Q1: What is an international grid connection?

A: An international grid connection refers to a network of transmission lines that deliver electric power across national borders. The differences between international and domestic grid connections are institutional rather than technical; an international grid connection needs to be operated with international institutional differences in mind.

An international grid connection refers to a network of transmission lines that deliver electric power across national borders. Individual transmission lines constituting such a network are referred to as “interconnectors.”

The same transmission line technology is applied to international and domestic grid connections alike. Yet an interconnector that goes across the sea is usually composed in part of submarine cables.

The greatest difference between domestic and international grid connections lies in institutions, which differ from country to country. Different countries have different grid technical standards, operators, regulatory systems, and regulators. Constructing and operating interconnectors requires coordination and agreement among the countries concerned in view of these differences. For the trade of electricity, attention should be paid to differences in currencies and tariffs as well as transaction systems.

International grid connections are well developed in Europe and North America. “Electricity trading” through these grids is a daily occurrence there.

Figure: Grids in Europe in 2017
Source: ENTSO-e, Statistical Factsheet 2017
Q2: Can electricity be imported and exported across national borders or the sea?

A: Cross-border trading in electricity is practiced in many parts of the world. The United Kingdom and Ireland, both of which are surrounded by the sea like Japan, trade electricity with other countries through submarine transmission lines.

Electricity is an international trade item like oil and LNG. For example, European countries import or export some 10% of electricity generated on average. Denmark tops the list with its import and export ratios both exceeding 30%. Italy and Belgium have high import ratios while Germany, Sweden, France, and Norway have high export ratios.

Apart from Europe, the United States, China, and Russia import and export electricity as well. Yet their import and export ratios are around 1%.

The UK, an island nation like Japan, imports and exports electricity by taking advantage of offshore window power generation and interconnectors. The objectives are to secure supply capacity while phasing out old thermal power such as coal-fired plants and to reduce electricity prices. The UK is already connected with other countries by several submarine transmission lines. It is also vigorously planning to install several new interconnectors.

Figure: Electricity import and export ratios of major countries and regions (FY2014)
Source: Asia International Grid Connection Study Group Interim Report
Q3: What are the advantages of building an international grid connection?

A: An international grid connection has many advantages, including more stable energy supply, a greater deployment of renewables, and more competitive electricity prices.

An international grid connection has three major advantages: ensuring more stable supply in times of disaster, supporting a greater deployment and utilization of renewables, and offering cheaper electricity.

First, an international grid connection could avoid—with emergency power interchange via interconnectors—planned outages and blackouts associated with a disaster, like the ones in the wake of the Great East Japan Earthquake on March 11, 2011, and the Hokkaido Eastern Iburi Earthquake on September 6, 2018. This advantage may be greater in Hokkaido, Kyushu, and other regions that have poor cross-regional transmission systems with other country regions.

Second, an international grid connection can promote a greater deployment of variable renewable energy such as solar PV and wind power. In Europe, where international grid connections are well developed, international transmission lines offer flexibility. European grid operators mutually trade electricity generated by variable renewable energy sources.

Third, an international grid connection could connect Japan with other countries, which in turn would allow Japan to use electricity generated by sources with low generation costs such as hydro, wind, and solar PV (in China and Mongolia, for example). The availability of such electricity in Japan will help reduce electricity bills in our family budget.
Q4: How relevant is the construction of an international grid connection in Asia?

A: In Northeast Asia, countries with a large market sit close to one another, including China, Japan, and South Korea. Linking large markets to share renewables will bring many economic and environmental benefits to the region.

Seen in the context of interconnector development, Northeast Asia is best characterized by a cluster of major power consumption centers or centers of economic activity. The region is home to the second (China), third (Japan), and eleventh (South Korea) largest economies in the world in terms of dollar-denominated nominal GDP in 2017. And they sit side by side. Japan, China, South Korea, and Mongolia together account for 76% of Asia’s power generation and 77% of its power consumption. Connecting these four countries with transmission lines will give rise to a single enormous electricity market.

Northeast Asia is also endowed with renewable resources, including hydro and wind power in the Russian Far East and solar PV in Mongolia. The potential for wind power and solar PV in Mongolia has been highly valued. For example, the US National Renewable Energy Laboratory (NREL) reported in 2001 that Mongolia has a wind power potential of 10,673 TWh per year. In 2016, the International Renewable Energy Agency (IRENA) reported that the country has a solar PV potential of 4,777 TWh. A simple addition shows that the Mongolia’s wind and solar PV potential far exceeds the combined electricity demand of China and Japan (4,876 TWh and 949 TWh, respectively, as of 2015 according to IEA WEO 2017). Larger windmills now available could generate more electricity. Connecting Northeast Asian countries with transmission lines will make it possible to supply major electricity markets with cheaper and cleaner power.

Figure: Potential for wind power (top) and solar PV (bottom) in Mongolia
Q5: How much electricity will enter Japan?

A: The typical interconnector in Europe has a transmission capacity of 1-1.4 GW. An interconnector connecting Japan and a neighboring country would have a capacity of around 2 GW (equivalent 2-3% of Japan’s maximum demand) as the first step.

A look at typical interconnectors involving large-capacity direct current transmission lines suggests that the amount of electricity entering Japan, or the transmission capacity to be specific, would be 1,000-1,400 MW (1-1.4GW). The Asia International Grid Connection Study Group Second Report, released in June 2018, assumes that a Japan-South Korea interconnector and a Japan-Russia interconnector would have a capacity of 2 GW each as the first step.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Project</th>
<th>Distance (km)</th>
<th>Static etc. (km)</th>
<th>Transmission method</th>
<th>Grid voltage (kV)</th>
<th>DC voltage (kV)</th>
<th>Capacity (GW)</th>
<th>Commissioned</th>
<th>Cumulative operation in</th>
<th>Transformer cost</th>
<th>Transmission line cost</th>
<th>Total cost</th>
<th>$/10,000 MW (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SAPEI</td>
<td>Italy</td>
<td>435</td>
<td>420</td>
<td>AC-Commmiend</td>
<td>400</td>
<td>±500</td>
<td>1,000</td>
<td>2011</td>
<td>$180m</td>
<td>$400m</td>
<td>$750m</td>
<td>$20</td>
</tr>
<tr>
<td>2</td>
<td>BritNed</td>
<td>UK -Netherlands</td>
<td>259</td>
<td>250</td>
<td>AC-Commmiend</td>
<td>400</td>
<td>±450</td>
<td>1,000</td>
<td>2011</td>
<td>$220m</td>
<td>$350m</td>
<td>$600m</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>NemoLink</td>
<td>UK -Belgium</td>
<td>141</td>
<td>130</td>
<td>AC-Commmiend</td>
<td>400</td>
<td>±400</td>
<td>1,000</td>
<td>2019</td>
<td>—</td>
<td>—</td>
<td>$500m</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Estlink 2</td>
<td>Estonia -Finland</td>
<td>171</td>
<td>145</td>
<td>AC-Commmiend</td>
<td>330</td>
<td>450</td>
<td>650</td>
<td>2014</td>
<td>$100m</td>
<td>$180m</td>
<td>$320m</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>NorNed</td>
<td>Netherlands -Norway</td>
<td>583</td>
<td>580</td>
<td>AC-Commmiend</td>
<td>380</td>
<td>±450</td>
<td>700</td>
<td>2008</td>
<td>$270m</td>
<td>$65m</td>
<td>$600m</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>Fennoskan</td>
<td>Sweden -Finland</td>
<td>196</td>
<td>194</td>
<td>AC-Commmiend</td>
<td>400</td>
<td>±500</td>
<td>800</td>
<td>2011</td>
<td>$170m</td>
<td>$150m</td>
<td>$315m</td>
<td>23</td>
</tr>
<tr>
<td>7</td>
<td>Skagerak 4</td>
<td>Denmark -Norway</td>
<td>243</td>
<td>145</td>
<td>AC-Commmiend</td>
<td>400</td>
<td>±500</td>
<td>700</td>
<td>2014</td>
<td>$180m</td>
<td>$68m</td>
<td>—</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>Nord.Link</td>
<td>Germany -Norway</td>
<td>623</td>
<td>516</td>
<td>AC-Commmiend</td>
<td>380</td>
<td>±525</td>
<td>1,400</td>
<td>2019</td>
<td>$900m</td>
<td>$500m</td>
<td>$1,500m</td>
<td>20-26</td>
</tr>
</tbody>
</table>

A typical interconnector has a capacity of around 1 GW. Constructing several interconnectors would meet 2-3% of Japan’s maximum demand or 156 GW (total of the 10 electricity companies according to FY2015 Electric Power Investigation Statistics). It is not that a significant portion of Japan’s electricity demand will be met with imported electricity.

Of course, it will make it possible for Japan to export electricity. As it stands, Japan will have no choice but to curtail output when it has surplus electricity generated by renewables due to low demand. Such interconnectors will allow Japan to transmit a maximum of 2 GW electricity abroad.
**Q6: Which countries will Japan be connected to?**

| A: | Direct transmission lines would connect Japan with neighboring Russia and South Korea. Over a longer term, Japan would be able to trade electricity with China and Mongolia via South Korea. |

Direct transmission lines would link Japan with neighboring Russia and South Korea because of their geographical proximity. It is only 43 km from Cape Soya in Hokkaido to Sakhalin Island in Russia and no more than 200 km from the Japanese city of Fukuoka to the South Korean city of Busan—a rather short distance compared with some of the existing submarine transmission lines in Europe. (The NorNed interconnector between the Netherlands and Norway covers a distance of 580 km).

A link with Russia will allow the country to send cheap renewable-generated electricity by taking advantage of wind power resources in Sakhalin Island and hydropower resources in the Amur River basin in the Russian Far East. It will also allow Japan to send electricity generated by wind power in Hokkaido to Russia as Hokkaido is suitable for wind power generation.

A link with South Korea will connect Japan with the southeastern part of South Korea (Busan or a nearby area), which is near to western Japan. In electricity trading between Japan and South Korea, it would be viable to send abundant electricity generated by solar PV in Kyushu and other parts of western Japan to South Korea. Of course, South Korea will be able to export electricity generated by its domestic renewable energy sources to Japan.

South Korea and China are now moving ahead with a bilateral interconnector project. If Japan is connected to South Korea via a transmission line, it will be able to trade electricity with China via South Korea. Because China and Mongolia are already interconnected by a transmission line, multilateral electricity trading will be possible among Japan, South Korea, China, and Mongolia as well. It will be also possible to buy Asia’s solar- or wind-generated electricity in Japan.

![Geographical relationship among Sakhalin Island, Busan, and Japan](source: Created by Renewable Energy Institute)
Q7: What parts of Japan will be connected?

A: Hokkaido or Kyushu is near to one of the partner countries (Russia and South Korea, respectively) but far from the major consumption centers in Japan (Kanto and Kansai). Several areas can be identified as candidate connection points in Japan in light of such criteria as distance and available transmission capacity (ATC) of domestic transmission lines.

Linking with areas in Japan that are near to connection points in partner countries will mean a short submarine transmission line. The shortest route will be between Cape Soya in the Japanese prefecture of Hokkaido and the Russian island of Sakhalin or the Japanese city of Fukuoka and South Korean city of Busan (or a nearby area).

Linking with Hokkaido or Kyushu, on the other hand, will mean a long distance transmission to the major power consumption centers such as Tokyo and Osaka. Electricity sent from a neighboring country will not be used up in Hokkaido or Kyushu alone.

In that sense, connection points nearer to consumption centers may lead to better use of interconnectors.

Additionally, imported electricity cannot be transmitted unless the transmission line involved has ATC, which means an additional cost of constructing a new transmission line in Japan.

For all these reasons, several candidate connection points will be considered in light of three major criteria: (i) geographical proximity to connection points in the partner countries (Russia and South Korea); (ii) geographical proximity to the major consumption centers in Japan (the Greater Tokyo Area and Kansai); and (iii) ATC of the transmission lines to the major consumption centers in Japan.

The Asia International Grid Connection Study Group Second Report, released in June 2018, has identified three candidate connection points in Japan each for Japan-Russia and Japan-South Korea interconnectors: Wakkanai (Hokkaido), Ishikari (Hokkaido), and Kashiwazaki (Niigata) for the former and Maizuru (Kyoto), Matsue (Shimane), and Imari (Saga).

Figure: Route maps of Japan-Russia and Japan-South Korea interconnectors (the white and dotted lines denote sections in Japan that are in need of transmission line reinforcement)
Source: Asia International Grid Connection Study Group Second Report
Q8: What would be the cost for Japan to interconnect?

A: A Japan-South Korea or Japan-Russia interconnector is estimated to cost 200-600 billion yen depending on the length of the route and the number of AC/DC converters. This estimation considers the costs of submarine cables and AC/DC converters as well as overhead lines and underground cables in Japan.

The Asia International Grid Connection Study Group Second Report, released in June 2018, has identified several candidate routes for an interconnection linking Japan and South Korea and one linking Japan and Russia (see Q7) and estimated construction costs for each route.

Estimated construction costs differ depending on the length of the route and the number of units that convert direct current to alternate current (AC/DC converters).

A Japan-Russia interconnector is estimated to cost 430.5 billion yen for the route that directly connects Sakhalin Island and Kashiwazaki in the Japanese mainland of Honshu with a submarine cable (1,255 km) and 573.0 billion yen for the route between these two connection points via Wakkanai and Ishikari, both in Hokkaido.

A Japan-South Korea interconnector is estimated to cost 246.5 billion yen for the route that directly connects Busan (or a nearby area) and Maizuru in Kansai with a submarine transmission line (627 km) and 212.3 billion yen for the route that connects Busan with Imari in Kyushu and then with Kansai via the Shikoku and Chugoku areas.

Roughly speaking, the estimated construction cost is 200-250 billion yen for a Japan-South Korea interconnector and 400-600 billion yen for a Japan-Russia interconnector.

The cost of submarine cable construction and the unit price of AC/DC converters (1GW) are estimated based on existing cases in Europe: 0.3 billion yen/km and 15.7 billion yen/unit, respectively.

Meanwhile, the per-kilometer cost of constructing a new onshore transmission line in Japan is estimated by using the results of research and surveys in Japan for reference. The estimated cost is 664 million yen/km for an overhead line and 915 million yen/km for an underground cable—a higher cost than the cost of a submarine cable in Europe. The unit cost of an overhead line or an underground cable in Japan is more than twice that in Europe and North America. This suggests factors peculiar to Japan are at work.

The estimation based on these unit costs shows that the longer the section in need of new transmission line is, the higher the construction cost will be. (Among such sections is a transit section in Hokkaido in a Japan-Russia interconnector).

* The estimation is based on the following specifications of submarine cables: DC ±500 kV; a transmission capacity of 2 GW, 3 cables per route (bipole/one circuit, metallic return method).
### Table 1: Construction cost for Japan-Russia interconnector

Source: Asia International Grid Connection Study Group Second Report

<table>
<thead>
<tr>
<th>Routes</th>
<th>Specifications</th>
<th>AC/DC converter</th>
<th>Interconnector</th>
<th>Domestic lines</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1: Sakhalin-Kashiwazaki</td>
<td>Submarine cables</td>
<td>4 units</td>
<td>JPY 430.5 bn.</td>
<td>-</td>
<td>JPY 430.5 bn.</td>
</tr>
<tr>
<td>R2: Sakhalin-Ishikari-Kashiwazaki</td>
<td>Submarine cables</td>
<td>6 units</td>
<td>JPY 196.1 bn.</td>
<td>JPY 265.8 bn.</td>
<td>JPY 461.9 bn.</td>
</tr>
<tr>
<td>R3: Sakhalin-Wakkanai-Ishikari-Kashiwazaki</td>
<td>Onshore; Overhead lines</td>
<td>6 units</td>
<td>JPY 110.0 bn.</td>
<td>JPY 483.0 bn.</td>
<td>JPY 573.0 bn.</td>
</tr>
<tr>
<td>R4: Sakhalin-Ishikari-Tomakomai-Fukushima</td>
<td>Onshore; Underground cables</td>
<td>6 units</td>
<td>JPY 196.1 bn.</td>
<td>JPY 330.3 bn.</td>
<td>JPY 526.4 bn.</td>
</tr>
</tbody>
</table>

### Table 2: Construction cost for Japan-South Korea interconnector

Source: Asia International Grid Connection Study Group Second Report

<table>
<thead>
<tr>
<th>Routes</th>
<th>Specifications</th>
<th>AC/DC converter</th>
<th>Interconnector</th>
<th>Domestic lines</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1: Busan-Malzuru</td>
<td>Submarine cables</td>
<td>4 units</td>
<td>JPY 246.5 bn.</td>
<td>-</td>
<td>JPY 246.5 bn.</td>
</tr>
<tr>
<td>K2: Busan-Matsue-Hino</td>
<td>Matsue-Hino to be reinforced</td>
<td>4 units</td>
<td>JPY 171.8 bn.</td>
<td>30.6 bn. JPY</td>
<td>JPY 202.4 bn.</td>
</tr>
<tr>
<td>K3: Busan-Imari/Ohta-Ikata</td>
<td>Submarine cables</td>
<td>8 units</td>
<td>JPY 129.0 bn.</td>
<td>83.3 bn. JPY</td>
<td>JPY 212.3 bn.</td>
</tr>
</tbody>
</table>
Q9: Who will undertake interconnector projects?

A: Various operators in Japan could undertake interconnector projects depending on the systems and business models applicable. In China, South Korea, and Russia, all of which are potential interconnector partners, state-run transmission system operators are implementing interconnector projects.

A look at interconnector projects around the world shows that they are operated in various forms. Some of them are operated by transmission system operators in partner countries. Others are operated by companies that have been established by power companies that own power plants or investment companies specifically for this purpose.

Most countries regulate transmission business. Who operates such business is determined by the regulatory framework of each country. In Japan, electricity transmission business, including both general and specified transmission and distribution businesses, require a license to operate. Yet Japan has no business license specifically for international transmission business. The future institutional development, which will determine what kind of license is needed for international transmission business, will dictate the requirements of operators.

A feasibility study on a Japan-Russia Power Bridge Project in the late 1990s, an aborted project that would have connected Sakhalin Island and Japan with a submarine transmission line, was studied by a Japanese general trading company and Russia’s now-defunct state-run power company.

In South Korea, Russia, and China, all of which are potential interconnector partners for Japan, state-run transmission system operators are implementing a number of interconnection projects. In March 2016, companies in four countries including Japan concluded a memorandum of understanding on research and planning for the promotion of an international grid connection. They were the State Grid Corporation of China, the Korea Electric Power Corporation, Rosseti (Russia’s state-owned transmission company), and the SoftBank Group of Japan.
Q10: Isn’t overdependence on electricity supply from abroad problematic?

A: Electricity is traded even between countries that are at odds over diplomatic issues. Risks can be dispersed by, for example, connecting with several countries with a limited scale of interconnections so as not to depend too much on a single country.

Overdependence on a single country for Japan’s energy demand entails energy security risks. In fact, efforts are being made in international electricity trading to disperse such risks, including controlling the scale of transmission line and connecting with several countries.

Studies on interconnectors between Japan and neighboring countries have primarily considered a transmission capacity of around 2GW. A capacity of 2 GW, accounting for a few percent of Japan’s overall electricity demand, will not lead to overdependence on other countries.

Skeptics often cite a crisis involving gas supply from Russia to Ukraine, which depended on Russia for 93% of its annual gas imports in 2013. This is a case not applicable to Japan.

Interconnection with neighboring countries will lead to the diversification of energy supply routes for Japan, a country nearly 100% dependent on imports to meet its demand for fossil fuel for its thermal power plants.

A look at the world shows that electricity has been traded without much problems, even between countries involved in a diplomatic row. After the two world wars, Europe deepened its interdependence on interconnection of electricity and other energy sources. Such interdependence is now considered a foundation for peaceful and stable relations among European countries.

Interconnectors could be suspended in times of accident or disaster. Mitigating such risks will require signing an agreement between countries or companies on how to address the technical aspect of the suspension and compensate for damages.