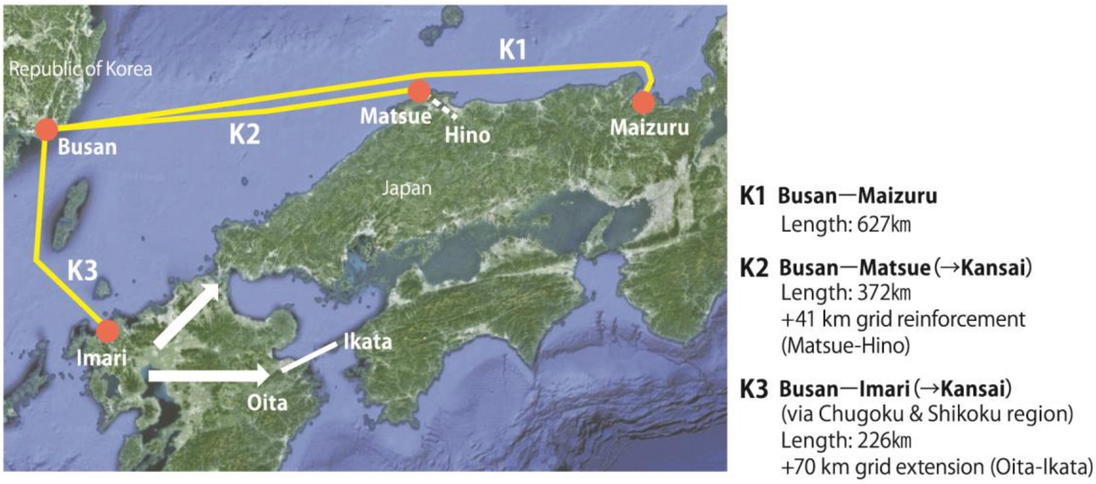


Transmission lines	1	2	3	4	5
Available transmission capacities (MW)	710	2,010	1,860	1,190	1,190

Source: Adapted by the Renewable Energy Institute from Chugoku Electric Power, "Map of available transfer capacities (220 kV and over)" [in Japanese], accessed December 19, 2017, http://www.energia.co.jp/retailer/keitou/access.html; and Shikoku Electric Power, "Map of available transfer capacities and total transfer capacities (187 kV and over)" [in Japanese], accessed December 26, 2017, http://www.yonden.co.jp/business/jiyuuka/tender/index.html.

For the route connecting to the Chugoku region (2 in Figure 8 above), electricity could not be supplied to the Kansai region from cables that come ashore at Matsue without reinforcement for some sections that are short of available transmission capacity. Taking such considerations into account, Figure 12 shows the K1, K2, and K3 Japan–South Korea interconnector routes including reinforced sections in Japan. As the figure shows, if existing inter-regional connections were effectively utilized when planning routes in Japan, even the route connecting to the Kyushu region (K3) might not need more than a few dozen kilometers of transmission line reinforcement.

Figure 12: Routes between South Korea and demand centers in Kansai: Overview



Source: Adapted by Renewable Energy Institute from Google Earth.

Section 2: Estimated construction costs

Based on the findings from the analysis of possible interconnector routes in the previous section, in this section the construction costs were estimated for Japan–Russia and Japan–South Korea interconnectors. As some of the possible routes may require reinforcement of grid capacity between landing points and demand centers in Japan, the costs for such reinforcement were estimated. An overview of construction costs for the interconnectors as a whole was also presented, including transmission lines in Japan, followed by a review of additional costs to be examined.

1) Calculating construction unit costs

Before estimating the total cost, firstly, how much the construction of interconnectors would cost per kilometer was calculated. As noted, the interconnectors were assumed to have the capacity to transport 2 GW of DC power, including transmission lines in Japan. DC power was assumed rather than AC power because it has a lower transmission loss rate and enables the frequency to be controlled in individual regions. In addition to the unit cost for submarine cables and AC-DC converters—which account for most of the construction expenses—the per-kilometer cost for overhead lines and underground cables was also calculated to enable comparison with the construction cost for transmission lines in Japan. Table 9 summarizes the assumptions on which calculations are based, the sources of reference data, and reasons for employing those assumptions or data sources. As the overall configuration of an interconnector is defined by such factors as the configuration of its main circuit and the types of AC-DC converters used, it was supplemented with our own research with relevant information collected from experts and service operators.

For submarine cables, it was assumed that their main circuit configuration would employ the bipolar metallic return method, with three cables of the same specifications, including the metallic return. Per-kilometer construction expenses for submarine cables were calculated based on cost data obtained from several recent DC submarine cable projects in Europe designed to transfer electricity at a similar voltage, after adjusting for differences in transmission capacities and the number of cables, the latter being dependent on whether the metallic return method is adopted or not. The results indicated that construction of submarine cables would cost 293 million yen per kilometer.[28] For AC-DC converters,

[28] This is more than 201 million yen per kilometer, which is the unit cost calculated in the Agency for the Cooperation of Energy Regulators' *Report on Unit Investment Cost Indicators and Corresponding Reference Values for Electricity and Gas Infrastructure* (August 2015). The agency's unit cost is based on the maximum value of the interquartile range among the projects for 250–500 kV DC submarine cables. Our per-kilometer cost also turns out to be between 254 million yen

voltage-source converter (VSC) models are adopted, and that a 1 GW-class converter costs 15.7 billion yen. Construction of overhead lines, assuming DC transmission lines of ±500 kV, costs 664 million yen per kilometer, while underground cables require 915 million yen per kilometer.

Table 9: Examination of construction unit costs

Interconnector components	Assumptions and/or data sources	Reasons for assumptions or data sources
Main circuit configuration	Bipolar metallic return method	・ The bipolar system, which uses two cables for the main line, is adopted for greater resilience in case of cable malfunction and to make it easier to manufacture large-capacity cables. ・ The earth return method is common in Europe, but the metallic return method was assumed in line with existing facilities in Japan (Hokkaido–Honshu HVDC link and Anan–Kihoku DC trunk line).
Submarine cables	Mass-impregnated (MI) cables; Cost data from Europe	・ Japan has little experience with DC submarine cables, while Europe is more advanced, with many long-distance DC submarine cables already in place. Therefore relatively recent European cost data publicly available was referred here. ・ The use of MI (Mass Impregnated) cables because this type of cable is commonly used for long-distance submarine cables in Europe and elsewhere. ・ European projects usually use two cables of the same specifications. In Japan, three cables may be required to set up a return. Accordingly, three cables of the same specifications to allow the return to also be used as a main line were assumed. The per-kilometer cost is therefore 50% more than for two cables.
AC-DC converters	European Network of Transmission System Operators for Electricity (ENTSO-E)	・ As power lines within each Japanese area transmit AC electricity, AC-DC converters are needed at both ends of interconnectors and other points. ENTSO-E's *Offshore Transmission Technology* (2011) was referred to the study. ・ VSCs were assumed, because these self-commutated AC-DC converters, which make an entire system easier to simplify, are currently popular. Current-source converters with the same specifications as VSCs in terms of capacity and voltage may be priced differently. ・ A bipolar system for the main circuit configuration was assumed, two 1 GW converters would be installed per site to offer 2 GW of transmission capacity.
Overhead lines	Deloitte Touche Tohmatsu	・ The data presented in Deloitte Touche Tohmatsu's *Study on cost and period for construction of transmission lines* [in Japanese] (March 2012) was referred, which was submitted to METI's Advisory Committee for Natural Resources and Energy, at a meeting of its study group on the master plan for reinforcement of inter-regional connections. ・ The per-kilometer cost for DC ±500 kV overhead lines was calculated based on that for DC ±250 kV overhead lines on the assumption that pylons for the former should cost more.
Underground cables	OCCTO	・ The unit cost for underground cables was referred, including civil engineering work, found in OCCTO's *Standard unit costs of transmission and conversion facilities* [in Japanese] (March 29, 2016). ・ Calculation of per-kilometer construction cost for DC ±500 kV lines is based on data for AC 33 kV to 275 kV lines.

Source: Created by Renewable Energy Institute

and 351 million yen, the lowest and median construction costs, respectively, calculated based on data available from the National Grid's *Electricity Ten Year Statement 2015*, under the same assumptions as those for the projects in this report.

Table 10 summarizes the construction unit costs examined above. As seen in the table, construction of submarine cables costs the least per kilometer, amounting to less than half the cost of overhead lines and less than one-third of the cost of underground cables. The difference may partly reflect the price competition induced by recent rapid deployment of long-distance DC submarine cables in Europe. In Japan, construction of overhead lines costs more than double what it costs in Europe and the United States,[29] presumably a consequence of some unique conditions in the country.

Table 10: Calculation of construction unit costs

Interconnector components	Costs	Data sources	Notes
Submarine cables	293 million yen/km	DC submarine transmission line projects in Europe (SAPEI,[30] MON.ITA,[31] NordLink,[32] and North Sea Link[33])	DC ±500 kV; transmission capacity of 2 GW; and three MI cables Calculated assuming that cables are laid separately
AC-DC converters	15.7 billion yen/unit	ENTSO-E (2011) referred to in Table 9	VSC 1,250 MW Lowest value at 500 kV
Overhead lines	664 million yen/km	Deloitte Touche Tohmatsu (2012) referred to in Table 9	Unit cost for DC 500 kV estimated
Underground cables	915 million yen/km	OCCTO (2016) referred to in Table 9	Unit cost for DC 500 kV estimated

Source: Created by Renewable Energy Institute.

2) Estimated cost for Japan–Russia interconnector

For the Japan–Russia interconnector, it was examined three possible cross-border routes in the previous section (Figure 7). Table 11 below summarizes the estimated expenses for submarine cables and AC-DC converters, along with the total construction cost. Table 12 summarizes expenses needed to reinforce possible routes in Japan. For onshore sections, transmission lines may be constructed either overhead or underground. This report assumes overhead lines between Wakkanai and Ishikari, which are mountainous areas, and underground cables between Ishikari and Tomakomai, which are mostly urban areas.

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[29] The comparison is based on construction costs for overhead lines found in the Institution of Engineering and Technology's *Electricity Transmission Costing Study* (January 2012), and the Western Electricity Coordinating Council's *Capital Costs for Transmission and Substations: Recommendations for WECC Transmission Expansion Planning* (October 2012), as well as the lowest construction cost for overhead lines presented in OCCTO's *Standard unit costs of transmission and conversion facilities* [in Japanese] (March 2016).

[30] Prysmian, "Prysmian Cables & Systems Secures Contract for 400 Million Euro in Italy," press release, June 6, 2006, https://www.prysmiangroup.com/en/en_2006-400M-contract-Italy.html.

[31] "Prysmian, Some €400 M Contract for Montenegro-Italy Power Link," *Your Cable and Wire News*, October 31, 2012, http://www.yourcableandwirenews.com/prysmian%2C+some+%E2%82%AC400+m+contract+for+montenegroitaly+power+link_31854.html.

[32] Nexans, "NordLink HVDC Interconnector between Norway and Germany Will Use Nexans' Subsea Power Cables," press release, February 12, 2015, https://www.nexans.com/Corporate/2015/1502_Nexans-Stanett_NordLink_GB.pdf.

[33] Prysmian, "New HVDC Subsea Interconnector between Norway and the UK," press release, July 14, 2015, https://www.prysmiangroup.com/en/en_2015_PR_HVDC-NO-UK.html.

Table 11: Construction cost for Japan–Russia interconnector (cross-border sections)

Sections	Length	Submarine cables (billion yen)	AC-DC converters (billion yen)	Total (billion yen)
Sakhalin–Kashiwazaki	1,255 km	367.7	62.8 (4 units)	430.5
Sakhalin–Ishikari	455 km	133.3	62.8 (4 units)	196.1
Sakhalin–Wakkanai	161 km	47.2	62. (4 units)	110.0

Source: Created by Renewable Energy Institute.

Table 12: Construction cost for Japan–Russia interconnector (Reinforcement of sections in Japan)

Sections	Onshore length	Offshore length	AC-DC converters (billion yen)	Total (billion yen)
	Overhead lines or underground cables	Submarine cables		
Wakkanai–Kashiwazaki (Onshore: overhead lines)	297 km	800 km	31.4 (2 units)	463.0
	197.2 billion yen	234.4 billion yen		
Ishikari–Fukushima (Onshore: underground cables)	108 km	683 km	31.4 (2 units)	330.3
	98.8 billion yen	200.1 billion yen		

Source: Created by Renewable Energy Institute.

Based on the two tables above, Table 13 presents an overview of routes R1–R4 (as defined in Figure 10), which includes reinforcement of the routes within Japan. Compared with the route linking Sakhalin directly to Kashiwazaki, the routes going through Hokkaido cost 10% to 30% more for construction, due mainly to higher expenses for onshore transmission lines. On the other hand, as mentioned in the previous section, they may be used to efficiently transport electricity generated from wind power in northern Hokkaido.

Table 13: Overview of construction cost for Japan–Russia interconnector

Routes		Specifications	AC-DC converters	Cross-border (billion yen)	In Japan (billion yen)	Total (billion yen)
R1	Sakhalin–Kashiwazaki	All submarine cables	4 units	430.5	—	430.5
R2	Sakhalin–Ishikari–Kashiwazaki	All submarine cables	6 units	196.1	265.8	461.9
R3	Sakhalin–Wakkanai–Ishikari–Kashiwazaki	Onshore: overhead lines	6 units	110.0	463.0	573.0
R4	Sakhalin–Ishikari–Tomakomai–Fukushima	Onshore: underground cables	6 units	196.1	330.3	526.4

Source: Created by Renewable Energy Institute.

3) Estimated cost for Japan–South Korea interconnector

For the Japan–South Korea interconnector, it was examined three possible cross-border routes in the previous section (Figure 8). Table 14 below summarizes the estimated expenses for submarine cables and AC-DC converters, along with the total construction cost.

Table 14: Construction cost for Japan–South Korea interconnector (cross-border sections)

Sections	Length	Submarine cables (billion yen)	AC-DC converters (billion yen)	Total (billion yen)
Busan–Maizuru	627 km	183.7	62.8 (4 units)	246.5
Busan–Matsue	372 km	109.0	62.8 (4 units)	171.8
Busan–Imari	226 km	66.2	62.8 (4 units)	129.0

Source: Created by Renewable Energy Institute.

Table 15: Construction cost for Japan–South Korea interconnector (Reinforcement of sections in Japan)

Sections	Length	Submarine cables or overhead lines (billion yen)	AC-DC converters (billion yen)	Total (billion yen)
Oita–Ikata (submarine cables)	70 km	20.5	62.8 (4 units)	83.3
Matsue–Hino (overhead lines)	41 km	30.6	—	30.6

Source: Created by Renewable Energy Institute.

Table 15 summarizes the expenses needed to reinforce possible routes in Japan. It was estimated the construction costs for reinforcing the two interconnector sections mentioned in the previous section of this report: a submarine cable that links the Kyushu region, where the cables initially come ashore, to the Shikoku region; and a section of overhead line starting from the point where the cables come ashore in the Chugoku region (Matsue–Hino). In the previous section of this report, it was assumed the submarine cable would have a transmission capacity of 1 GW; but here, for ease of calculation, its capacity was assumed to be 2 GW, like the other routes. With regard to the per-kilometer construction cost needed to reinforce overhead lines, it was referred to the Deloitte Touche Tohmatsu report mentioned in Table 9, using their original estimate of 746 million yen per kilometer unchanged, since AC 500 kV was also assumed.

Next, Table 16 below presents an overview of Japan–South Korea interconnector routes K1–K3 (as defined in Figure 12), which includes reinforcement of routes in Japan. An interconnector that came ashore in the Kyushu region could be used to efficiently transport renewable electricity generated in Kyushu and would also make the best use of existing electrical grids in the Shikoku and Chugoku regions.

Table 16: Overview of construction cost for Japan–South Korea interconnector

Routes		Specifications	AC-DC converters	Cross-border (billion yen)	In Japan (billion yen)	Total (billion yen)
K1	Busan–Maizuru	All submarine cables	4 units	246.5	—	246.5
K2	Busan–Matsue–Hino	Matsue–Hino to be reinforced	4 units	171.8	30.6	202.4
K3	Busan–Imari & Oita–Ikata	All submarine cables	8 units	129.0	83.3	212.3

Source: Created by Renewable Energy Institute.

4) Review of additional costs to be examined

The construction costs above have been examined in terms of expenses for laying cables (including materials for cables) and installing AC-DC converters. In this section, the review of some necessary additional costs is available that should be examined despite the limited impact they would have on the total construction cost.

(1) Other expenses for laying cables

Necessary equipment must be installed in, and removed from, cable laying vessels. Other items that may also be needed include: horizontal directional drilling around landing points; protection work around any intersection with existing pipelines or cables; dredging work; and barges for laying cables in shallow waters.

(2) Operation and maintenance (O&M)

Generally, operation and maintenance costs amount to 1% to 3% of the total construction expenses each year.[34]

(3) Route survey

Before planning a route, a survey must be performed. It may cost several billion yen or more, depending on the nature of the survey and the length of the route.

(4) Fluctuation of material prices

Prices of materials such as copper, which is the conductor used for cables, may change along with market fluctuations.

(5) Compensation for fishing industry

When there is an active fishing industry around a landing point in particular, fisheries cooperative associations and other stakeholders may be compensated.

(6) Environmental impact assessment

The Japanese Ministry of the Environment (MOE) is considering the need for environmental impact assessments of submarine cables for offshore wind power plants and other facilities. Environmental impact assessments may also be required for interconnectors.

34 Cross-regional Network Development Committee, OCCTO, *Process of planning for Tokyo–Chubu interconnection facilities* [in Japanese], August 24, 2015.

5) Summary of estimated construction cost

Construction of interconnectors with a transmission capacity of 2 GW, including reinforcement of sections in Japan, would cost 430.5–573.0 billion yen for an interconnector between Japan and Russia, and 202.4–246.5 billion yen for an interconnector between Japan and South Korea. According to data from the 10 power companies in Japan for the 23 years between FY1993 and FY2015,[35] their annual capital expenditure for transmission and distribution facilities and substations stood at around three trillion yen in the 1990s, before declining gradually, and staying at around one trillion yen from FY2004 onward. During those 23 years, their average annual capital expenditure amounted to approximately 1.8 trillion yen. In comparison, the construction costs for the Japan–Russia and Japan–South Korea interconnectors mentioned above, divided by the 25 years needed to recover the capital expenditure, would account for maximum ratios of 1.3% and 0.5%, respectively, of the average annual capital expenditure of the 10 Japanese power companies.

Among the possible Japan–Russia routes, the construction cost turned out to be lowest for the one connected directly to a location near a Japanese demand center through a long-distance submarine transmission line. On the other hand, if a cable came ashore in Hokkaido to be connected with renewable energy sources available there, multiple benefits could be expected, such as use of the subsequent transmission line in Japan as an inter-regional interconnector. Recovery of capital expenditure and social benefits of interconnectors are discussed in Chapter 4.

[35] Federation of Electric Power Companies of Japan, *FEPC Infobase 2016* [in Japanese].

Chapter 4:
Interconnector Business Models, Social Benefits, and Legal Frameworks

Chapter 4 applies business models to the Japan–Russia and Japan–South Korea interconnector routes examined in the previous chapter, discussing the prospects for recovery of investments, the potential for social benefits, and the legal frameworks to bring these about. Section 1 reviews business models in other parts of the world where interconnectors are already in use, and estimates potential profitability if these models were to be applied to the Japan–Russia and Japan–South Korea routes. Section 2 reviews previous studies to discuss the likely social benefits of interconnectors. Finally, Section 3 reviews legal frameworks to establish the business models examined in Section 1.

Section 1: Business models for investment recovery and estimation results

The Interim Report cited three important purposes of interconnector construction: (1) improvements in economic efficiency via market coupling; (2) stable supply of electricity via cross-border transmission operations; and (3) mitigation of fluctuations in output from fluctuating renewable power sources. However, investors in interconnectors need some additional means of recovering their investments. This section therefore estimates recovery of interconnector investment in light of business models based on interconnector projects around the world.

1) Review of business models for interconnectors

The Interim Report pointed out that interconnectors in Europe have three business models: (1) revenues from transmission rights based on explicit auctions and contracts among enterprises; (2) revenues from congestion charges due to differences in day-ahead market prices between two connected regions; and (3) revenues from a regulated grid tariff. The report also noted that cross-border electricity trading in Northeast Asia is based on long-term contracts on a negotiation basis.

In addition, the results of the study in North America conducted in 2017 (as mentioned in Chapter 2) showed that interconnectors are constructed when required as part of projects to supply electricity across borders from certain power sources to certain demand centers. Despite being interconnectors, they are treated as if they were power lines, and their business model is based on recovering the investment in transmission lines from the proceeds of electricity sales. This study coupled with other previous studies[36] indicates that interconnector business models can be classified into the four types shown in Table 17: namely, congestion charge model, transmission rights sales model, regulated grid tariff model, and generators/suppliers dedicated line model.

First, the congestion charge model is an investment recovery method used when market coupling is implemented between two countries or within the domestic markets, that can be seen in Europe or in the US, e.g. PJM. If grid congestion occurs between markets, the market operator implements market splitting. However, regardless of this market splitting, electricity continues to be physically transported through the grid. Therefore, the transmission owner is entitled to income equivalent to the multiple of the amount of electricity actually transmitted and the price difference between the markets; this income is obtained through the market operator. However, this method is not effective for recovering investment in a grid if the grid capacity is sufficient and market splitting does not occur. Therefore, it can be said that areas where the congestion charge model is employed for investment recovery in European countries and a part of the US are the areas where market splitting occurs frequently.

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[36] OCCTO, *Final report of the survey on rules for use of inter-regional connections (overseas survey in the second half of FY2016)* [in Japanese] (2017); OCCTO and JEPX, *Interim report of the workshop on the rules for use of inter-regional connections* [in Japanese] (2016); Deloitte Touche Tohmatsu, *Business report of the basic survey on promoting deployment of new energy (survey on reinforcing cross-regional connection infrastructure for expansion of renewable energy deployment) in FY2014* [in Japanese] (2015); and Rahmatallah Poudineh and Alessandro Rubino, "Business Model for International Grid Connections in the Mediterranean Basin," *Oxford Institute for Energy Studies Paper* EL 19 (2016).

Table 17: Overview of business models for interconnectors

Investment recovery model	Description	Examples
Congestion charge model	When congestion (and market splitting) occurs in a transmission line connecting two market areas, a transmission owner can obtain income equivalent to the multiple of the wholesale price difference between the markets and the amount of electricity actually transmitted.	• Between local markets in Europe • PJM in North America
Transmission rights sales model	A transmission operator sells the right to use the transmission line to power generators or retail electricity companies.	
Regulated grid tariff model	The construction and maintenance costs for the interconnector are regarded as fully distributed costs of the transmission operator and the investment is recovered by having all consumers in its service area pay a grid tariff to cover transmission costs.	• Skagerrak 4 (between Denmark and Norway) • Between Russia and China
Generators/ suppliers dedicated line model	A transmission line is constructed as part of a power supply project to a specific consumer or market from a specific power plant or supplier, and the investment is recovered through electricity sales revenues.	• Between Russia and China • Between Canada and the United States

Source: Created by Renewable Energy Institute.

Second, the transmission rights sales model is a long-established investment recovery method. In this model, power generation companies and retailers pay interconnector owners to secure a certain amount of transmission capacity (rights to transmit electricity). Transmission rights can be set without coupling of wholesale electricity markets. For example, EDF in France has procured transmission rights in the long term for the interconnector between England and France.[37] On the other hand, advanced market coupling will bring about inter-market power supply contracts. If market splitting occurs under such circumstances, power generation companies cannot supply power across different markets, and the need arises to purchase and sell power separately in the market where the contract was made. Transmission rights are utilized as a means to avoid such a situation.

Transmission rights are roughly divided into physical transmission rights (PTRs) and financial transmission rights (FTRs). With PTRs, part of the actual amount of electricity transmitted during market splitting is deemed to belong to the transmission rights holder. FTRs, on the other hand, are based on the concept of compensating the loss due to market splitting. Therefore, in principle, it is hard to set PTRs at a level exceeding the transmission capacity, but it is possible for FTRs. Meanwhile, different methods are used to sell transmission rights depending on each case. For example, explicit auction allows the interconnector owners to sell the rights directly, while implicit auction allows the rights to be sold through the markets.

37 Roman Inderst and Marco Ottaviani, "Cross Border Electricity Trading and Market Design: The England-France Interconnector," *London Business School Case Study* CS-04-008 (2004).

Third, the regulated grid tariff model is an investment recovery method widely used for construction of domestic transmission lines in many countries, and it is also used for many interconnectors. Costs to construct and maintain transmission lines are regarded as fully distributed costs of the transmission owners. The investment is recovered through a grid tariff paid by all consumers in its service area to cover the transmission costs. Under this system, therefore, investment costs and the grid tariff are strictly regulated by the government.

Fourth, the generators/suppliers dedicated line model is for construction of transmission lines from specific power plants or suppliers to demand centers. The power transmission in this case is in principle unidirectional, and the investment is recovered by revenues from electricity sales. Therefore, interconnectors constructed from areas with inexpensive power sources to large demand centers are observed. For example, Canada has exported electricity to the United States for more than 100 years, and there are multiple interconnectors between these two that employ this business model.

The four business models described above are implemented in combination with each other according to the needs of different regions and systems.

As mentioned in the Interim Report, the investment in interconnectors takes two forms: the merchant and regulated schemes. The merchant scheme is regarded as a for-profit business of investors in interconnectors, and is employed in Europe—especially in the UK. The nature of the merchant scheme makes it less compatible with the regulated grid tariff model, so it is usually based on other business models. With the regulated scheme, on the other hand, revenues are subject to public regulations in one form or another. Typically, the business model employed is the regulated grid tariff model, and the business is regulated by the national government in the same way as other domestic transmission businesses. Meanwhile, the congestion charge model can be employed only in areas where a wholesale electricity market has to some extent been developed and market coupling has been implemented. Therefore, construction of a new interconnector between two areas where none exists followed by investment recovery using the congestion charge model would require an arrangement between the two markets, and in some cases an agreement between both countries, in addition to the construction of transmission lines.

2) Estimation assumptions and methodology

The estimation on investment recovery for Japan–Russia and Japan–South Korea interconnectors was conducted. Recovery of investment was assessed using the internal rate of return (IRR) method. The IRR is the discount rate required to make the net present value of the investment project equal to zero. If the rate is higher than a predetermined discount rate, the project is considered worthy of investment. The revenues used in calculation were pretax, and the costs included both initial investment and O&M costs. In general, the discount rate for public works investment is around 4%. If interconnectors are regarded as a form of infrastructure contributing to the public welfare, a discount rate of 4% or higher could be considered a guideline for investment decisions.[38] In terms of business models for the potential interconnector routes determined in Chapter 3, the estimation assumed three options for all four routes of the Japan–Russia interconnector (the generators/suppliers dedicated line model, the regulated grid tariff model, and the transmission rights sales model) and four options for all three routes of the Japan–South Korea interconnector (the same three, plus the congestion charge model). The congestion charge model was used only for the Japan–South Korea interconnector routes because the Russian Far East does not have a wholesale electricity market that would allow the congestion charge model to be simulated.

[38] Hiroshige Tanaka, *Economic analysis of costs and benefits: Theories in the environment and public sectors* [in Japanese] (Chuo University Press, 2003): 39.

First, for the Japan–Russia interconnector based on the generators/suppliers dedicated line model, it was assumed that all electricity from Russia would be bid for and sold on the market for the JEPX Tokyo area. For the Japan–South Korea interconnector, it was assumed that electricity from China or Mongolia would be transported through South Korea, and then bid for and sold on the JEPX market at the point where each route connects with Japan, which would be the JEPX Kansai, JEPX Chugoku, and JEPX Kyushu areas. Prices used to sell electricity to Japan were assumed to be free-on-board (FOB) prices, and the differences between JEPX prices and FOB prices were regarded as revenues for the entities that invested in the transmission lines. These estimates employing the generators/suppliers dedicated line model did not include revenues from power flows from Japan to Russia or South Korea. As trading on the JEPX was limited before the full liberalization of the retail electricity market in 2016, the evaluation period was set from 2016 to 2017, and the annual data for each year were analyzed and compared. The assumptions used for the generators/suppliers dedicated line model are shown in Table 18.

Table 18: Assumptions for recovering investment in interconnectors: Generators/suppliers dedicated line model

Payback period	25 years[39]
O&M ratio	1–3% of the initial investment costs[40]
Supplied power	From 1 GW to 2 GW
JEPX prices	Annual data for 2016 and 2017 (every half hour)
FOB prices	5–9 yen/kWh (in increments of 1 yen)

Source: Created by Renewable Energy Institute.

Second, the estimates based on the regulated grid tariff model assumed that general electricity transmission and distribution utilities at the points where each route connects with Japan would cover the construction and O&M costs. The amount in question would be the sum of 50% of the cross-border costs and all the in-Japan costs shown in Tables 13 and 16. In addition, it was assumed that each general electricity transmission and distribution utility would collect a grid tariff from consumers in their service area. The remaining costs would be covered by transmission operators, etc. in the counterpart country. Table 19 shows the assumptions used for the regulated grid tariff model. Assumptions for the payback period and the O&M ratio are the same as those for the generators/suppliers dedicated line model above.

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39 The BritNed interconnector, operated as a merchant scheme, has a 25-year period of regulatory exemption, while the statutory useful life of Japanese substations and similar facilities is 22 years. Based on these facts, as well as interviews with a range of manufacturers, the payback period was assumed to be 25 years for the purposes of these estimates.

40 Based on the OCCTO Cross-regional Network Development Committee's *Process of planning for Tokyo–Chubu interconnection facilities* [in Japanese] dated August 24, 2015, which indicated annual O&M costs amounting to 2.3% of construction costs for interconnection facilities and substation-related facilities, and 1.5% of construction costs for transmission lines.

Table 19: Assumptions for recovering investment in interconnectors: Regulated grid tariff model

Grid tariffs	0.06–0.10 yen/kWh (in increments of 0.01 yen)	
Ratio of costs covered by the Japanese side	Sum of 50% of cross-border costs and 100% of in-Japan costs	
Electricity demand[41]	TEPCO service area	289.9 TWh
	Kansai Electric Power service area	148.6 TWh
	Chugoku Electric Power service area	60.2 TWh
	Kyushu Electric Power service area	85.7 TWh

Source: Created by Renewable Energy Institute.

Third, turning to the transmission rights sales model, future trading prices for transmission rights cannot easily be forecast from the market environment at the moment. Therefore, the estimation is based on trading prices set with reference primarily to cases in Europe. This estimation assumes only PTRs because FTRs are transmission rights to compensate the loss due to transmission congestion and it is still too early to discuss them before the implementation of market coupling. In principle, the total amount of available PTRs is determined based on the transmission capacity. Accordingly, the assumptions used for estimation are as shown in Table 20. Average transmission rights prices shown in the table are the annual average of transmission rights prices from Country A to Country B and transmission rights prices from Country B to Country A. Assumptions for the payback period and the O&M ratio were the same as those for the other models.

Table 20: Assumptions for recovering investment in interconnectors: Transmission rights sales model

Available transmission rights	2 GW each direction
Annual average transmission rights prices	0.2, 0.4, 0.6, 0.8, and 1.0 yen/kWh

Source: Created by Renewable Energy Institute.

Fourth, for the congestion charge model, simulation to find out how often market splitting occurs after market coupling was technically necessary. However, it was possible to regard the situation prior to market coupling as essentially comprising a split market. Based on this premise, therefore, actual trading prices were used to make rough estimations for Japan and South Korea, where wholesale electricity markets are operated. Estimation for the congestion charge model was undertaken for the Japan–South Korea interconnector only, using the assumptions shown in Table 21. Assumptions for the payback period and the O&M ratio were the same as those for the other models.

[41] Based on electricity demand data used to calculate each company's grid tariffs. For example, in the case of the TEPCO service area, the average demand figures for FY2012 to 2014 used by TEPCO Power Grid when applying for authorization of its grid tariff in 2016 were 82.0 TWh for extra-high voltage, 102.2 TWh for high voltage, and 105.7 TWh for low voltage. For the purposes of these estimates electricity demand was assumed to be the sum of these figures.

Table 21: Assumptions for recovering investment in interconnectors: Congestion charge model

Annual average capacity factor	50%, 75%, and 100%
Currency conversion	Use the middle rate of the day before the transaction date
JEPX prices	Annual data for 2016 and 2017 (every half hour)
Market prices in the counterpart country	Data for contract prices at the same time on the same day as JEPX prices

Source: Created by Renewable Energy Institute.

3) IRR estimation results for a Japan–Russia interconnector

The tables below show the results of estimations regarding investment recovery for the Japan–Russia interconnector based on each business model mentioned above. Table 22 shows the results using the generators/suppliers dedicated line model, Table 23 uses the regulated grid tariff model, and Table 24 uses the transmission rights sales model. The range of the IRR estimations within the tables is due to the influence of JEPX market prices in 2016 and 2017 and O&M ratios assumed.

First, for the generators/suppliers dedicated line model using only 1 GW of grid capacity, the median of the IRR range is positive when the FOB prices are around 5–6 yen per kWh or lower. However, the profitability improves when using 2 GW. This shows that the generators/suppliers dedicated line model is a business model where the profitability fluctuates according to FOB prices and the capacity factor of transmission lines. Also, while a 1 percentage point difference of O&M ratio changes the IRR by approximately 1 percentage point, the difference in market prices between 2016 and 2017 changes the IRR by approximately 2 percentage points. This is because the estimation assumes that all electricity acquired from Russia is bid for and sold on the JEPX market. If, however, the sales price in Japan could be fixed by a contract on a negotiation basis, it might be possible to reduce the effects of price volatility on profitability. In actual fact, therefore, profitability is likely to vary from one case to another.

Second, for the regulated grid tariff model, the median of the IRR range is positive when the grid tariff is 0.06 yen per kWh or higher for the R1 route, 0.08 yen per kWh or higher for the R2 route, and around 0.10 yen per kWh or higher for the R3 and R4 routes. For the R1 route, the estimation is based on the premise that Russia would cover 50% of construction costs even though more of the transmission line would be in Japanese territorial waters and exclusive economic zones than Russian. If Japan were to cover all construction costs for the R1 interconnector, the grid tariff that would make the median of the IRR range for the R1 route positive is estimated to be approximately 0.10 yen per kWh, the same as for the R3 and R4 routes. Accordingly, if all consumers in the TEPCO service area paid around 0.5% of the electricity price as a grid tariff, it would be possible to import electricity from Russia through an interconnector.

Table 22: IRR estimation results for a Japan–Russia interconnector based on the generators/suppliers dedicated line model (Positive IRR median values are bordered in red.)

FOB prices	5 yen/kWh	6 yen/kWh	7 yen/kWh	8 yen/kWh	9 yen/kWh
R1: Sakhalin–Kashiwazaki (Market to sell electricity: JEPX Tokyo area; Construction costs: 430.5 billion yen)					
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 (Market to sell electricity: JEPX Tokyo area; Construction costs: 461.9 billion yen)					
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 (Market to sell electricity: JEPX Tokyo area; Construction costs: 573.0 billion yen)					
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 (Market to sell electricity: JEPX Tokyo area; Construction costs: 526.4 billion yen)					
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%

Source: Created by Renewable Energy Institute:

Table 23: IRR estimation results for a Japan–Russia interconnector based on the regulated grid tariff model (Positive IRR median values are bordered in red.)

Grid tariffs	0.06 yen/kWh	0.07 yen/kWh	0.08 yen/kWh	0.09 yen/kWh	0.10 yen/kWh
R1: Sakhalin–Kashiwazaki (Construction costs: 430.5 billion yen)	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 costs: 461.9 billion yen)	–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 costs: 573.0 billion yen)	–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 costs: 526.4 billion yen)	–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%

Source: Created by Renewable Energy Institute.

For the R2, R3, and R4 routes, it is assumed that AC-DC converters would be installed in Hokkaido and that electricity generated in the Hokkaido Electric Power service area could be transmitted to the TEPCO service area. In certain circumstances, a grid tariff might be collected from consumers in the Hokkaido Electric Power service area in addition to consumers in the TEPCO service area. In that case, the payment per kWh may be reduced. In any case, if consumers could gain benefits outweighing what they pay for the grid tariff, construction of an interconnector using this business model would be entirely feasible.

Third, moving on to the transmission rights sales model, the median of the IRR range is positive when the annual average transmission rights prices are 0.8 yen per kWh or higher for the R1 route and 1.0 yen per kWh or higher for the R2, R3, and R4 routes. As a reference, in terms of the prices of transmission rights traded via explicit auction in Europe, the annual average prices were normally 0.26 yen per kWh or lower (converted at a rate of 130 yen per euro), although they could be around 0.65 yen per kWh when the contract prices were high. Whether PTRs or FTRs, transmission rights for interconnectors constructed between coupled markets serve as a tool for power supply contracts involving more than one market to hedge against losses caused by market splitting. In other words, those who purchase transmission rights pay to cover the risk of market splitting. For such a situation to occur between Japan and Russia, it will take some time until a market between the two countries has been developed and liberalized.

Also, investors in interconnectors could earn revenues by selling long-term fixed transmission rights. In this case, operators supplying electricity from their chosen power sources would add transmission rights prices to their acquisition prices when selling electricity. Therefore, this business model falls under the generators/suppliers dedicated line model in this report.

Table 24: IRR estimation results for a Japan–Russia interconnector based on the transmission rights sales model (Positive IRR median values are bordered in red.)

Annual average transmission rights 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 costs: 430.5 billion yen)	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 costs: 461.9 billion yen)	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 costs: 573.0 billion yen)	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 costs: 526.4 billion yen)	Max. –14.0%	Max. –5.9%	–8.7 to –2.1%	–3.8 to 0.6%	–0.7 to 2.9%

Source: Created by Renewable Energy Institute.

4) IRR estimation results for a Japan–South Korea interconnector

For a Japan–South Korea interconnector, as for a Japan–Russia interconnector, Tables 25, 26, and 27, respectively, show the results of estimations regarding investment recovery based on the generators/suppliers dedicated line model, the regulated grid tariff model, and the transmission rights sales model.

First, for the generators/suppliers dedicated line model, revenues vary depending on the routes because electricity from each of the three assumed routes is bid for and sold in a different JEPX area. The difference in the IRR between the K3 route, which sells electricity to the Kyushu area, and other routes was up to 2 percentage points (in 2017) due to market splitting in Japan. There was, moreover, a difference of around 10 percentage points in the IRR between 2016 and 2017, the two years examined, because the wholesale electricity price in 2017 was higher than in 2016 across western Japan. The IRR estimates for a Japan–South Korea interconnector using the generators/suppliers dedicated line model have a wider range than the estimates for a Japan–Russia interconnector using the same model, as shown in Table 22. Moreover, 1 percentage point difference in the O&M ratio changes the IRR by 1 percentage point. Nevertheless, if Japan's wholesale electricity market situation remains unchanged and electricity supplied from South Korea is priced up to 6 yen per kWh (for the K1 route) or 7 yen per kWh (for the K2 and K3 routes), construction of an interconnector employing the generators/suppliers dedicated line model is well worth considering in terms of investment recovery. At the same time, there are many factors that would affect profitability, as in the case of a Japan–Russia interconnector. It would be important, therefore, to reduce the influence of price volatility in an actual business situation by taking steps such as making contracts on a negotiation basis.

Table 25: IRR estimation results for a Japan–South Korea interconnector based on the generators/suppliers dedicated line model (Positive IRR median values are bordered in red.)

FOB prices	5 yen/kWh	6 yen/kWh	7 yen/kWh	8 yen/kWh	9 yen/kWh
K1: Busan–Maizuru (Market to sell electricity: JEPX Kansai area; Construction costs: 246.5 billion yen)					
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 (Market to sell electricity: JEPX Chugoku area; Construction costs: 202.4 billion yen)					
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 (Market to sell electricity: JEPX Kyushu area; Construction costs: 212.3 billion yen)					
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%

Source: Created by Renewable Energy Institute.

Second, the regulated grid tariff model is slightly less effective for recovery of investment in a Japan–South Korea interconnector compared with a Japan–Russia interconnector. The estimations assume that the investors are general electricity transmission and distribution utilities, so the costs are covered by all consumers in the service area of each company: Kansai Electric Power, Chugoku Electric Power, and Kyushu Electric Power, respectively. Compared to TEPCO, which has a large number of consumers, the charge per capita is higher in those areas, which makes the business model less effective. Nevertheless, for the K1 route at least, the median of the IRR range is positive when the grid tariff is 0.06 yen per kWh or higher (Table 26). If it is assumed the region that would benefit from an interconnector as including the service areas of multiple companies or the entire 60 hertz area, the cost burden estimated under the regulated grid tariff model would be smaller. If the regulated grid tariff model were actually selected, therefore, it would be important to determine the region that would benefit from the interconnector.

Table 26: IRR estimation results for a Japan–South Korea interconnector based on the regulated grid tariff model (Positive IRR median values are bordered in red.)

Grid tariffs	0.06 yen/kWh	0.07 yen/kWh	0.08 yen/kWh	0.09 yen/kWh	0.10 yen/kWh
K1: Busan–Maizuru (Construction costs: 246.5 billion yen)	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 costs: 202.4 billion yen)	–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 costs: 212.3 billion yen)	–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%

Source: Created by Renewable Energy Institute.

For a Japan–South Korea interconnector, as for a Japan–Russia interconnector, the estimation is based on the premise that cross-border construction costs would be paid equally by both countries. If Japan were to cover all the costs, the grid tariffs would double. However, unlike a Japan–Russia interconnector, none of the three potential routes for a Japan–South Korea interconnector are located mostly within Japan. Therefore, sharing the costs on a fifty-fifty basis, which already takes place in Europe and other regions, would be entirely reasonable.

Third, with the transmission rights sales model for a Japan–South Korea interconnector, lower construction costs compared to a Japan–Russia interconnector mean that, in two of the routes, the median of the IRR range could be positive with annual average transmission rights prices of around 0.4 yen per kWh. However, the prices are still higher than the current trading prices of transmission rights in Europe. As transmission rights prices are actually affected by market conditions and reserve margin, there are many unpredictable and uncertain elements at the present time. Nevertheless, the estimation shows that this business model used as an ancillary to the congestion charge model could serve as a means to earn revenues.

Table 27: IRR estimation results for a Japan–South Korea interconnector based on the transmission rights sales model (Positive IRR median values are bordered in red.)

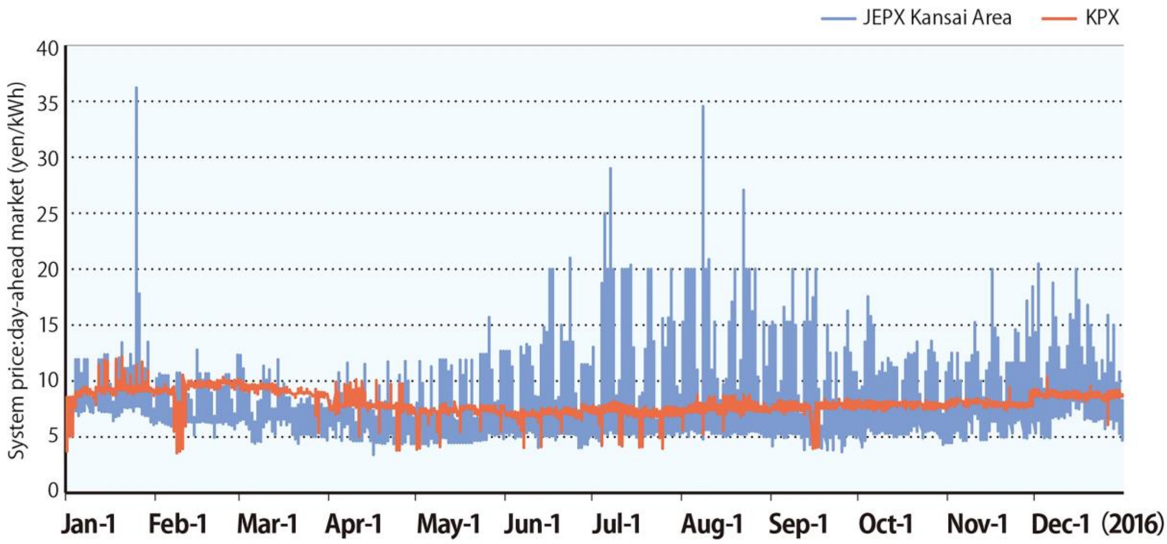
Annual average transmission rights prices	0.2 yen/kWh	0.4 yen/kWh	0.6 yen/kWh	0.8 yen/kWh	1.0 yen/kWh
K1: Busan–Maizuru (Construction costs: 246.5 billion yen)	Max. –5.2%	–2.9 to 1.3%	2.7 to 5.6%	6.7 to 9.2%	10.2 to 12.5%
K2: Busan–Matsue–Hino (Construction costs: 202.4 billion yen)	–12.5 to –3.4%	–0.1 to 3.3%	5.4 to 8.0%	9.8 to 12.1%	13.7 to 15.9%
K3: Busan–Imari & Oita–Ikata (Construction costs: 212.3 billion yen)	–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%

Source: Created by Renewable Energy Institute.

Finally, the IRR was estimated for a Japan–South Korea interconnector using the congestion charge model. The Korea Power Exchange (KPX), on which the nation's wholesale electricity is traded, employs a cost-based pool system, and the generation costs for each power source determined by the government's Generation Cost Evaluation Committee are used to bid in the market.[42] By contrast, on Japan's JEPX day-ahead market, bidding prices for each power source can be set arbitrarily taking marginal cost into account. In this way, the current approaches to the wholesale electricity market differ between Japan and South Korea. Consequently, as the system prices in the markets in Japan and South Korea during 2016 show (Figure 13), price volatility in Japan is greater than in South Korea. It is this price difference that results in congestion charges. In addition, depending on the time of day, bidirectional power flows between South Korea and Japan would be possible.

Based on the above premise, revenues were estimated by multiplying the market price difference between Japan and South Korea by the actual amount of electricity expected to be transmitted, and the results are shown in Table 28. According to the table, the congestion charge model could be expected to recover the investment in all the Japan–South Korea interconnector routes assumed in this estimation. Even if the capacity factor were set at around 50%, use of this business model would be possible. However, it should be noted that the rates of return in Table 28 could not be earned at the levels shown if the markets were actually coupled because the electricity prices of both countries would be likely to interact and converge. Nevertheless, coupling of the markets could result in a certain degree of economic profit.

Figure 13: Example of market prices in Japan[43] and South Korea (2016)



Source: Created by Renewable Energy Institute based on data from JEPX and KPX.

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42 Hisao Kibune, "The restructuring of the electricity industry in South Korea" [In Japanese], *Journal of Nagoya Gakuin University*; Social Sciences 42(2) (2005): 13–39.

43 For the generators/suppliers dedicated line model above, it was estimated wholesale electricity prices in Japan based on price data for the Chugoku and Kyushu regions, as well as for the Kansai region. As there was little difference between the three when shown on a graph, however, the Kansai region data was used as an example in the study.

Table 28: IRR estimation results for a Japan−South Korea interconnector if revenues could be earned from the price difference between wholesale electricity markets in both countries (Positive IRR median values are bordered in red.)

Capacity factors	50%	75%	100%
K1: Busan–Maizuru (Trading market: JEPX Kansai area) (Construction costs: 246.5 billion yen)	0.0 to 5.1%	5.5 to 10.2%	9.9 to 14.8%
K2: Busan–Matsue–Hino (Trading market: JEPX Chugoku area) (Construction costs: 202.4 billion yen)	2.6 to 7.4%	8.5 to 13.2%	13.4 to 18.5%
K3: Busan–Imar & Oita–Ikata (Trading market: JEPX Kyushu area) (Construction costs: 212.3 billion yen)	2.3 to 6.9%	8.1 to 12.5%	12.9 to 17.6%

Source: Created by Renewable Energy Institute.

5) Examination of the IRR estimation results

As described above, the Study Group discussed business models effective for investment recovery from the viewpoint of investors in interconnectors. As a result, it was found that the generators/suppliers dedicated line model would be feasible for either a Japan–Russia interconnector or a Japan–South Korea interconnector, provided that electricity could be procured at low prices. At the same time, the results implied that, as profitability is greatly affected by electricity procurement prices and Japan's market environment, long-term contracts on a negotiation basis may be required to ensure reliable business operations.

Estimation based on the grid tariff model showed that, if general electricity transmission and distribution utilities invested in an interconnector and recovered the construction costs by grid tariff, the construction costs of the transmission lines divided by all electricity demand in each service area would be approximately 0.1 yen per kWh. Accordingly, if consumers who paid the charges could gain benefits worth their payment, and understood the value of the investment, construction of an interconnector using the regulated grid tariff model would be feasible.

For the transmission rights sales model, the difficulty in predicting transmission rights prices presents many uncertainties in terms of the potential for investment recovery. In the United States and European countries, this business model is sometimes employed in combination with the congestion charge model. However, at the present time, investment recovery solely via sale of transmission rights remains problematic. In light of the challenges, two realistic options could be considered to use the transmission rights sales model for investment recovery. One would be sale of transmission rights by the interconnector operator following market coupling as a tool to earn revenues, and the other would be the long-term sale of transmission rights, which is similar to the generators/suppliers dedicated line model.

Finally, the IRR estimation for the congestion charge model was based on the premise that the wholesale electricity markets in Japan and South Korea would be coupled under the current system of each country, and investors in an interconnector could earn revenues from the market price differences. The estimation demonstrated that the congestion charge model would offer more opportunities for profits than the generators/suppliers dedicated line model and would enable investment recovery even with a relatively low capacity factor because the interconnector could be used according to price differences. However, if the markets were actually coupled, the difference between the wholesale electricity prices of both countries would decrease and profitability would be affected by the change of system and the special rules for new market coupling, among other developments. In order to adopt the congestion charge model, therefore, thorough discussion by investors in transmission lines, market operators, and governmental regulatory bodies would be required.

Section 2: Assessment of social benefits of interconnectors

As mentioned at the beginning of Section 1, international grid connections generally offer three main benefits: improvements in economic efficiency, stable supply via cross-border transmission operation, and mitigation of fluctuations in output from renewable power sources. Expansion of the network through appropriate, cumulative investments in transmission facilities increases the benefits provided by the entire electricity system. This is not confined to interconnectors—it holds true for regular domestic grids as well and plays a public role beyond mere investment recovery. This section draws on previous studies to evaluate potential social benefits from the Japan–Russia and Japan–South Korea interconnectors that are the subjects of this report.

1) Previous cost-benefit analyses in the energy field

Cost-benefit analysis is a method to evaluate the ratio of benefit public investment brings to society as a whole, relative to its costs. In Japan, this method has been used in many fields such as flood control projects and expressway construction, including some recent projects in the energy field. Therefore, this section starts with a broad overview of previous cost-benefit analyses in the energy field in Japan and abroad. Table 29 shows a summary of previous studies. In the table, the ✓ symbol indicates items quantified in previous analyses, blank boxes indicate that items were neither quantified nor considered.

Table 29: Examples of cost-benefit analyses in the energy field conducted in Japan and abroad

Benefits	**(A)** METI (2015)	**(B)** OCCTO (2017)	**(C)** MOE and Mitsubishi Research Institute (2015)	**(D)** METI and Mizuho Information & Research Institute (2016)	**(E)** Research Institute of Innovative Technology for the Earth (RITE) (2014)	**(F)** Central Research Institute of Electric Power Industry (CRIEPI) (2015)	**(G)** Otsuki (2017)	**(H)** (Ref.) ENTSO-E (2017)
1. Reduction in fuel costs of thermal power plants		✓	✓	✓	✓	✓	✓	✓
2. Reduction in equipment costs of existing power plants					✓	✓		partially evaluated
3. Economic effects (GDP and employment)			✓	✓				
4. Greenhouse gas reduction			✓	✓	✓	✓	✓	✓
5. Improvement of energy security (self-sufficiency rate and effect of stockpiling cost reduction)			✓	✓	partially evaluated			
6. Reduction in nuclear power risk costs					✓			
7. Reduction in nuclear power plant siting grants					✓			
8. Expansion of renewable energy	✓						✓	✓
9. Resilience and flexibility in dealing with transmission accidents and unimplemented transmission line plans								✓
10. Reduction of overall transmission line loss								✓

Costs	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1. Fuel cost increase owing to decreased power generation efficiency in thermal power plants accompanying lower capacity factors	✓		✓					
2. Fuel cost increase associated with increased start-stop frequency 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: Created by Renewable Energy Institute.

In cost-benefit analysis (A) above, the METI Agency for Natural Resources and Energy's Advisory Committee for Natural Resources and Energy considered the costs required to stabilize grids for deployment of renewable energy.[44] The committee suggested solutions for grid stabilization and examined their additional costs; the solutions suggested were: (1) frequency adjustment using existing thermal power plants and pumped-storage hydropower plants, (2) grid reinforcement, and (3) other measures such as utilization of market functions, power conditioner systems with an output control function, and frequency control with storage batteries. With regard to grid reinforcement costs in particular, the committee assumed that wind power plants would be deployed in Hokkaido (2.7 GW) and in the Tohoku region (3.2 GW) and electricity generated from these plants would be transported to demand centers (in the service area of TEPCO). The committee calculated that in that case the total grid reinforcement costs required would be approximately 900 billion yen, and if those costs were covered by additional 5.9 GW of wind power capacity, the costs would be around 9 yen per kWh.

In OCCTO's Long-term Cross-regional Network Development Policy published in March 2017 (analysis (B) above), OCCTO assumed reinforcement of inter-regional connections to eliminate power interchange restrictions in Japan, and estimated the impact of fuel cost reduction at thermal power plants on renewable energy generation in FY2013 and FY2014.[45] According to the results, annual costs for reinforcing inter-regional connections would be about 77 billion yen, while the impact of fuel cost reduction would be about 22–23 billion yen per year. Benefits other than the impact of fuel cost reduction at thermal power plants were not considered in this analysis.

In cost-benefit analyses (C) and (D) above, two government-related teams studied the costs and benefits of renewable energy deployment. The two teams were the MOE in association with the Mitsubishi Research Institute, and METI in association with the Mizuho Information & Research Institute. Both teams examined various potential benefits, such as the economic ripple effect, reduction of fuel costs for thermal power plants, reduction of imports of fossil fuel resources, reduction of greenhouse gas emissions, and improvement of the energy self-sufficiency rate.[46] However, each study had different cost assumptions as to whether grid reinforcement or renewable energy investment should be included in the costs. In addition, cost-benefit analyses (E), (F), and (G) —RITE,[47] CRIEPI,[48] and Otsuki[49]—also analyzed the costs for renewable energy deployment and the corresponding benefits. Meanwhile, a separate study conducted by the World Bank in 2010 on the causes of progress in inter-regional electricity market integration, although not a cost-benefit analysis, pointed out benefits, such as: reduction of investment in facilities to meet peak electricity demand by securing reserve capacity; generation of economies of scale by deploying major power sources made possible by expanded market size; and promotion of competition by integrating electricity markets.[50]

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44 Advisory Committee for Natural Resources and Energy (the Power Generation Cost Analysis Working Group of the Subcommittee on Long-term Energy Supply-demand Outlook within the Strategic Policy Committee), *Report on Analysis of Generation Costs, Etc. for Subcommittee on Long-term Energy Supply-demand Outlook* (2015).

45 OCCTO, *Long-term Cross-regional Network Development Policy* [in Japanese] (March 2017).

46 Mitsubishi Research Institute, *FY2014 report on the contracted study on the possibility of dissemination of renewable energy and other distributed energy in 2050* [in Japanese] (2015); and Mizuho Information & Research Institute, *FY2015 baseline survey on the promotion of new energy deployment: Survey on industries related to renewable energy, etc.* [in Japanese] (2016).

47 Systems Analysis Group, RITE, *Latest Estimate of Power Generation Costs by Power Source, and Cost-Benefit Analysis of Alternative Power Sources* (2014).

48 Kenji Okada and Masahiro Maruyama, "Mechanisms and issues of transmission system reinforcement under the unbundling situation in Europe" [in Japanese], *CRIEPI Research Report* Y14019 (2015).

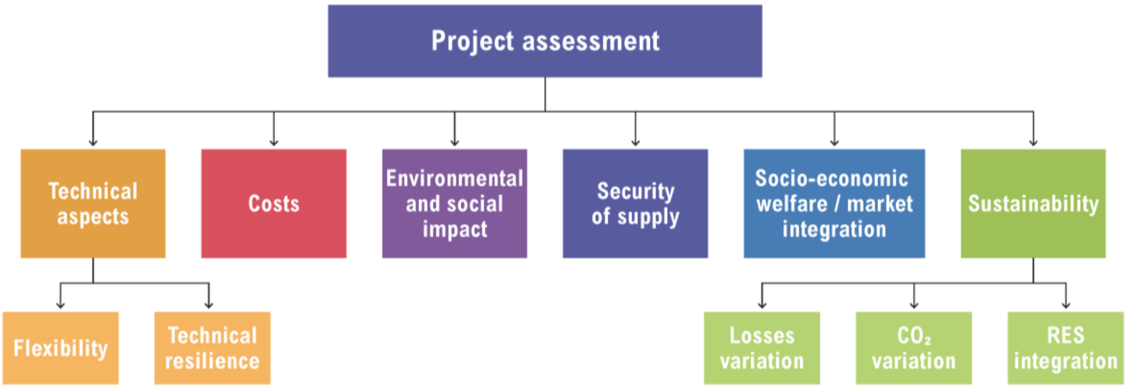
49 Takashi Otsuki, "Costs and Benefits of Large-Scale Deployment of Wind Turbines and Solar PV in Mongolia for International Power Exports," *Renewable Energy* 108 (2017): 321–35.

50 Economic Consulting Associates, *The Potential of Regional Power Sector Integration: Literature Review* (2010).

Recognizing that, in contrast to these previous cost-benefit analyses in the energy field, the Study Group needed to focus specifically on investment in interconnectors when reviewing benefits, the cost-benefit analysis conducted by ENTSO-E[51] in Europe was also referred, which undertook such a review. Figure 14 shows the approach to cost-benefit analyses at ENTSO-E. In addition to socio-economic welfare and security of supply, renewable energy source (RES) integration is considered to be a benefit of transmission line construction. According to ENTSO-E's approach, even if these benefits are difficult to quantify, they are qualitatively assessed as elements in the decision-making process.

By reviewing previous cost-benefit analyses within the energy field in this way, it was found that interconnectors offer various benefits, while many analyses in Japan are limited, being based solely on quantitative data. This report follows the approach used by ENTSO-E, dealing primarily with the three benefits presented in the Interim Report (improvements in economic efficiency, stable supply of electricity, and mitigation of fluctuations in output to address the increase in fluctuating renewable power sources). In the following paragraphs, potential benefits offered by construction of Japan–Russia and Japan–South Korea interconnectors will be discussed in more specific terms.

Figure 14: ENTSO-E's approach to cost-benefit analysis for reinforcement of transmission lines



Source: ENTSO-E https://preview.entsoe.eu/publications/tyndp.(accessed March 2018)

2) Benefits brought by the Japan–Russia and Japan–South Korea interconnectors

The first potential benefit is improvements in economic efficiency. In this regard, our scenarios of the Japan–Russia and Japan–South Korea interconnectors assume that inexpensive renewable energy electricity would be imported from Russia, Mongolia, China, and other countries to Japan. Consequently, the system price on the JEPX would be expected to decrease, which could contribute to the reduction of electricity prices for consumers in Japan. In general, when market splitting occurs due to transmission congestion, construction of new transmission lines promotes the use of cheaper power sources, increasing surpluses in both the producer and consumer sectors. In the case of a Japan–Russia interconnector, low-price electricity supplied from Russia could increase consumer surplus in Japan, while improvement of the capacity factor in power plants could increase producer surplus in Russia. Moreover, if a Japan–Russia interconnector was constructed through Hokkaido via routes R2, R3, or R4, for example, market splitting between Hokkaido and eastern Japan could be reduced and the electricity prices in Japan could potentially be lowered. In the case of a Japan–South Korea interconnector, it is likely that the difference between wholesale electricity prices in the two countries would be reduced, causing market prices to decrease as a result.

[51] ENTSO-E, *Guideline for Cost Benefit Analysis of Grid Development Projects* (2017).

The second potential benefit is stable supply of electricity. To achieve this, interconnectors would widen the transmission network, enabling reserve capacity sharing across Northeast Asia. When the Great East Japan Earthquake occurred in 2011, planned outages had to be implemented because many power plants had been shut down. But if it proves possible to establish inter-regional transmission operations including overseas power sources, the chances of avoiding a similar situation in future are higher. This would also contribute to reducing the costs required for electricity systems across Northeast Asia.

The third potential benefit is mitigation of fluctuations in output from renewable power sources. The cross-border transmission operations enabled by interconnectors would be effective in this regard, and would contribute to the expansion of renewable energy deployment in Northeast Asia. For instance, the existing hydropower in the Amur River basin shown in Section 1 of Chapter 3 could be effectively utilized as a solution for output fluctuations in wind power and solar PV in Hokkaido. Also, in the Kyushu region in particular, curtailment of output has become more likely as a result of large-scale deployment of solar PV. However, if surplus electricity could be exported to South Korea and other countries, both stable supply and further renewable energy deployment could be achieved in the Kyushu region.

In addition to these main benefits, the benefits from an interconnector would likely spread to other areas in the medium to long term. For example, increased renewable energy deployment could help to phase out thermal power plants and contribute to reduction of fuel costs, facility maintenance costs, and carbon dioxide emissions, as well as improvement of Japan's energy self-sufficiency rate. These could be significant benefits not only for Japan but also for other countries such as China, which is suffering from serious air pollution. Moreover, increased investment in the areas generating renewable electricity and lower electricity prices in the areas importing electricity could potentially lead to the growth of GDP, enhancement of industrial competitiveness, and expansion of job opportunities.

Furthermore, international relations could be expected to improve and strengthen: although this would be an indirect, long-term benefit, electricity trading is expected to strengthen relationships of economic interdependence and further develop diplomatic relations. In Japan, some people have voiced strong concerns from a national security perspective about electricity trading with neighboring countries. However, the history of European integration[52] starting from the European Coal and Steel Community established in 1952 indicates the possibility that energy interdependence can actually bring peace. Renewable energy is based in individual regions within a country, but at the same time requires network connections with other countries. As such, expansion of renewable energy could serve as a trigger to explore new diplomatic relations in Northeast Asia through energy.

Section 3: Legal frameworks for interconnectors

The Interim Report examined the international coordination and domestic legislative provision necessary to develop interconnectors in general terms, and summarized the main considerations. Based on these considerations, this section further examines legal frameworks concerning international transmission business as they relate to implementation of the investment recovery models studied in Section 1 of this chapter. The focus here is on Japanese legislation, with particular attention to regulations on operation of electricity business. Specific ideas for interconnector frameworks that could be implemented between two countries are also mentioned.

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52 Etsuko Shimada, *History of economic development in Europe* [in Japanese] (Nihon Keizai Hyouronsha, 1999). According to the book, the establishment of the common market by the European Coal and Steel Community caused the abolishment of foreign currency restrictions and tariffs, enabling large-scale, economic intraregional trading of steel products and raw materials in the short term, and triggering the movement toward market integration and political integration in the long term.

1) International transmission business and licenses

In this report, international transmission business is defined as the business of investing in an interconnector, maintaining and managing it, and recovering the investment in some way. With ownership unbundling and legal unbundling commonly adopted in Europe, many business operators are also engaged in grid operations. On the other hand, with functional unbundling, which is common in North America, grid operations are separately handled by ISOs.

In Japan, the Electricity Business Act assigns licenses to companies by type of electricity business, such as generation or transmission, and imposes regulations accordingly. Establishing an interconnector therefore requires consideration of the business license to be assigned. Currently, the Electricity Business Act defines three transmission-related licenses—the general electricity transmission and distribution license, the electricity transmission license, and the specified electricity transmission and distribution license; but interconnectors are not considered under any of these licenses. Nevertheless, in European countries such as France, Sweden, and Denmark, some TSOs operate international transmission business as an extension of their original business. Moreover, as an example, Japan's Telecommunications Business Act stipulates business licenses with no distinction between domestic and international businesses, and adopt a separate authorization system for international matters such as agreement with foreign countries. First, therefore, the possibility of engaging in international transmission business with licenses specified under existing law is examined.

Among the three licenses mentioned above, the specified electricity transmission and distribution license is not suitable for interconnectors because it is intended for transmission and distribution in very small areas. On the other hand, the general electricity transmission and distribution license and the electricity transmission license allow operation of an international transmission business if its service qualifies as a wheeling service (consisting of cross-area wheeling service and intra-area wheeling service stipulated in Article 2, paragraph 1, items 4 and 5, respectively, of the Electricity Business Act). However, whether an international transmission business is considered to be a wheeling service depends on the content of the international agreement, such as the entity named in the transmission contract for the interconnector and the legal treatment of electricity adjustments to be made at both ends of the interconnector. The discussion below is based on the premise that an international transmission business would qualify as a wheeling service; the opposite case will be discussed in "5) Creation of a new international transmission license."

First, general electricity transmission and distribution utilities are responsible for stable supply of electricity in their service areas, and construct, maintain, and operate transmission lines for this purpose. They are already allowed to construct these transmission lines outside of their service areas (Article 24 of the Electricity Business Act). Moreover, with the recent expansion of inter-regional transmission operations, there has been increasing demand for stable supply beyond individual service areas. Therefore, as long as an interconnector fulfilled this role, general electricity transmission and distribution utilities should be able to operate international transmission business as part of their existing business.

Second, international transmission business can also be conducted with an electricity transmission license. If the partner country is regarded as an additional adjacent service area or power source, an interconnector can play a similar role to an inter-regional connector or a transmission line that connects a power generating facility with the electrical network, and the business can be regarded as a cross-area wheeling service to general electricity transmission and distribution utilities.

These two transmission-related licenses are accompanied by various regulations such as rules on services (including obligation to provide wheeling service) and regulations related to safety of electric facilities and environmental preservation. Among them, restriction of concurrent business and prohibition of discriminatory treatment are closely related to implementation of the investment recovery models studied in Section 1.

Restriction of concurrent business is associated with unbundling of generation and transmission. As transmission-related licensees are in principle not allowed to operate generation and retail business (Articles 22-2 et seq. and 27-11-2 et seq. of the revised Electricity Business Act to be enforced on April 1, 2020), the point in question is whether they can adopt the generators/suppliers dedicated line model. On the other hand, prohibition of discriminatory treatment raises the question of whether preferential allocation of certain transmission line capacity to specific companies is permitted. Such allocation is needed to ensure reliable access to the transmission rights that are a prerequisite for adopting the generators/suppliers dedicated line model.

With these two regulations in mind, the feasibility of the regulated grid tariff model and the generators/suppliers dedicated line model is examined, which were considered effective in Section 1, with the general electricity transmission and distribution license and the electricity transmission license.

2) The general electricity transmission and distribution license and the regulated grid tariff model

If international transmission business is operated with a general electricity transmission and distribution license, investment recovery with the regulated grid tariff model can be assumed. If operation of an interconnector is regarded as part of general electricity transmission and distribution business, the fully distributed cost method can be used and the mechanism for collecting fees from all consumers can be employed.

In this case, a general electricity transmission and distribution utility is dependent on the grid tariff from its own service area. Therefore, as pointed out in Section 1, the fee per consumer varies considerably depending on the areas connected to interconnector. Considering the inter-regional benefits from interconnectors discussed in Section 2, it seems reasonable that the costs should be covered by consumers in multiple service areas.

Such cases have already been observed under the current electricity business system. For example, in the ongoing project to upgrade inter-regional connection facilities between Tokyo and Chubu,[53] the upgrade costs for the Higashishimizu frequency converter operated by Chubu Electric Power will be covered by general electricity transmission and distribution utilities in nine regions across the country, except for Okinawa Electric Power. Eight such utilities other than Chubu Electric Power will pay contributions for construction of the frequency converter and its usage fees to Chubu Electric Power, and their payments will be funded by grid tariffs collected from their service areas. This is because this inter-regional connection facility upgrade project is regarded as a countermeasure against the risk of wide-area shutdown of power sources associated with large-scale disasters, which contributes to stable supply and brings wide-ranging benefits to consumers in all nine regions. This model can appropriately be called an "indirect regulated grid tariff model," and it can serve as a reference when considering the regulated grid tariff model for international transmission business.

3) The general electricity transmission and distribution license and the generators/suppliers dedicated line model

On the other hand, the general electricity transmission and distribution license is less compatible with the generators/suppliers dedicated line model because generation and sales of electricity by general electricity transmission and distribution utilities themselves as a means to recover investment in an interconnector would conflict with the restriction of concurrent business. Actually, such restriction is commonly imposed on TSOs in Europe. Therefore, recovering investment by their own electricity trading is basically not considered in their business models.

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[53] OCCTO, *Cross-regional Network Development Plan for Interconnection Facilities between Tokyo and Chubu* [in Japanese] (June 2016).

Meanwhile, Japan's Electricity Business Act does not have any special provision on wholesale business of electricity, and it seems wholesale business by general electricity transmission and distribution utilities is not prevented. Also, wholesale supply of electricity based on the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (hereinafter, "Renewable Energy Special Measures Act") is an example of wholesale business actually operated by general electricity transmission and distribution utilities themselves. However, in light of the purpose of restriction of concurrent business, it is reasonable to assume that wholesale business with free price setting would not be automatically allowed, even if benefits as specified in the Renewable Energy Special Measures Act, such as special needs and simplification of the system,[54] were applicable to international transmission business.

Thus, use of a direct generators/suppliers dedicated line model would be difficult with a general electricity transmission and distribution license. However, an investment recovery method that could be described as an "indirect generators/suppliers dedicated line model" could be considered based on a framework of "general cost sharing" or "specified cost sharing" for inter-regional network development under the current system. That is to say, according to the OCCTO Network Codes or other rules, if a transmission line brings wide-ranging benefits to consumers in a service area, the general transmission and distribution utility will cover the costs (general cost sharing); on the other hand, if a transmission line brings benefits to specified business operators or consumers through specified electricity trading, those business operators or consumers will cover the costs (specified cost sharing).

For example, in the recent facility upgrade project for the inter-regional connection between Tohoku and Tokyo, it was decided that companies indicating they wanted the upgrade should cover the costs partially (through specified cost sharing) in addition to Tohoku Electric Power, which owns the facility (through general cost sharing).[55] In this case, specified cost sharers were companies involved in renewable energy and other new power generation, and they would recover these costs in the form of revenues from electricity sales. In return for partial payment of the costs, the specified cost sharers could secure capacity in the inter-regional connection stably for the long term with certification from OCCTO. This is called the "certified contract system" for power supply contracts on power sources to be constructed together with inter-regional connections (Article 144 of the Operational Rules, and Article 209 et seq. of the Network Codes, of OCCTO).[56] Meanwhile, in relation to prohibition of discriminatory treatment, this process of upgrading the inter-regional connection was operated by OCCTO and was open to a wide range of applicants (Article 57 of the Operational Rules and Article 40, etc. of the Network Codes). Therefore, it would appear that non-discriminatory treatment was ensured by the procedures followed.[57] If this system was applied to an interconnector operated by a general electricity transmission and distribution utility, the generators/suppliers dedicated line model could be implemented indirectly.

[54] With regard to the reasons for shifting to the system with purchases by general electricity transmission and distribution utilities, see *Change of the entity responsible for purchasing in the renewable energy feed-in tariff system* [in Japanese], Document 6 for the third meeting of the Basic Policy Subcommittee on Electricity (part of the Electricity and Gas Industry Committee in METI's Advisory Committee for Natural Resources and Energy) (2015).

[55] OCCTO, *Cross-regional Network Development Plan between Tohoku and Toky*o [in Japanese] (February 2017).

[56] Note that power flows are not always secured, especially when the routes are disconnected by failures. Also, not all contracts are certified. Some contracts for which certification has been sought did not receive certification. See OCCTO, *Results of examination for certification of contracts on interconnection operation* [in Japanese], July 29, 2015.

[57] This kind of interpretation is observed in the criteria of the FERC when allowing exceptions to open access to transmission lines, or in cases where exceptions to third-party access were allowed in Europe. For the US example, see FERC, *Allocation of Capacity on New Merchant Transmission Projects and New Cost-Based, Participant-Funded Transmission Projects*, 142 FERC ¶ 61,038 (2013). For the example in Europe, see European Commission, *Commission Decision on the Exemption of ElecLink Limited under Article 17 of Regulation (EC) No. 714/2009 for an Electricity Interconnector between France and Great Britain,* C(2014)5475 final, July 28, 2014.

As this certified contract system allows companies to secure grid capacity preferentially for the entire duration of a power supply contract, it is effective for investment recovery. However, it is undeniable that this conflicts with the concept of efficient capacity allocation using market mechanisms. As the ratio of preferentially allocated capacity to total grid capacity increases, market domination and the risk of market manipulation also increase. Given that this system is predicated on the first-come-first-served rule, therefore, it needs to be reconsidered once implicit auction replaces the first-come-first-served rule as the grid capacity allocation method. Even if a system allowing a certain amount of preferential allocation is established for interconnectors, the system's requirements, scope, duration, and other factors would need to be examined[58].

4) The electricity transmission license and investment recovery models

With regard to the electricity transmission license, an examination of the regulated grid tariff model for recovery of investment in interconnectors was conducted. As electricity transmission licensees (electricity transmission utilities) do not have service areas, they cannot directly recover investment by grid tariff as general electricity transmission and distribution utilities do. However, general cost sharing may be applicable to the costs of an interconnector. One example is the upgrading of a frequency converter operated by a Japanese electricity transmission utility, J-POWER, that is one of the inter-regional connection facilities between Tokyo and Chubu mentioned earlier. This frequency converter in Sakuma is owned by J-POWER, but its upgrade costs are covered by contributions for construction and usage fees paid by general electricity transmission and distribution utilities. As these utilities recover their costs from the grid tariffs collected in each service area, an indirect regulated grid tariff model could be employed as in the case of the Higashishimizu frequency converter.

Next, indirect use of the generators/suppliers dedicated line model could also be considered feasible if the abovementioned concept of specified cost sharing is applied. Although the examples of inter-regional network development do not include any examples of specified cost sharing for an inter-regional connection owned by a electricity transmission utility, OCCTO's Network Codes and other rules do not distinguish between license types in determining whether to allow specified cost sharing. Therefore, if specified cost sharing is allowed for a cross regional connection of an electricity transmission utility, an indirect generators/suppliers dedicated line model could be employed.

With the indirect generators/suppliers dedicated line model, not only electricity transmission utilities, but also general electricity transmission and distribution utilities could be the operators of international transmission businesses and sell electricity based on the concept of specified cost sharing. In this case, however, given the concept of restriction of concurrent business in the case of legal unbundling, transmission business and electricity sales business must be operated separately by assigning each business to different companies in the corporate group, while ensuring all regulations including codes of conduct are complied with.

Table 30 gives an overview of the above discussion on the relationship between the licenses for international transmission business and the investment recovery models. With the general electricity transmission and distribution license, the direct regulated grid tariff model is the most compatible. However, investment recovery is also possible using the indirect regulated grid tariff model with multiple cost sharers, or the indirect generators/suppliers dedicated line model applying the concept of specified cost sharing. It is likely that the electricity transmission license would also allow use of similar investment recovery models.

[58] The capacity allocation rules for cross-regional interconnections in Japan have been changed since October 2018, from the "first-come-first-served" rule to the implicit auction. Due to this reform, the above noted mechanisms and the related provisions set by OCCTO were also revised or repealed. New general rules regarding the allocation of transmission rights to specific entities sharing the cost are still under discussion. (Noted in March 2019)

Table 30: Overview of general transmission and distribution license and transmission license, and the investment recovery models

Investment recovery model		General electricity transmission and distribution license	Electricity transmission license	Relevant system
Regulated grid tariff	Direct	A general electricity transmission and distribution utility (business operator) recovers investment from grid tariff.	Use of this model is impossible.	General cost sharing for inter-regional network development
	Indirect	· A general electricity transmission and distribution utility (business operator) recovers investment via payment from other general electricity transmission and distribution utilities. · Other general electricity transmission and distribution utilities recover their payments from grid tariffs.	· A electricity transmission licensee (business operator) recovers investment via payment from general transmission and distribution utilities. · Those utilities recover their payments from grid tariffs.	
Generators/suppliers dedicated line	Direct	Use of this model is difficult.	Use of this model is difficult.	Wholesale supply under the Renewable Energy Special Measures Act
	Indirect	· A general electricity transmission and distribution utility (business operator) recovers investment via payment from interconnector users. · Interconnector users recover their payments from electricity sales revenues.	· A transmission licensee (business operator) recovers investment via payment from interconnector users. · Interconnector users recover their payments from electricity sales revenues.	Specified cost sharing for inter-regional network development

Source: Created by Renewable Energy Institute.

5) Creation of a new international transmission license

Throughout the discussion thus far, we have pointed out the differences between the two existing licenses in terms of investment recovery models. Another difference between these two is that the general electricity transmission and distribution license is more difficult to obtain than the electricity transmission license. Accordingly, if a new entrant that is not a general electricity transmission and distribution utility wishes to start international transmission business, the way to enable investment recovery is to apply for the electricity transmission license and employ a business model that is not the direct regulated grid tariff model. In other words, new entrants should assume that they cannot adopt the direct regulated grid tariff model, as indicated in Table 30.

In light of these circumstances, the creation of a new international transmission license different from the existing two licenses could be considered as another option. This license could be designed flexibly according to policy objectives. For example, it could be designed so as to make the direct generators/suppliers dedicated line model available,[59] or to recover investment by grid tariffs collected inter-regionally. The license could also allow multiple business models to be selected according to the interconnector project. To address the issue regarding interpretation of "wheeling service" mentioned earlier, a new license for international transmission business could be created as a solution if the service of the business is not considered to be a wheeling service.

First and foremost, however, coordination with counterpart countries will be necessary to determine regulations regarding international transmission business. Also, regulations on foreign investment different from those on the licenses related to domestic transmission may be required. Given these factors, it may be reasonable to think that a separate license for international transmission business would be more appropriate and would allow prompt modification in the future. In addition, if this license becomes available, any companies can apply for it. However, creation of a new license would require revisions to the law.

6) Interconnector frameworks between two countries

In previous sections, the Japanese licenses for international transmission business were examined, however, as the actual business would be conducted with another country, various coordinating arrangements would be required according to the legal system and business practice of the counterpart country. The business entity to operate the international transmission business and the investment recovery method to be adopted would be determined by considering the electricity business laws, foreign investment regulations, general corporate legislation, tax systems, and various administrative procedures of both countries to be connected with each other.

First, the interconnector frameworks of foreign countries are roughly classified into three types as shown in Table 31 below. In the first framework, international transmission business is operated by one country. In the second framework, both countries are involved, but the business is operated in an integrated manner by one joint venture owned by both countries. In the third framework, both countries are involved, and the business is operated by two companies authorized by each country. Moreover, the third framework can be further divided into two types. In one type, the costs of the interconnector are simply split in half. In the other type, each country covers the costs of the interconnector within its territory. The framework to be adopted is determined based on the legal systems and business models in both countries.

[59] China's SGCC operates international transmission business with this business model.

Table 31: Examples of frameworks for interconnectors and related countries

		Interconnector name (parentheses indicate planned projects)		Interconnector operator/investor
One country	One company	East West Interconnector	Sea	EirGrid Interconnector DAC (Ireland)
		Skagerrak 1–3	Sea	Statnett (Norway)*
Two countries	One joint venture	BritNed	Sea	BritNed Development (UK-Netherlands joint venture)
		Biscay Gulf (Baixas–Santa Llogaia)	Sea Land	INELFE (France-Spain joint venture)
	Two companies	Skagerrak 4	Sea	Statnett (Norway): northern half of cable Energinet (Denmark): southern half of cable
		China–Russia	Land	Federal Grid (Russia): Russian territory SGCC (China): Chinese territory
		(Hertel–New York Interconnection) (Champlain Hudson Power Express)	Lake and land	Hydro-Québec (Canada): Canadian territory TDI (US): US territory

*The Danish side pays lease fees for Skagerrak 1–3 to cover half of O&M costs.
Source: Created by Renewable Energy Institute based on various materials.

As discussed in this report, at the moment Japan's counterparts for an interconnector could be Russia and/or South Korea. Russia has a history of establishing interconnectors with European countries, China, Mongolia, and other countries, and the legal system for interconnectors is already established there. However, the Sakhalin area, which was examined in this report as a landing point, is designated as a special zone under federal legislation. The area is not connected to the continent, and state-owned RusHydro monopolizes power generation and transmission there. Consequently, establishment of a Japan–Russia interconnector should be based on the federal legislation that prevails on the continent, but at the same time, it would probably be necessary to revise the legal system related to Sakhalin as needed and coordinate between Japan and Russia.

Like Japan, South Korea has no experience in interconnectors, its legal system is closed to other countries. State-owned KEPCO monopolizes transmission, distribution, and retail businesses. There is a wholesale electricity market with a compulsory pool system, and foreign investment in transmission business is regulated. Therefore, it is almost certain that KEPCO would be the main player of Korean side regarding Japan–South Korea interconnectors, but it greatly depends on how the existing legal system would be revised.

The further examination will be made on the specific design of frameworks for potential interconnectors, including the business entities involved, the investment recovery models to be adopted, and the nature of the cooperative bilateral relationship, based on discussions with the counterpart countries.

Conclusion

In this report, the Study Group examined interconnector routes for Japan–Russia and Japan–South Korea in detail, simulated the construction costs and investment recovery methods, and presented the results quantitatively. Social benefits to be provided and legal frameworks to establish the interconnectors were also examined. The study mission of international grid connections in North America was conducted also.

The results of the analysis suggest that it is physically and technically possible for Japan to construct interconnectors without any major problem in terms of connection to the onshore domestic network. Also, the construction costs of 2 GW interconnectors were found to be well recoverable, ranging from a little more than 200 billion yen (Japan–South Korea) to a little less than 600 billion yen (Japan–Russia) including the costs to reinforce Japan's domestic grids.

Although the legal frameworks need to be examined further, it was found that the existing transmission-related licenses could be used to some extent, and a new international transmission license could also be created. In the medium to long term, there is reason to expect that these frameworks could be developed into a market coupling mechanism through policy coordination with counterpart countries. It was also confirmed that international grid connection could offer various social benefits including improvement of diplomatic relations, as well as helping to develop Japan's electricity system into a more flexible and resilient one. For Japan, international grid connection is more than just an abstract theory; it is a realistic possibility.

On the other hand, there is little sign of increasing momentum in Japan for creating international grid connections in Northeast Asia. Compared with China or South Korea, in which specific actions are already being taken, Japan is actually falling further and further behind. This is partly due to the nation's lack of progress in electricity system reform and delay in deployment of renewable energy.

Dramatically decreasing costs and large-scale deployment of renewable energy are aspects of the global energy transformation and are inevitable. In this regard, expansion of international grid connections is key, and comprises another global phenomenon that many countries and regions are actively tackling according to their own circumstances. The *Recommendations by the Round Table for Studying Energy Situations* issued by Japan's Agency for Natural Resources and Energy on April 10, 2018, mentioned a strategy to expand renewable energy by utilizing interconnectors, but it only pointed out that this strategy poses many challenges for Japan and needs to be evaluated carefully.

Now that the international situation in Northeast Asia is changing significantly, there are high hopes that the Japanese government will make the shift from evaluation to action, because international grid connection is not an impossible task, but an extremely effective and feasible solution. Moreover, it would not only contribute to renewable energy expansion and stable supply of electricity, but would also bring new forms of innovation to the Japanese economy and new international relations to Northeast Asia.

We are determined to further examination of the issues that were not covered in this Second Report, and promote active and practical discussions on realistic concepts and designs for potential international grid connections for Japan.

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