Asia International Grid Connection Study Group

Third Report Summary

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

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

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Section 1: International grid initiatives in Northeast Asia

1) Renewable energy growth and the need for interconnectors

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

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

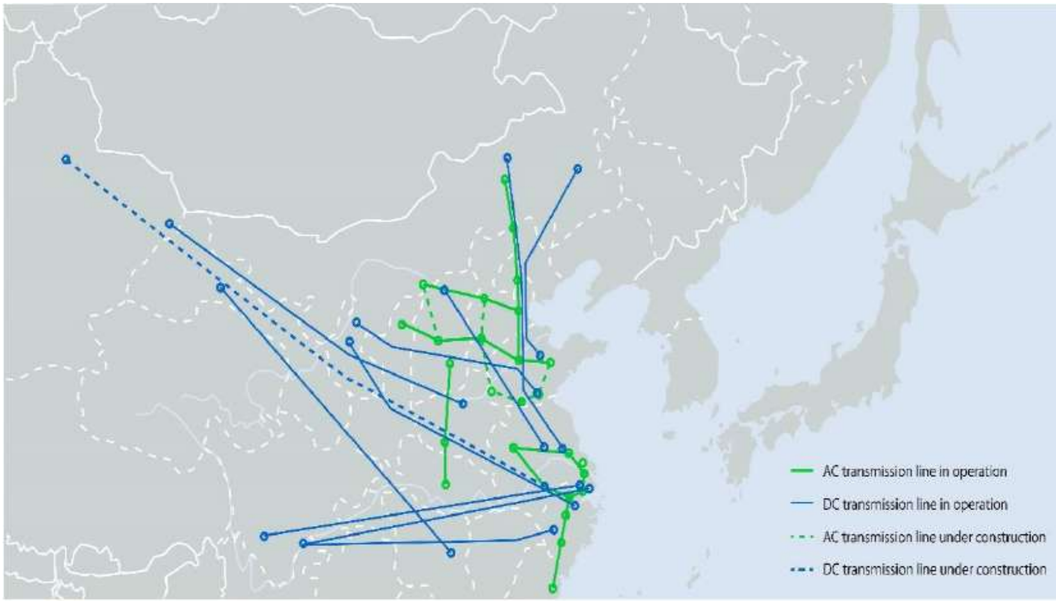
China: Installed capacity for renewable energy in China at the end of 2018 increased 12% year-on-year to 729 GW, accounting for roughly 38.4% of the total. Its total electricity generation increased 169 TWh to 1,867 TWh, or 26.7% of the total. The key 2020 targets for renewable energy deployment set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

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

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

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

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



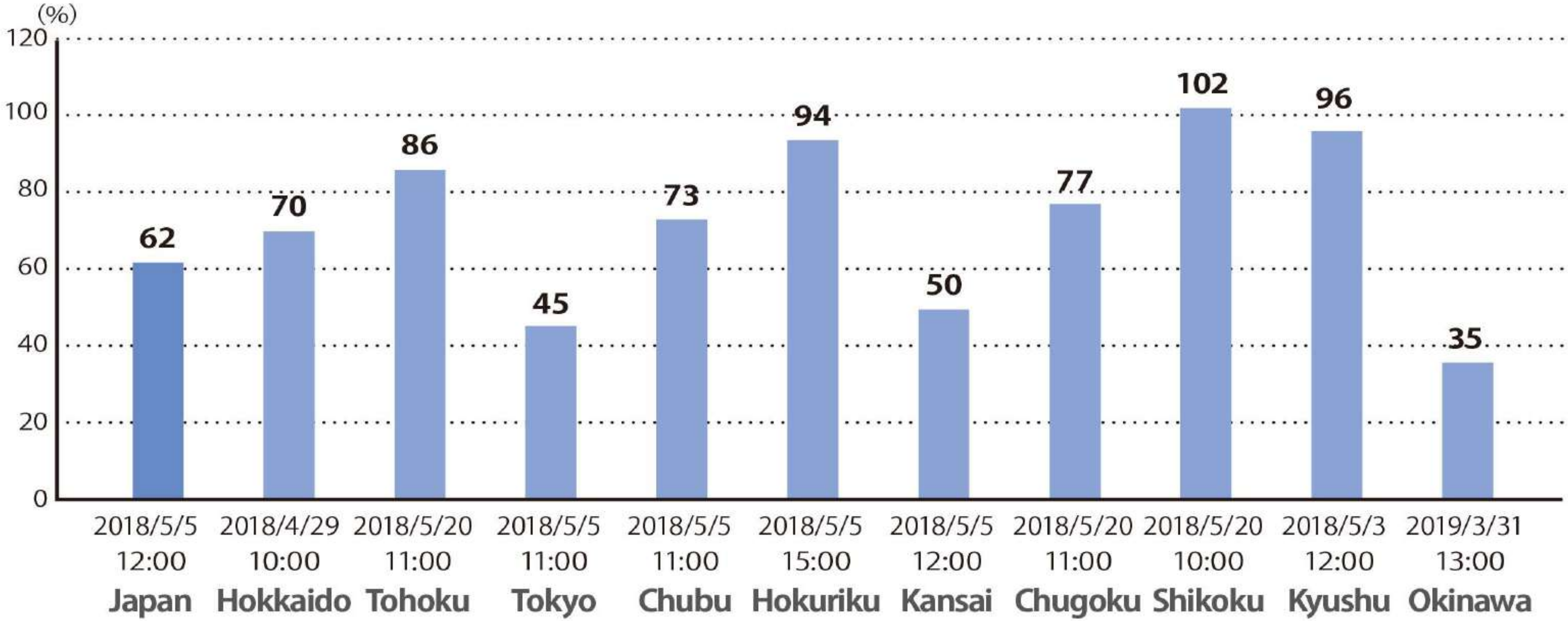
Source: Partially adapted by Renewable Energy Institute from SGCC (2019)

Section 1: International grid initiatives in Northeast Asia

1) Renewable energy growth and the need for interconnectors

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

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



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

Section 1: International grid initiatives in Northeast Asia

2) Changing political situation of Korean Peninsula and specific discussion of interconnectors

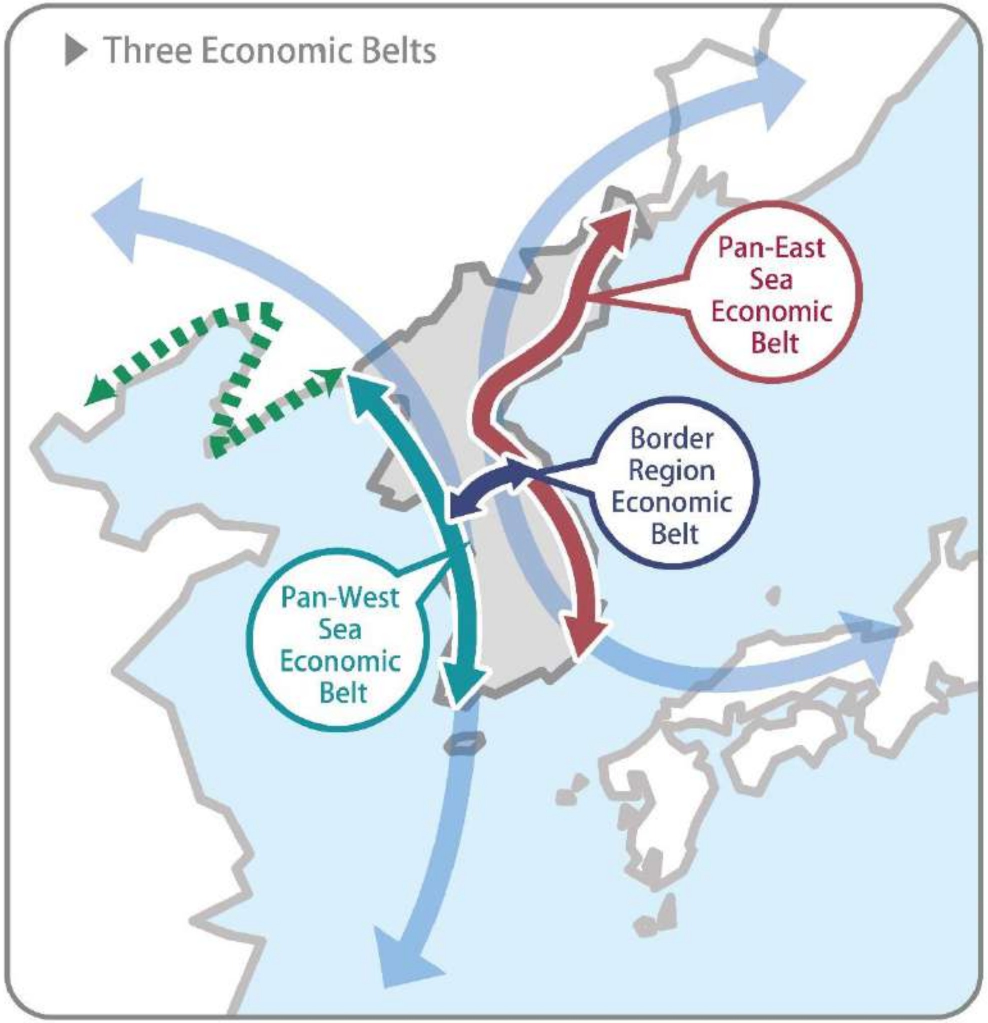
With the political situation on the Korean Peninsula improving, there have been multiple summits between the leaders of the Democratic People's Republic of Korea (North Korea) and South Korea, and the two countries have agreed to cooperate economically.

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

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

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

Figure 3: Moon Administration plan



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

Section 1: International grid initiatives in Northeast Asia

3) Progress on Japan-China-South Korea international connection project

A joint project study on a China-South Korea interconnector began in December 2017, and research is currently being conducted, including consideration of project plan proposals, verification of technical feasibility, and assessment of costs and benefits. A study published by GEIDCO on a Japan-China-South Korea route assumes transmission capacity of 2 GW, DC transmission of 500 kV and annual electric energy transmission of 10 TWh or more. The analysis concluded that the project will be economically feasible when transmission costs are approximately $0.038-0.066 / kWh and a mix of wind power (60%) and thermal power are transmitted from China to Japan.

Figure 4: Sketch of the China-Korea-Japan interconnection project

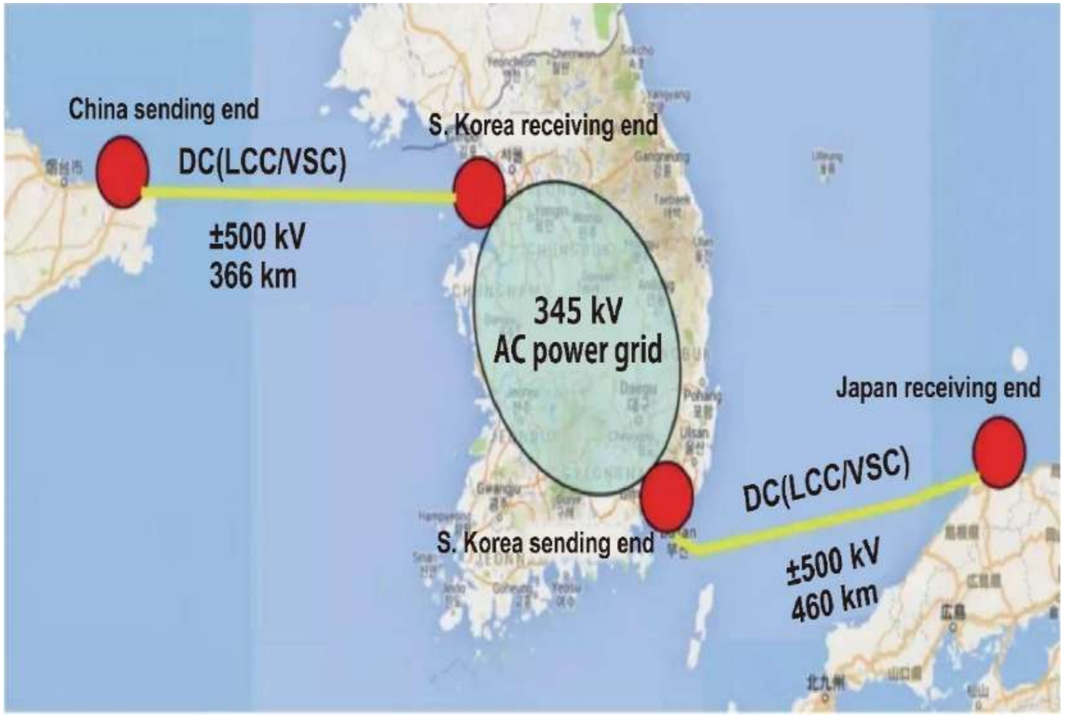


Table 2: Transmission cost for Japan-China-South Korea interconnector

Annual electricity transported (TWh)	Usage time (h)	Transmission cost (USD/kWh)		
		Plan (1)	Plan (2)	Plan (3)
10.5	5,200	0.0534	0.0662	0.0626
12.3	6,100	0.0469	0.0579	0.0548
14.0	7,000	0.0421	0.0517	0.0490
15.8	7,800	0.0383	0.0468	0.0444

Source: Renewable Energy Institute based on Yu, et al. (2018), Table 7

Section 2: Power system reform in Japan

On the matter of unbundling, TEPCO has already been legally separated as of April 2016 and its transmission division spun off as TEPCO Power Grid. The other major power utilities are steadily preparing to do the same by 2020, setting up companies to prepare for the split and taking other measures.

1) Progress in electricity markets

Three years have passed since liberalization of the retail electricity market, and PPS (Power Producer and Supplier) accounts for approximately 15% of electricity market supply (as of March 2019), with over 580 PPS registered. At the same time, various markets are being planned and established, and their integration should take place to build a flexible, efficient power system.

Base load market: The first auction of the market is being held in July 2019. In Japan, "base load power source" primarily refers to nuclear power, coal-fired power, and hydropower, and most of this is either owned by a major power utility or under a long-term contract. Most of these base load sources were built using the fully distributed cost method, so market prices are currently low, but because they are operated as "base load," they potentially lack flexibility in terms of grid operations.

Capacity market: A capacity market is also planned for 2020. With the liberalization of retail power and increased deployment of renewable energy, wholesale electricity market transactions will increase and market prices decrease, so there are concerns that investment in power sources will become harder to predict. The electricity itself will be traded on the normal wholesale electricity market, but this system will allow power capacity (kW) that will be procured in the future to be bought and sold in advance. In general, all power sources will be subject to the system, and there are concerns that it will be a rescue measure for existing large-scale power plants.

Non-fossil fuel energy value trading market: On the non-fossil fuel energy value trading market that began in May 2018, non-fossil fuel energy certificates for FiT (feed-in tariff) renewables were traded, but the current market is very sluggish. In 2020, there are plans to expand the scope to include large-scale hydropower, nuclear power and non-FiT renewables and begin issuing non-FiT non-fossil fuel energy certificates.

Section 2: Power system reform in Japan

2) Enhancing cross-regional transmission operations and interconnectors

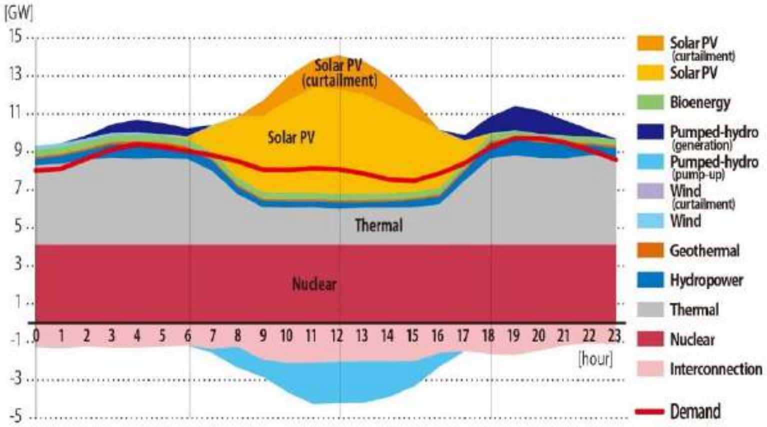
- **Operation of cross-regional transmission lines:** Operation changed in October 2018 from the previous first-come-first-served rule to implicit auction. All cross-regional transmission lines are allocated by the spot market of the Japan Electric Power Exchange (JEPX), and cross-regional transmission lines can now be used according to merit order beginning with the provider with the lowest costs, which has had the effect of increasing spot contract volume.
- **Enhancement of cross-regional transmission lines :** A proposal to distribute enhancement costs nationally, in principle, is being considered. Regarding enhancements related to the benefits of renewable energy in particular, cost-sharing through FiT surcharges will be considered. Having costs borne nationally would be desirable in itself, but the right way to collect contributions would be by allocation of profits from wheeling charges and other standard transmission operations. It is essential that the process be transparent, including assessments of the validity of benefits brought about by enhancements.
- A large-scale power outage occurred across the entire Hokkaido area due to the Hokkaido Eastern Iburi Earthquake that occurred on September 6, 2018. This led to a proposal being made to further enhance Hokkaido-Honshu HVDC Link. It can be assumed that national cost-sharing rules for cross-regional transmission lines enhancement would also apply to the proposed route for enhancements of Hokkaido-Honshu HVDC Link. Strengthening of cross-regional transmission lines are needed to install interconnectors with other countries, and the proposed Japan-Russia interconnector through Hokkaido would no doubt contribute to increasing the stability of Hokkaido's power supply.

3) Operating policy for integrating renewable energy into the grid

The Japanese version of "Connect and Manage" : It started to be applied for renewable energy with the goal of full-fledged deployment by 2022. Utilizing Japanese version of Connect and Manage though allows the connection to be made before the work is completed. However, with regard to grid management, it assumes balancing capacity of power flows would involve curtailing the generating facilities to be connected to the grid in the future, rather than curtailing from facilities that are already connected. As a result, this approach risks limiting the grid's balancing capacity or imposing excessive curtailment exclusively on newly connecting facilities. Furthermore, any future mechanism designed with interconnectors in mind should avoid treating existing and new generating facilities differently, and should instead enable electricity to be used efficiently in each time slot.

Curtailment of renewable energy: In the Kyushu area, where nuclear power is being put back into operation, solar PV and wind power, priority dispatch order is even lower than that of nuclear. The curtailment of electricity from VREs comes first than nuclear power output adjustment. Major power utilities in other regions are also expected to follow the trend. In addition, as already proposed in the Study Group's Second Report, if there is an interconnector through Kyushu, it would greatly contribute to reducing the curtailment.

Figure 6: Supply and demand balance in the Kyushu Electric Power area(24 March 2019)



Source: Renewable Energy Institute based on data released by Kyushu Electric Power

Chapter 2: International grid initiatives in the UK and Spain

Section 1:
Basic information on electricity in the UK and Spain

Both countries lack favorable conditions for international grid connections

- UK: As an island nation, has not historically depended on international grid connections; limited utilization until recent years.
- Spain: Located on the Iberian Peninsula, the westernmost part of Europe; has limited International Grid Connection with France for connecting it with the enormous continental European market.

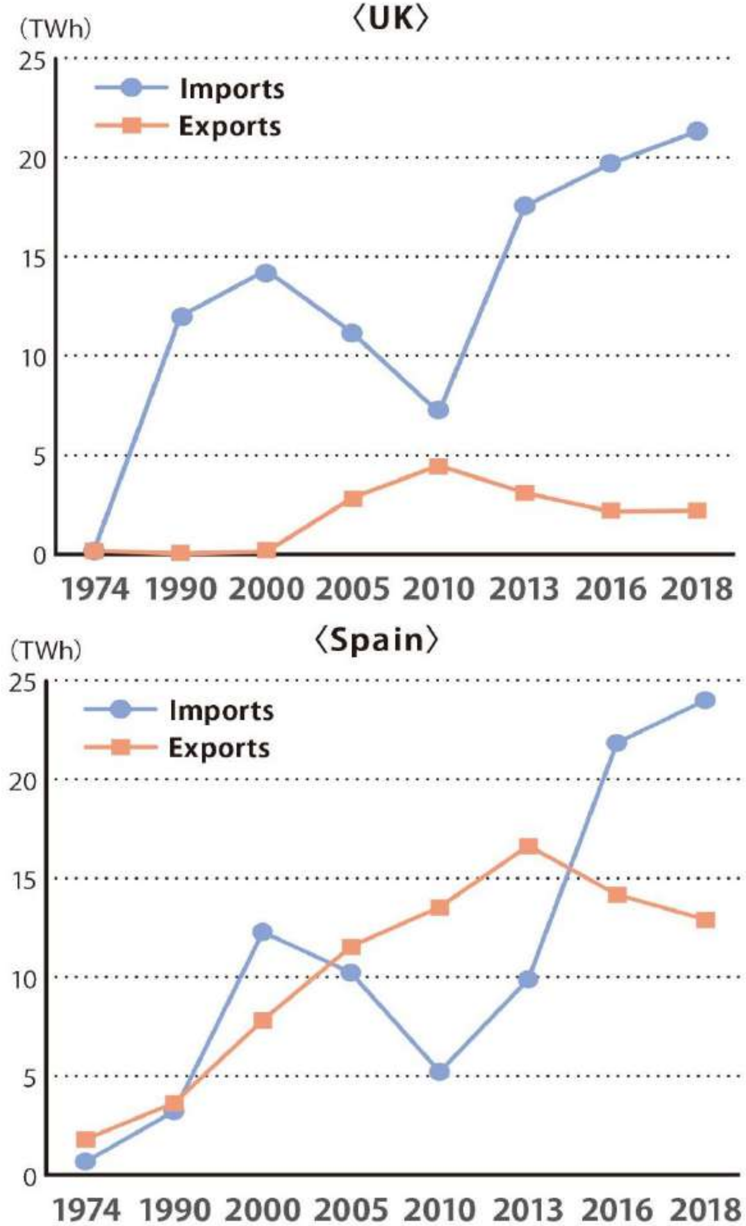
Both countries deploy renewable energy on a large scale (Table 3; p.11)
Power mix in 2018

- UK: Wind 17.9%, Biomass10.7%, Solar PV4.0%
- Spain: Wind 18.8%, Hydropower13.7%, Solar PV/CSP4.6%

Advanced countries in power system reform

- Completed ownership separation at an early date, and transmission system operators (TSOs) are independent of power producers (UK: National Grid in 1990; Spain: REE in 1985). No actions are taken to hinder competition for grid connection.
- Electricity imported/exported continues to increase (Figure 7). In the UK, imports far exceed exports partly because wholesale electricity prices are high.

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



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

Section 1: Basic information on electricity in the UK and Spain

Table 3: Basic electricity information in the UK and Spain (2018)

(TWh)	UK	Spain
Total electricity generation	319.7	263.3
Hydropower	7.9 (2.5%)	36.1 (13.7%)
Wind	57.1 (17.9%)	49.6 (18.8%)
Solar PV*	12.9 (4.0%)	12.2 (4.6%)
Biomass	34.1 (10.7%)	5.9 (2.3%)
Nuclear	59.1 (18.5%)	53.2 (20.2%)
Coal	16.8 (5.3%)	37.4 (14.2%)
Gas	125.8 (39.4%)	54.3 (20.6%)
Installed capacity	104GW (2017) Wind 22GW, Solar 13GW	104GW Wind 23GW, Solar*7GW
Imports	Total 21.3 France 13.3, Netherlands 6.4, Ireland 1.7	Total 24 France 15.5, Portugal 8.3
Exports	Total 2.2 Ireland 1.6, France 0.4	Total 12.9 Portugal 5.7, Morocco 3.6, France 3.5

Note*: Solar in Spain includes solar PV and CSP.
Source: Renewable Energy Institute based on IEA (2019b), BEIS (2018), BEIS (2019), REE (2019b)

Section 2: UK’s development of offshore wind power and enhancement of interconnectors

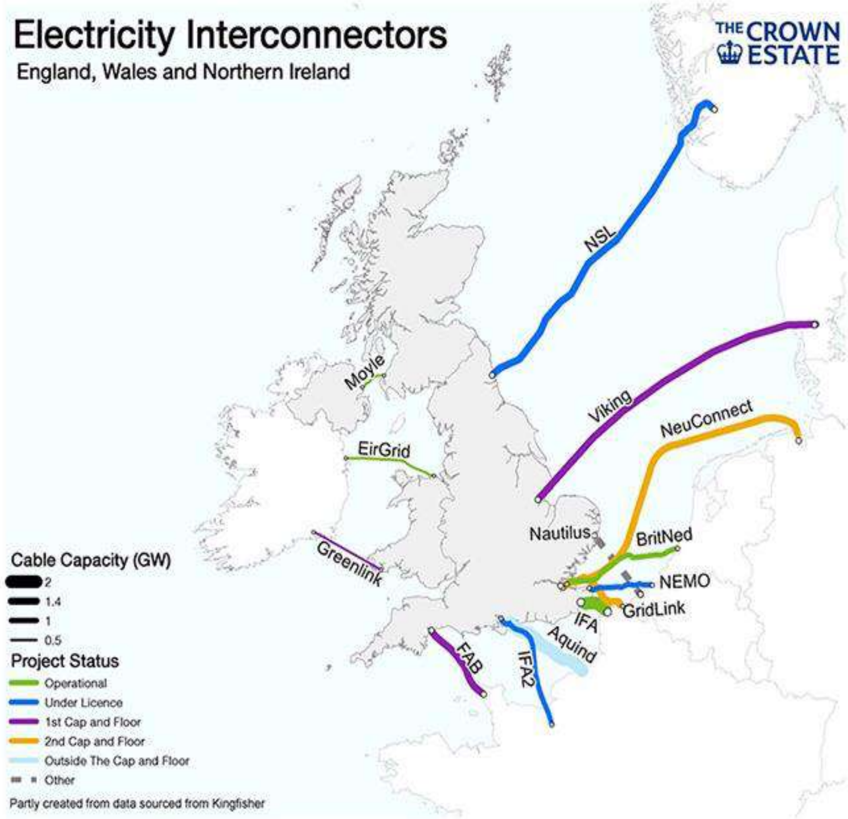
1) Development of offshore wind power

- Has deployed 8.2 GW, the most in the world (as of 2018).
- Has active support policies, including Crown Estate designating waters for development, and establishment of a legal framework for facility construction.
- As an example, a competitive bidding system was introduced in 2009 for offshore transmission lines. Submarine transmission lines are owned by financial institutions, etc., and power producers do not worry about grid connection because the grid is operated from a neutral standpoint by National Grid.
- Promoting a policy of phasing out coal-fired power by 2025 and has significantly reduced coal in recent years. Participates in the Powering Past Coal Alliance.
- Also establishing and enhancing nuclear power plants, but some projects are at a standstill.
- Impact of Brexit is difficult to predict.

2) Interconnector enhancement in recent years and “cap and floor”

- Submarine transmission lines were expensive, so for a long period of time, there was only the IFA connector with France, which was built in 1961.
- A series of new interconnectors built in recent years, bringing capacity to 4 GW as of 2018. Plans to increase capacity by three times over the next several years (Figure 8).
- The cost of submarine transmission cable has decreased, and the country also judged that compared to power plants and other facilities interconnectors are the only investment that fulfill all of the 3E’s(*).
- Regarding recovery of power grid investment, a cap and floor scheme was instituted (2014) that allowed the country to successfully balance reliability and cost reduction.

Figure 8: Map of electricity interconnectors in the UK



Source: Extracted from the Crown Estate (2018)

Cap and floor

If interconnector project revenue
- Exceeds a preset upper limit (cap),
  → The excess amount is returned to consumers
- Is less than the lower limit (floor),
  → Revenue is supplemented, with consumers bearing the cost
- Semi-regulated charge system

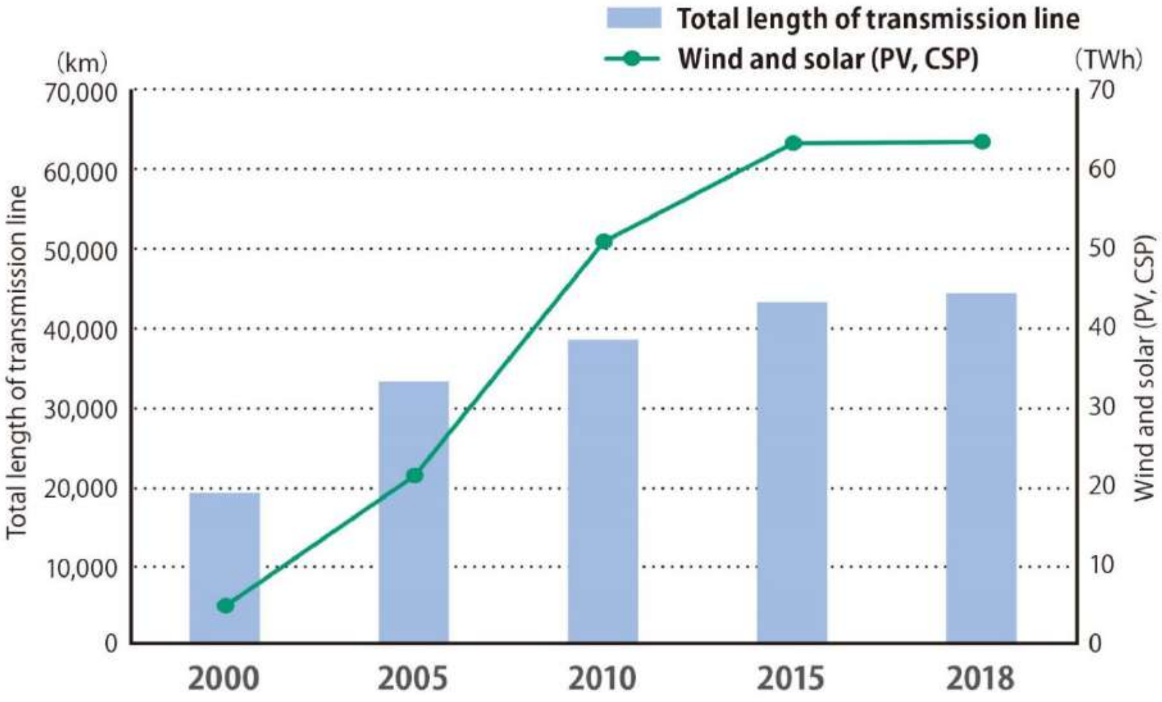
(*) 3E: The three E’s of energy policy are energy security, economic efficiency and environment.

Section 3: Spain's progressive grid operations and international grid connections

1) Deployment of renewable energy and REE grid operations

- FiT led to large-scale deployment of renewable energy in the 2000s, but from around 2010, it stagnated and FiT was retroactively suspended.
- Regarding expansion of variable renewable energy, the grid operator REE has actively taken measures to build a power system friendly to renewable energy through enhancement to its domestic power grid (Figure 9) and establishment of the Control Centre of Renewable Energies (CECRE), a new load dispatching department, based on advanced weather prediction.
- Wind power providers also conduct curtailment by centralized remote operation. The curtailment ratio since 2013 has been generally less than 1%.
- The Ministry for the Ecological Transition was established when the new administration took power in June 2018, and the country has renewed its proactive stance to the energy transition. It has set a goal of 100% renewable energy by 2050.

Figure 9: Spain's Grid Enhancements and Wind/Solar (PV, CSP) Electricity Generated



Source: Renewable Energy Institute based on REE (2001, 2006, 2011), REE (2016), REE (2019b), BP (2019)

CECRE Functions

- All power generating facilities over 10 MW must be directly controlled by CECRE.
- CECRE analyzes in real time power output and grid information every 20 minutes.
- Control signals to renewable energy facilities and if necessary.
- Regarding the output prediction system as well, predictions are made in one-hour intervals for the upcoming 48 hours and prediction values are updated every 15 minutes.
- The prediction margin of error is low, within the range of 2-3% (rated output basis)
- Instructions for wind power output are prepared sequentially to address output shortages and surpluses.

Section 3: Spain's progressive grid operations and international grid connections

2) Present and future of Spain's international grid connections (Figure 10)

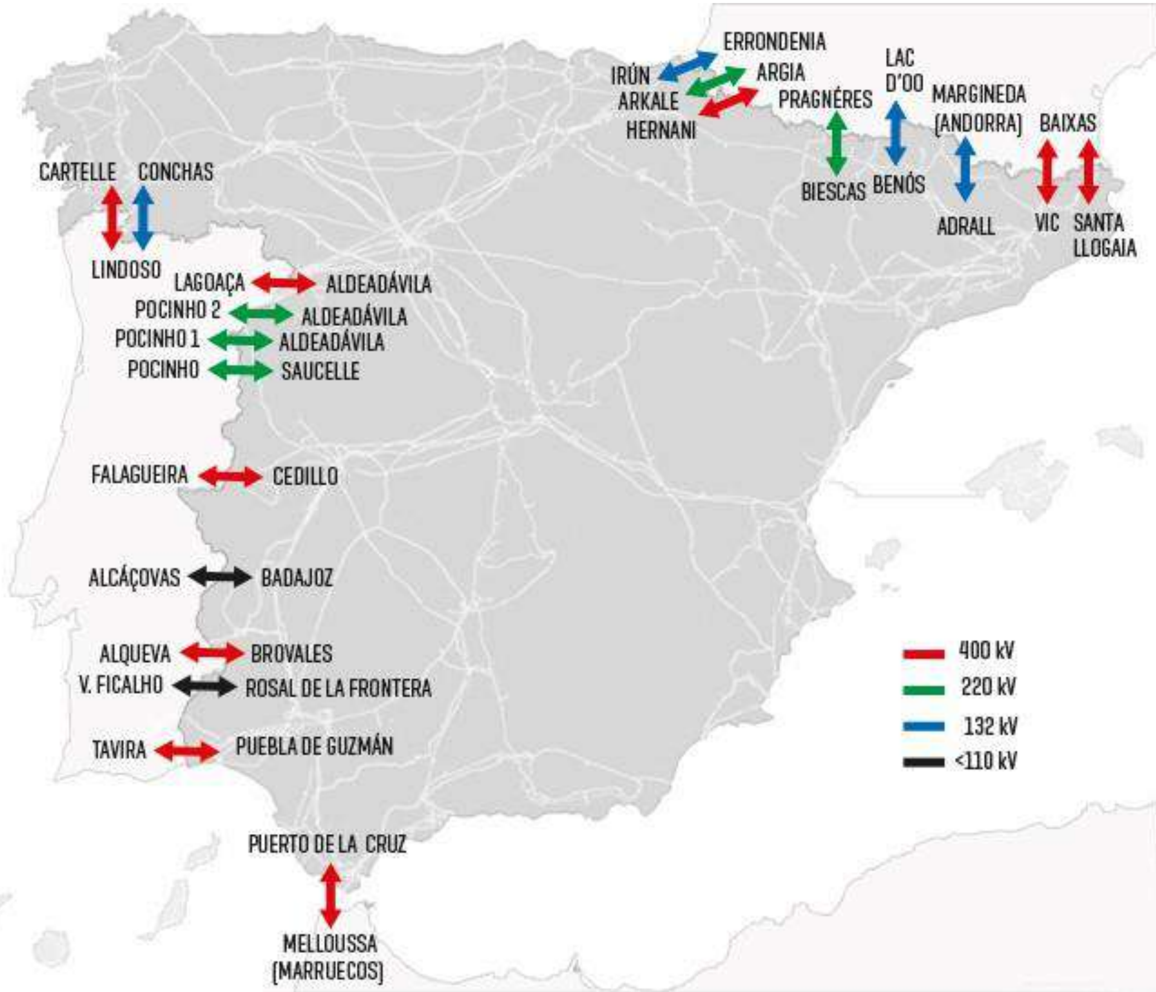
- European Commission target: Requires EU members to establish interconnectors at 10% of domestic installed capacity by 2020 and 15% by 2030

  → Spain is currently less than 5%, so there is significant potential for future expansion.

[Summary]

- With Portugal: 3.4 GW in export direction, 2.3 GW in import direction, so sufficient transmission capacity; markets and operations integrated.
- With Morocco: 0.9 GW in export direction, 0.6 GW in import direction; agreed in February 2019 on additional 0.7 GW enhancement.
- With France: 2.8 GW in export direction, 3.4 GW in import direction. Necessary to enhance connections with continental Europe going forward, but a route through the Pyrenees would be difficult for reasons of environmental protections. Submarine transmission lines (1 GW, 2 lines) are planned through the Bay of Biscay.

Figure 10: Map of current international electricity interconnections on the Iberian Peninsula



Source: Extracted from REE (n.d.)

Section 1: Approaches to the benefits of international grid connections

1) Characteristics of benefit analysis for international grid connections

- Differences in how benefits are set in cost-benefit analysis between domestic interconnectors and International Grid Connection (interconnectors):
  [Domestic interconnectors] Debate centers on increasing economic performance (increasing social welfare)
  [International Grid Connection (interconnectors)] Broad range of items are set, not just economic performance.
  - Economic benefits increase for connected regions and the country overall, but the benefits and drawbacks differ depending on the region and country, so multiple benefit items are set and discussions are comprehensive.
  - Cost-benefit analysis is utilized to discuss general future prospects, such as what situation would be most deficit for the overall region subject to the analysis from a medium/long-term perspective (after 2030, for example).

2) Prior cost-benefit analyses

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

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

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

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

Section 2: How interconnectors generate benefits

1) Viewing a phenomenon flow chart

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

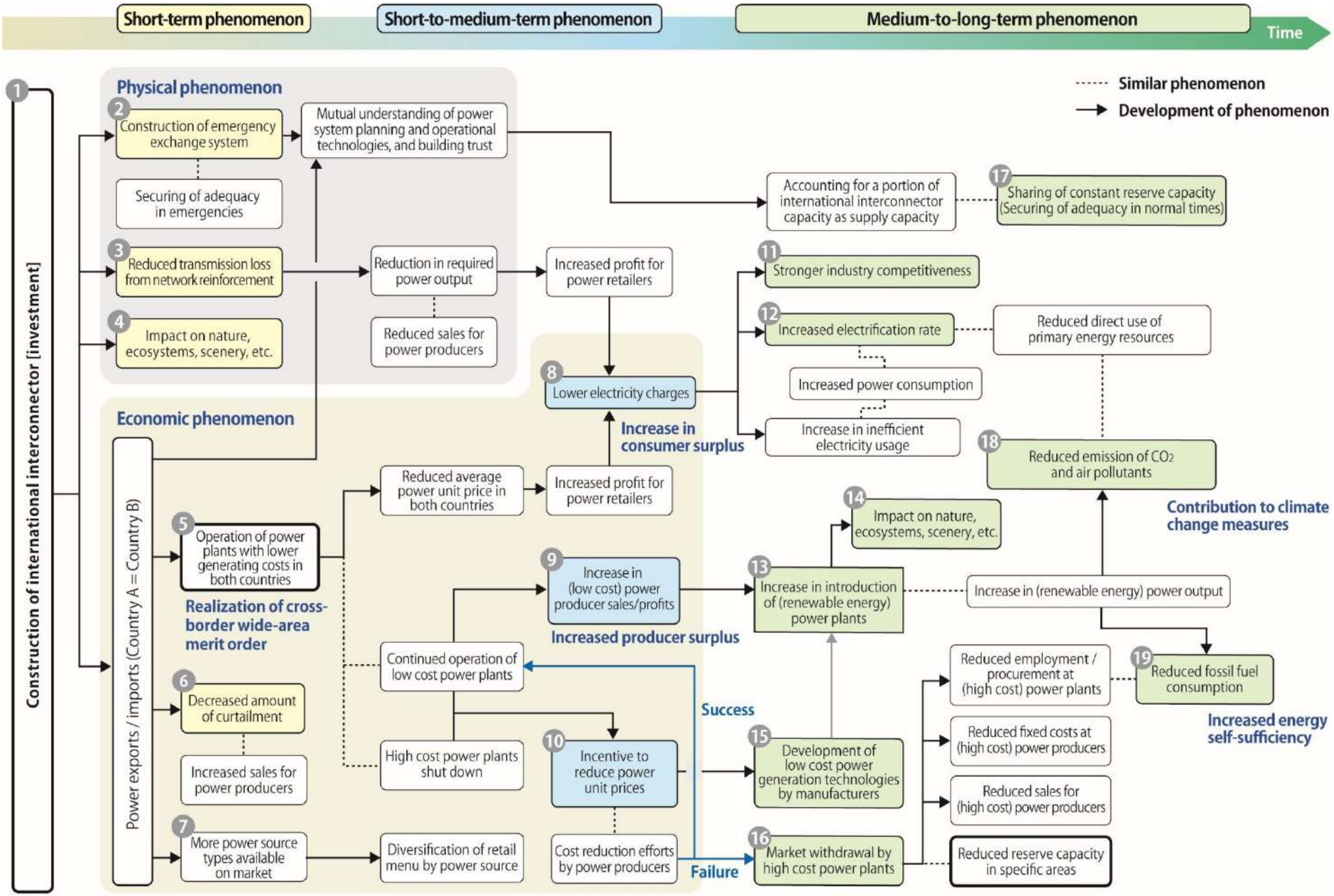
2) Economic phenomena

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

3) Physical and other phenomena

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

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



Source: Renewable Energy Institute.

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

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

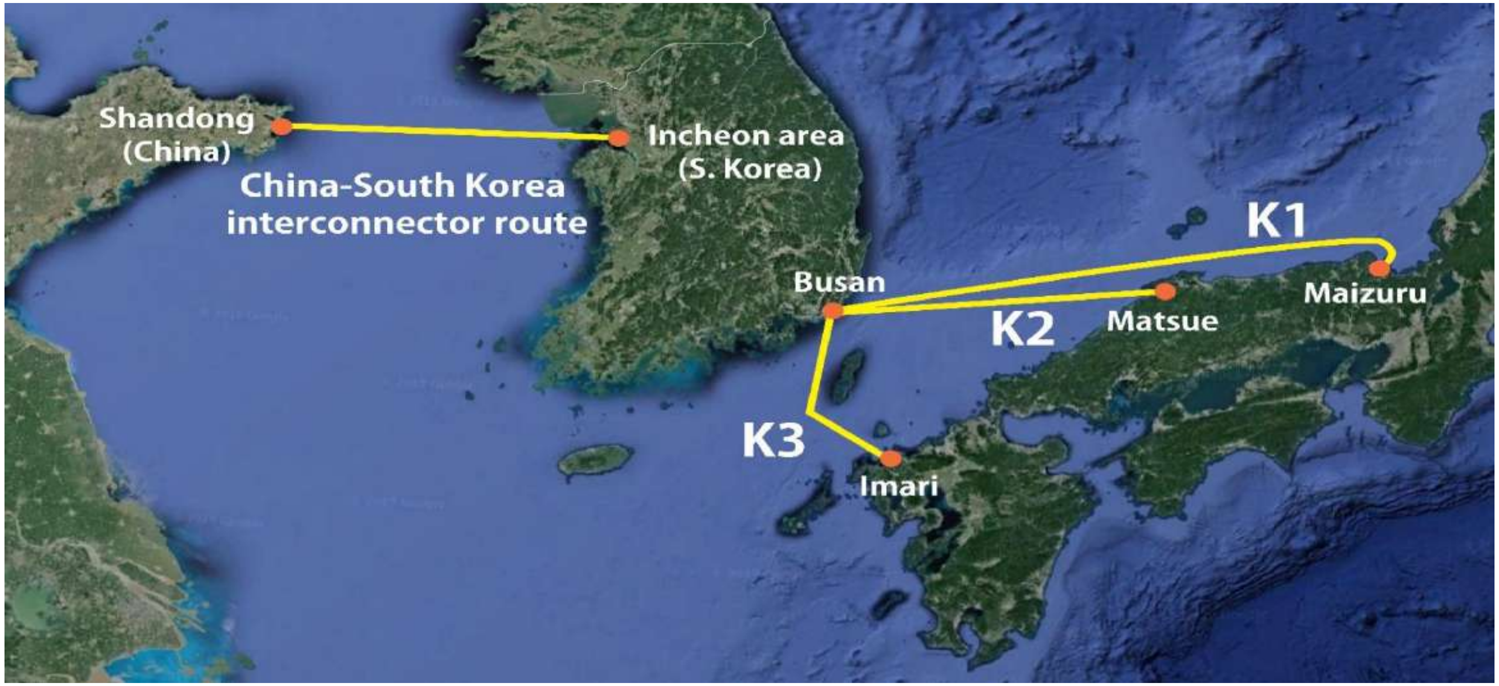
Source: Renewable Energy Institute based on ENTSO-E (2018), Ofgem (2017), ACE, et al. (2018)

Section 3: Analysis of the benefits of a Japan-South Korea interconnector

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

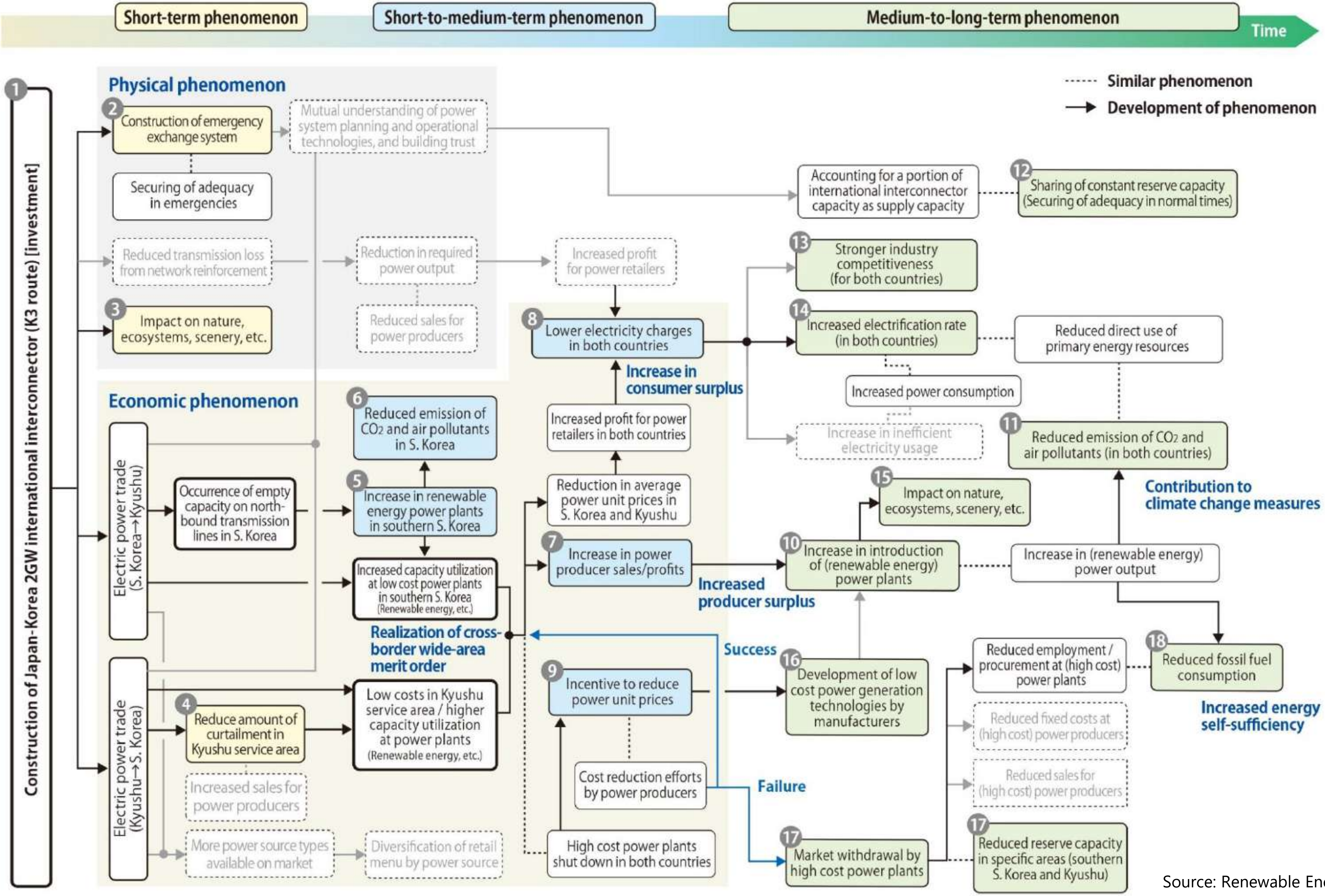
- Of the four Japan-Russia interconnector routes and three Japan-South Korea routes considered in the Second Report, one route (K3 route) was selected for the sake of expedience, and the specific benefits assumed to result from the interconnector were considered.
- However, this does not mean that Japan-South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

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



Source: Renewable Energy Institute.

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



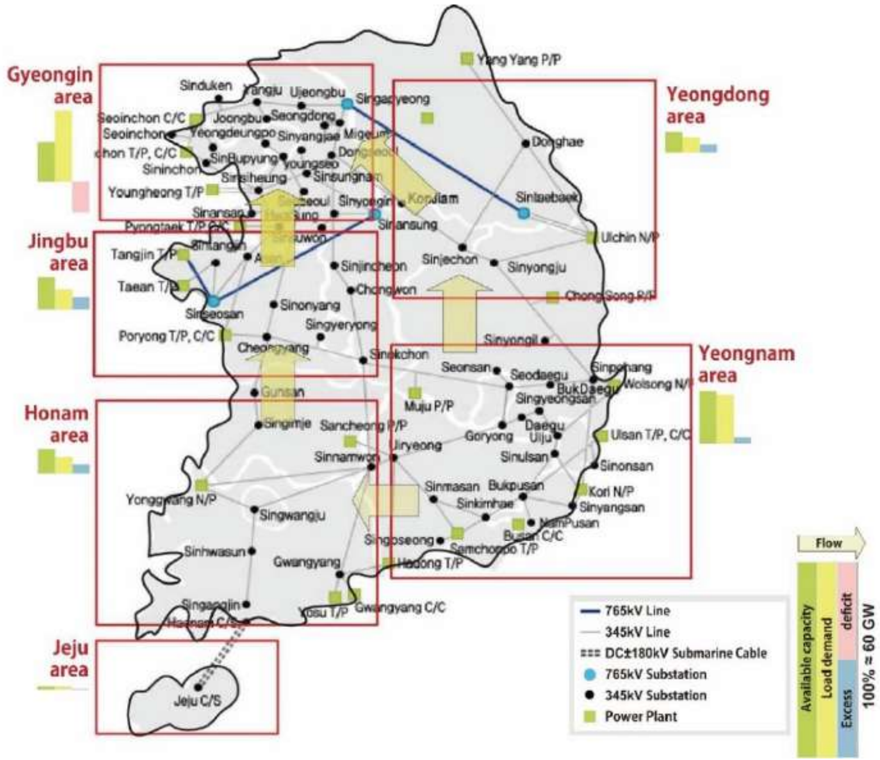
Source: Renewable Energy Institute.

Section 3: Analysis of the benefits of a Japan-South Korea interconnector

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

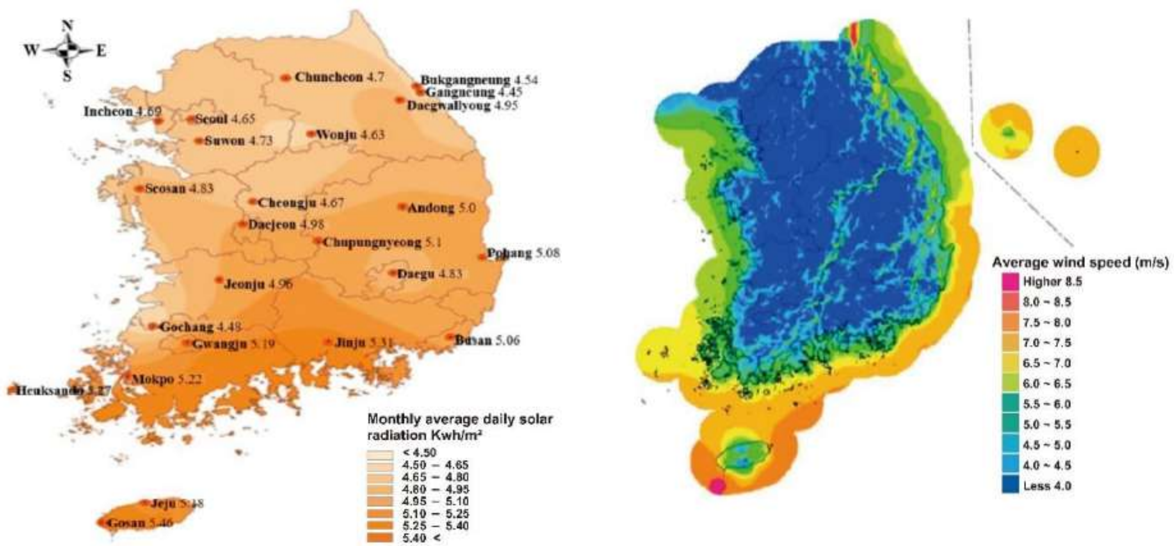
- It was suggested that when electricity flows from South Korea to Japan, there is the potential for expansion of renewable energy in South Korea domestically.
- This is related to electricity flows within South Korea. Within the country, electricity mainly flows from the southern region, where there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

Figure 14: Electric power flows in South Korea



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

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



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

Section 3: Analysis of the benefits of a Japan-South Korea interconnector

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

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

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

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

Figure 16: Accident scenarios

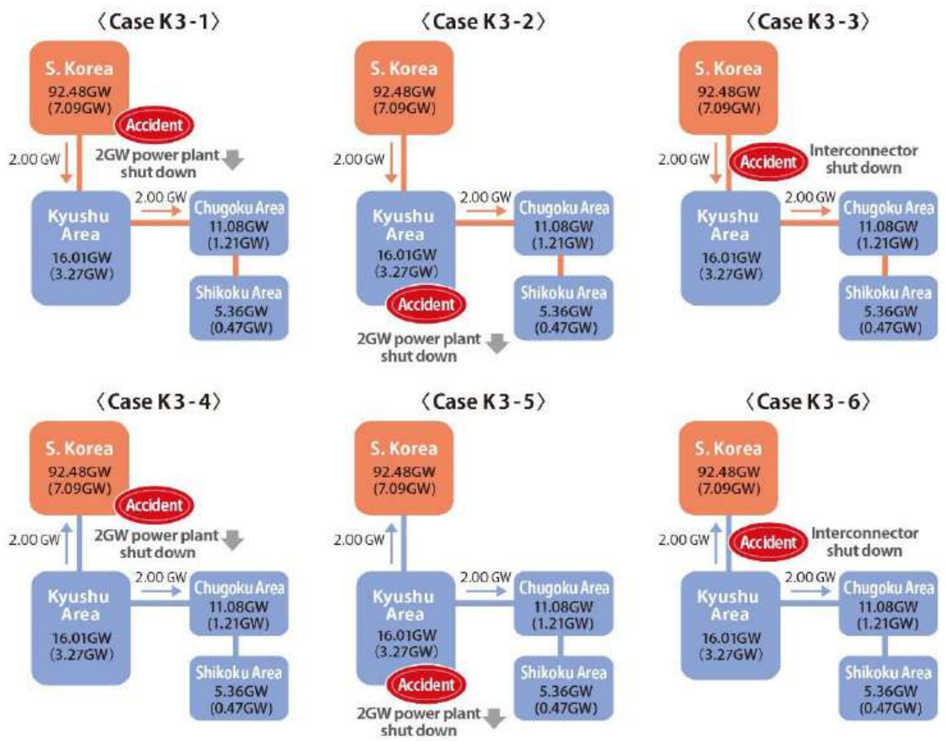


Table 6: Consideration of responses to accidents occurring related to

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

Source: Renewable Energy Institute.

Section 3: Analysis of the benefits of a Japan-South Korea interconnector

5) Summary

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

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

Results of discussions on the K3 route

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

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

1) Organizing phenomena with benefit incidence table

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

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

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

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

Source: Renewable Energy Institute.

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

2) Summary

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

Column: International gird connections and the environmental value of electricity

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RENEWABLE ENERGY INSTITUTE

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

1) **National emission calculations**

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

[Specific Example]

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

2) **Corporate emission calculations**

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

[Summary]

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

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

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

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

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

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

2) Fossil fuel security and the oil crisis

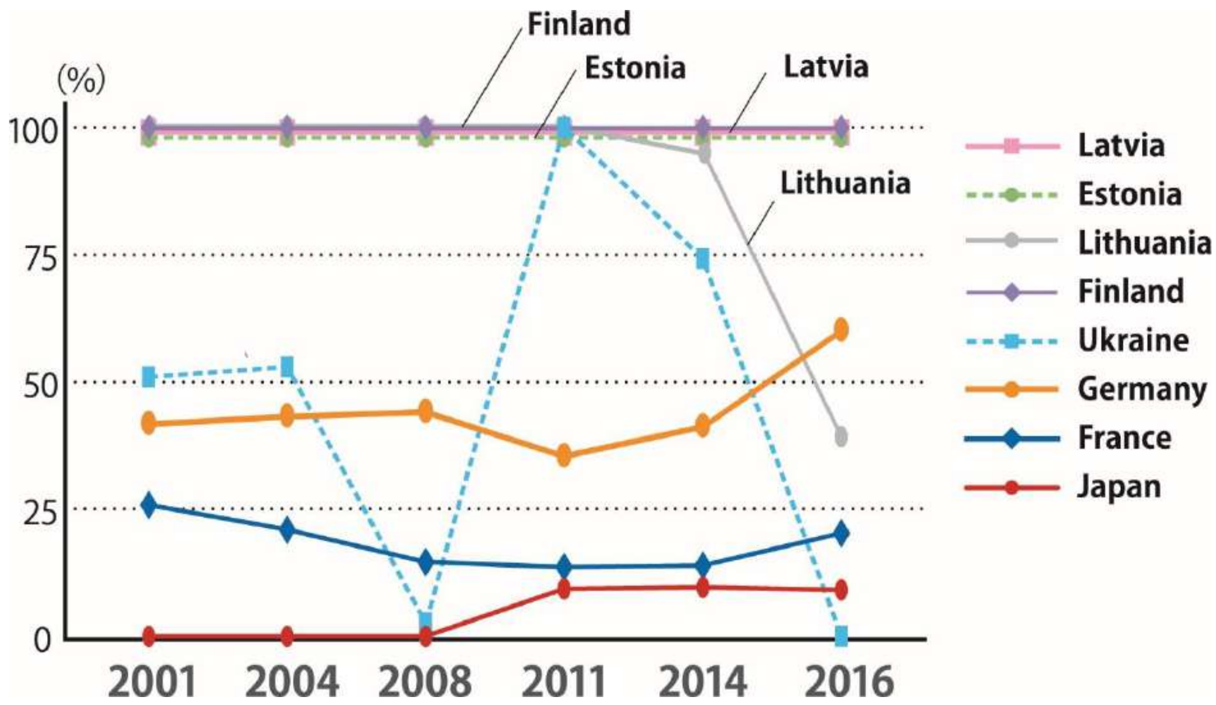
- Energy security as a concept has basically been a problem of fossil fuels. Oil in particular is concentrated in the Middle East, and geopolitical risk is high, so of these three risks, it was given highest priority.
- The oil crises of the 1970s are the typical example: Arab countries raised oil prices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

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

3) Suspension of exports for political reasons

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

Figure 18: Dependence on natural gas imports from Russia



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

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

Section 2: Electricity security and international grid connections

1) Electricity characteristics and security

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

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

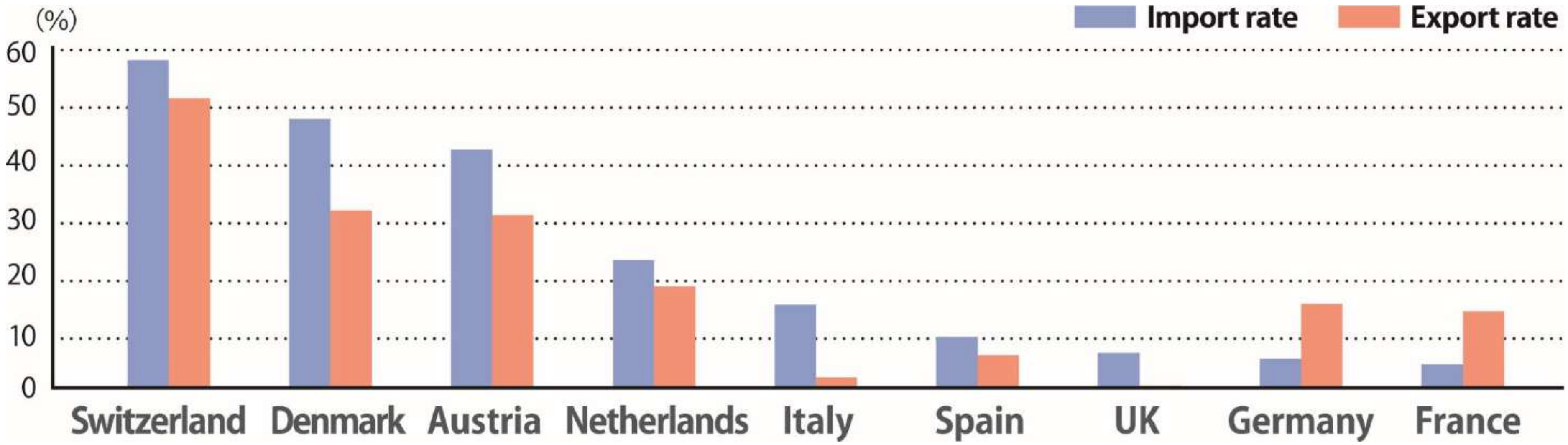
Table 8: Import rates by energy type and region (2016)

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

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

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

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



Section 2: Electricity security and international grid connections

2) Contribution of international grid connections to energy security

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

3) Electricity export suspension and emergency interchange examples

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

Conclusion

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

Section 2: Electricity security and international grid connections

4) Addressing export suspension through international agreements

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

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

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

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

Section 3: Energy security and international gird connections in the era of renewable energy

1) Transformation of the concept of energy security

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

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

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

CONCLUSION

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

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

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