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Full-length article

Impacts of a Japan–South Korea power system interconnection on the competitiveness of electric power companies according to power exchange prices

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Abstract: In many regions, international power system interconnections provide economic, energy-security, environmental, and technical benefits. In contrast, such interconnections remain scarce in Northeast Asia. In 2016, after approving a joint memorandum of understanding between major electric power companies from China, Japan, South Korea, and Russia, related initiatives regained momentum in the region. Nevertheless, the corresponding developments in Japan remain limited, mainly owing to the lack of involvement of Japanese electric power companies. This study represents a pioneering attempt to provide an economic assessment based on power exchange prices of a power system interconnection between Japan and South Korea regarding the competitiveness of electric power companies in terms of competitive business segments and strategic consequences. We found that although the position of Japanese generators may slightly deteriorate, that of the supply segment would substantially improve, thus suggesting that more opportunities than threats are derived from the interconnection. This promising outcome may foster the adoption of an interconnection with South Korea considering the positive economic and business perspectives in Japan. Furthermore, realizing the interconnection may improve the energy security and air quality in the region.

Keywords: Electricity grid interconnection, Japan, South Korea, Electric power company, Power exchange price.

1 Introduction

In many large regions worldwide, such as Europe, North and South America, and Africa, international power system interconnections have been extensively developed, and cross-border electricity trade is the norm rather than the exception [1]. In contrast, Northeast Asia (defined here as the region comprising China, Japan, North Korea, South Korea, Mongolia, and far-east Russia) has shown limited progress in developing such infrastructure and exchange [2]. In particular, Japan and South Korea—two of the world's largest economies, being the 3rd and 14th in terms of gross domestic product (constant 2010 US dollar) in 2018, respectively [3]—are among the few major developed economies lacking international power system interconnections [4], [5]. Consequently, these two countries cannot import/export electricity from/to at least one of their

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neighboring countries.

Implementing new interconnections and reinforcing the existing ones in Northeast Asia may provide economic benefits from the international competition for reducing the electricity prices, stability of power supply, and indirect support to the adoption of low-cost renewable energy (RE) on large scale [6], which is needed for sustainable economic development and environmental protection.

The concept of international power system interconnection across Northeast Asia is not new. Several previous initiatives have been proposed over the past 20 years: Northeast Asian Electrical System Ties in 1998 [7], Gobitec in 2009 [8], Asia Super Grid in 2011 [9], and Smart Energy Belt in 2016 [10]. However, these initiatives have achieved limited success to date. The slow progress may be explained by the challenges that should be overcome from planning to implementation, as well as problems with international diplomacy, which remains a hot topic in the region [11]. Nevertheless, a major milestone has been reached in March 2016, when major companies from China (State Grid Corporation of China), Japan (SoftBank), South Korea (Korea Electric Power Corporation), and Russia (Rosseti) signed a joint memorandum of understanding to cooperate on research and planning for an interconnected power grid spanning Northeast Asia [12], renovating the impetus for international power system interconnections across the region.

Except for Japan transmission system operators, SoftBank, whose business focuses largely on information technology and telecommunication services and not on the transmission of electricity, and major state-owned transmission system operators in all the Northeast Asia countries signed this joint memorandum of understanding and are collaborating to establish the world's largest power system generating electricity [13]. However, the absence of Japan transmission system operators in this enterprise is slowing down concrete progress in Japan and may even prevent the project realization. Therefore, their participation is imperative. The interest and involvement of Japan electric power companies (EPCOs) should be promoted considering both their competitive business segments (e.g., generation and supply) and non-competitive business segments (e.g., transmission and distribution) to establish international power system interconnections.

Various studies on international power system interconnections in Northeast Asia are relatively recently and consider both qualitative and quantitative analyses. For instance, the potential economic and environmental benefits from connecting power grids and developing RE in Northeast Asia at the regional level have been analyzed in [14–16]. An earlier study has revealed the potential cost-effectiveness of an interconnection between Japan and Korea [17]. Similarly, the power flow for an interconnection between Japan and South Korea has been analyzed in [18]. Despite the insights obtained from these studies, they fail to comprehensively assess the current potential impacts of international power system interconnections in Japan.

The Japan–South Korea power system interconnection should be prioritized as a decisive first step for broader interconnections because an interconnection with Russia is currently unlikely owing to diplomatic reasons (no peace treaty has been ratified between Japan and Russia to formally end World War II hostilities). In addition, various economic and energy-security concerns remain. Moreover, national energy policies and cost of generating technologies should be updated to understand the current market dynamics and anticipate future opportunities. Finally, business models should be devised for the competitive business segments of Japan EPCOs.

In this paper, we address the abovementioned limitations of existing studies. In Section 2, we provide information on the complementarities between Japan and South Korea in terms of electricity generation mixes and demand patterns. In Section 3, we propose a methodology based on a comparison of recent power exchange prices and detail the assumptions for the corresponding calculations. Section 4 reports the results from our estimations, and we draw conclusions on the Japan–South Korea interconnection in Section 5.

2 Electricity supply and demand complementarities between Japan and South Korea

In the framework of a Japan–South Korea interconnection, there is an existing complementarity between the power systems, and it is expected to continue to some extent at least in the medium term (horizon 2030). As demonstrated in [19], complementarity is key for international power system interconnections to provide benefits.

2.1 Complementarity of electricity generation mixes

There is a complementarity of electricity generation between Japan and South Korea. Fig. 1 [20], [21] shows that in Japan, most electricity (total gross electricity generation of more than 1,000 TWh) was generated from gas (35%), coal (31%), and RE sources (18%) in fiscal year (FY) 2018. In South Korea, most electricity (total gross electricity generation of less than 600 TWh) was generated from coal (45%), gas (25%), and nuclear plants (23%) in 2018.

Although Japan and South Korea heavily rely on coal and gas for electricity generation (66 and 70%, respectively), the most widely used fossil fuel differs between these countries, as Japan is more dependent on gas, whereas South Korea is more dependent on coal (35 and 45% of electricity generation, respectively). Furthermore, RE (mainly hydropower and solar power) and nuclear power are the key sources of low-carbon electricity in Japan and South Korea, respectively. Finally, the electricity generation mix of Japan is characterized by flexible (gas) and fluctuating (RE) electricity generation, whereas that of South Korea is characterized by baseload technologies (coal and nuclear power).

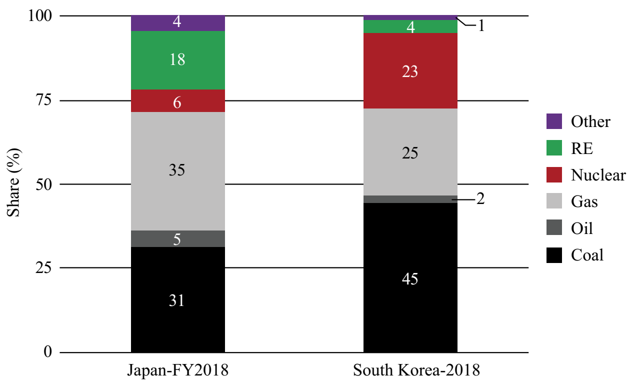

Fig. 1 Electricity generation mixes of Japan and South Korea in 2018. (RE includes hydropower, biofuels, renewable waste, geothermal, wind, solar, and marine power. Other includes pumped storage hydropower, non-renewable waste—industrial and non-renewable municipal waste, and other sources, such as fuel cells and electricity from chemical heat. FY comprises the period from April 1st to March 31st of the next year.)[20–21]

Considering the national targets for electricity generation mixes by 2030 for both countries, some of these differences may be attenuated but are likely to persist [22], [23]. For instance, Japan targets nuclear and RE shares to reach 20–22 and 22–24%, respectively, being similar to the South Korean objectives of 24 and 20%, respectively. However, Japan is unlikely to meet its target for nuclear power due to a slow restart of nuclear reactors throughout the country. At the beginning of 2020, only 9 of the 33 nuclear reactors had actually restarted commercial operation [24], with high uncertainty regarding future restarts because of rising costs, difficulties in meeting more stringent safety standards, and a lack of acceptance from the Japanese society. These factors may foster RE deployment for Japan to meet its goal to counteract climate change: 26% reduction in greenhouse gas emissions by FY 2030 with respect to the emissions in FY 2013 [25]. Moreover, Japan is more supportive of the expansion of solar power than that of wind power, with targets of 64 and 10 GW for these sources, respectively [26]. South Korea has a more balanced plan, aiming for approximately 37 GW of solar power and 18 GW of wind power [27]. Although both countries plan to reduce their reliance on fossil fuels, Japan (slightly) prioritizes gas (future share of 27%) over coal (26%), whereas South Korea prefers coal (future share of 36%) over gas (19%). Thus, the electricity generation mix of Japan is likely to be characterized by flexible and fluctuating electricity generation, whereas that of South Korea will be focused on baseload technologies. Overall, these differences indicate the future complementarity in terms of electricity generation mixes between Japan and South Korea.

2.2 Complementarity of electricity demand patterns

Complementarity of electricity demand patterns may also be relevant for a possible interconnection. In Japan and South Korea, electricity demand patterns exhibit clear seasonality. Both power systems present demand peaks in summer and winter. For instance, the summer peak demand for Japan was 165 GW in 2018 (latest available data), and that for South Korea was 90 GW in 2019, both related to cooling needs typically occurring in July and August. The winter peak demands for Japan and South Korea were 146 and 85 GW, respectively, from heating needs typically occurring between December and February of the next year [28–32]. Despite seasonality, peak demand tends to occur on different periods in Japan and South Korea, as supported by empirical evidence from recent years (summer 2015–winter 2019), thus suggesting complementarity of peak demand. In fact, on a summer day, the peak electricity demand occurred around 15:00 and 17:00 in both countries. In addition, the winter electricity demand peaked either around 10:00 or 19:00 in Japan and around 10:00–11:00 in South Korea. Thus, although complementarity is not clear during summer, more promising synergies may be achieved in winter.

Besides these considerations on possible complementarities of supply and demand between Japan and South Korea power systems, we consider a novel assessment of the potential impacts of international power system interconnections on Japan EPCOs. Specifically, we adopt an approach to compare power exchange day-ahead electricity prices in relevant areas of Japan and South Korea over 2018 and 2019. The corresponding results unveil both the reasons underlying the possible opposition of Japan EPCOs to a power system interconnection with South

Korea and possible strategic adjustments to promote this interconnection.

3 Methodology

The comparison of electric power exchange prices in Japan and South Korea can illustrate the advantages and drawbacks of an interconnection. On the upside, power exchange prices provide empirical data of power system day-ahead electricity prices per hour (South Korea) or half-hour (Japan) over several years, providing very detailed and freely available data to ensure the replicability of the results. On the downside, comparing prices from power exchange methods regulated by different mechanisms and assuming that trade may take place between the Japan and South Korea without affecting domestic electricity prices may impact the analysis accuracy [33]. Nevertheless, that effect may be negligible in this study due to our analysis of a relatively small interconnector. Potential problems can be properly addressed at later stages through, for example, a computer simulation of the power systems from the two countries. As this study represents an early effort to understand how electricity trade can be implemented between Japan and South Korea and what could be the consequences on the competitive business segments of EPCOs, we can disregard the abovementioned problems.

3.1 Power exchange characteristics

The Japan Electric Power Exchange (JEPX) and Korea Power Exchange (KPX) offer day-ahead electricity prices resulting from the dispatch of power plants based on the merit order (i.e., generation sources are ranked in ascending order of price, and the market price is set by the highest marginal cost). In addition, the participation of power systems is voluntary in the JEPX [34], but it is mandatory in the KPX with a few unrepresentative exceptions, such as generators in islands that are not connected to the grid operated by the KPX and electricity generated through new and RE sources with capacity up to 1 MW [35]. Moreover, the bidding prices of generating units are almost freely determined in the JEPX, because the selling bids are only required to be within the wide range of 10–999,000 JPY/MWh or approximately 0.1–9300 USD/MWh at the discretion of the generators [36]. In contrast, the KPX regulates the variable costs of power plants according to the merit order that is decided by the Generation Cost Assessment Committee [37].

These characteristics of the power exchange entities have consequences on both market liquidity and price volatility. For instance, due to the ongoing electricity system reform in Japan [38], the JEPX market liquidity has rapidly increased in recent years. Although the JEPX is not all inclusive, its participation in the market is considerable, being 209 TWh in FY 2018 and 216 TWh in the first 9 months of FY 2019 (December 31, 2019) [39], from the total net electricity supply of around 1000 TWh per year in Japan [20]. In contrast, the KPX is almost a perfectly liquid market, usually above 500 TWh, which represents approximately 99% of the total net electricity supply, which is traded annually via power exchange, in South Korea [32].

Regarding price volatility of the JEPX in west Japan (JEPX–West) and the KPX in mainland South Korea (KPX–Mainland), our electricity price areas of interest, the JEPX–West prices were more evenly distributed and reached extremes relatively frequently (i.e., below 50 USD/MWh and at least 150 USD/MWh) in more than 12% of the time over 2018 and 2019 [39] compared to the KPX–Mainland prices, which mainly concentrated around 80–100 USD/MWh, and reached extremes few times [40].

3.2 Assumptions

We selected electricity price areas assuming that west Japan (Chubu, Chugoku, Hokuriku, Kansai, Kyushu, and Shikoku) and mainland South Korea (excluding Jeju island, which has its own electricity pricing) can be interconnected with a 2 GW interconnector [41], [42]. Three possible interconnection routes can link Busan in mainland South Korea to three possible landing spots in west Japan: Imari (Kyushu), Maizuru (Kansai), and Matsue (Chugoku), as illustrated in Figure 2. Except for the Maizuru route, these routes would require either reinforcement or extension of the west Japan electrical grid for power to be transmitted without congestion throughout west Japan. The total cost of these projects is estimated to be JPY 202–247 billion, or approximately USD 1.9–2.3 billion. Further transmitting electricity to east Japan (Hokkaido, Tohoku, and Tokyo) would probably incur additional grid reinforcement costs,

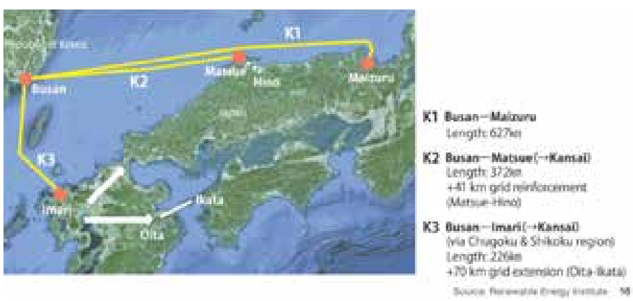

Fig. 2 Three possible interconnection routes for west Japan–mainland South Korea interconnector

Source: Asia International Grid Connection Study Group [41].

and we do not consider this option because all electricity that can be imported from South Korea is expected to be consumed in the large demand centers of west Japan, especially in the Kansai area (e.g., Osaka, Kobe, Kyoto). The electricity prices calculated for Japan are thus based on those from the six west areas. As the electricity prices in 77% of the half-hours over the 2-year study period are equal across the six areas, and variations remain within a small range of 5 USD/MWh, we obtain the electricity price for JEPX–West as the average price among these six areas.

In this study, we covered the period 2018–2019 to reflect the latest developments in the electricity markets of Japan and South Korea. In Japan, after the Fukushima Daiichi nuclear accident in 2011, electricity generation from coal and gas has increased, and RE generation has been considerably deployed, especially from solar photovoltaic generation, which increased from 3.6 GW in 2010 to 55.5 GW in 2018, with the difference of 52 GW representing an approximately 15-fold increase [43] and achieving substantial energy efficiency gains. Thus, our analysis focuses on very recent circumstances that can represent the current market outlook.

We gathered and stored the necessary day-ahead electricity prices from the JEPX–West [39] and KPX–Mainland [40] as raw data on January 1, 2020. Then, we applied some simple adjustments to conduct a comparative analysis. Specifically, we split KPX–Mainland data into half-hourly prices to agree with the division in half-hourly prices of JEPX–West. In addition, we expressed the average monthly exchange rates given in Japanese yens and Korean won as US dollars between January 2018 and December 2019 [44].

The key assumptions for our analysis are 100% availability of the 2 GW west Japan–mainland South Korea interconnector, sufficient and similar available marginal generating capacity on both sides of the interconnector to provide electricity at the same price levels in the importing and exporting country, and no harmonization of power exchange rules. The assumptions regarding the interconnector availability and prices may be considered optimal. The assumption about the sufficient available capacity is feasible in the considered areas. Moreover, if an additional export demand of 2 GW was added to the domestic summer and winter peak demands, there would always have been reserve margins of at least about 4% in the study period [30–32]. This reserve margin is above the minimum of 3% required for stable supply of electricity across Japan [45] and below the 10% reserve margin considered to ensure stable power supply in South Korea, but above the 5% (except for the 4.4% margin on August 13, 2019) reserve margin threshold, below which a supply warning is issued [46]. The assumption on the harmonization of rules is for practical purposes. Again, this analysis aimed to provide a first, relatively simple attempt to address the particularly complicated interconnection problem without undermining correctness.

We then assume that electricity trade proceeds as follows. Every half-hour, 2 GW of power is exported/imported from the market with the lower/higher electricity price to that with the higher/lower electricity price at the lower price. The results of this half-hour trading are aggregated in terms of export/import volume and export/import monetary value over 2018 and 2019. Finally, we estimate the gains/losses of market participants (i.e., generators and suppliers) in two scenarios, either with or without international electricity trade. Without trade, the generators sell to the suppliers 2 GW of power in their respective domestic markets at the corresponding market price every half-hour. When considering international electricity trade, the generators in the market presenting lower price sell extra 2 GW of power at their market price to the suppliers in the market presenting the higher price every half-hour. The generators in the market presenting the higher price do not sell the 2 GW, which is imported by the suppliers. We aggregate and compare the results from these two scenarios over 2018 and 2019. Fig. 3 illustrates our novel methodology and the key assumptions for the calculations.

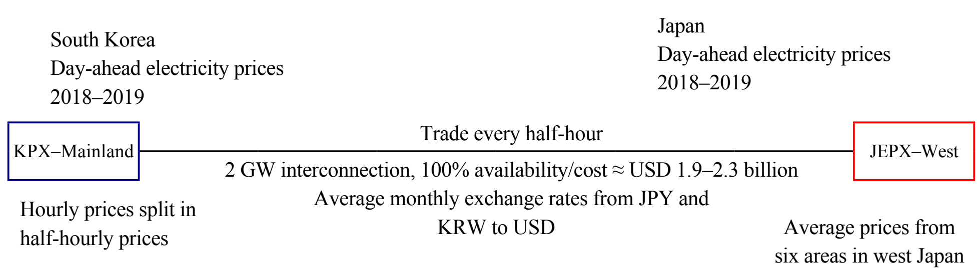

Fig. 3 Diagram of proposed methodology for interconnection analysis and its key assumptions

4 Estimation results

From the collected information, we thoroughly analyzed the following aspects: electricity flow directions between JEPX–West and KPX–Mainland (electrical energy amount and monetary value) and the consequences for competitive business segments of EPCOs.

4.1 Price comparison and potential savings

Fig. 4 shows the JEPX–West and KPX–Mainland day-ahead electricity prices every half-hour over 2018 and 2019. Two important observations can be made: 1) as expected, JEPX–West prices were more variable and presented more extreme values compared with KPX–Mainland prices. In fact, JEPX–West prices varied between 0.1 and almost 900 USD/MWh, whereas KPX–Mainland prices varied between 45 and 185 USD/MWh. In addition, the JEPX–West prices were below the KPX–Mainland prices in some periods and vice versa. Therefore, there are clear opportunities considering the power exchange prices for both countries to trade electricity through a bidirectional interconnector, as both countries would benefit from importing and exporting electricity depending on the situation of their local power systems.

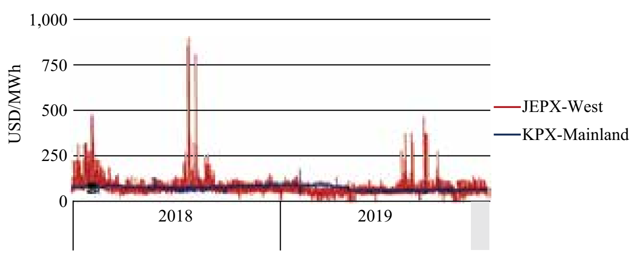

Fig. 4 Day-ahead half-hourly electricity prices in JEPX–West and KPX–Mainland over 2018 and 2019 [39], [40]

Fig. 5 shows the periods when the JEPX–West prices were lower and higher than the KPX–Mainland prices to illustrate the potential electricity trade flows through the interconnector. During the shoulder seasons, spring and autumn, when the electricity demand for heating and cooling reduces, the JEPX–West prices were often lower (68% of the time in these periods) than the KPX–Mainland prices. This was particularly evident in March and April 2019, when low-carbon emission electricity with low marginal cost was generated from photovoltaic plants, hydropower plants, and the nine nuclear reactors in Kansai, Kyushu, and Shikoku to satisfy the moderate demand, resulting in frequent low prices below 50 USD/MWh in JEPX–West. Such low price level was rarely seen in KPX–Mainland. Moreover, at around 18:00 on July 25, 2018, when a very high demand occurred in JEPX–West for cooling during a heatwave [47], the price difference in favor of KPX–Mainland was enormous, exceeding 800 USD/MWh, indicating that west Japan could have saved a subst antial amount of money if an interconnection with mainland South Korea was available at that time.

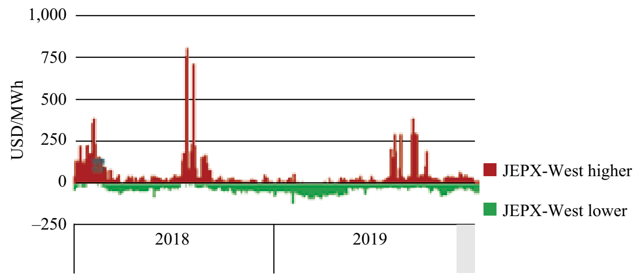

Fig. 5 Day-ahead half-hourly electricity price differences between JEPX–West and KPX–Mainland over 2018 and 2019 [39], [40]

Over the 2-year study period, the frequent price divergences between the two power systems were substantial, with mean of 22 USD/MWh and standard deviation of 30 USD/MWh. Under the assumptions of this study, the total savings from the proposed interconnector would have amounted for approximately USD 800 million. This amount would cover 35–40% of the interconnector estimated costs in only 5% of its lifetime, considering a 40-year lifetime, which is a common assumption for such projects in Europe.

In addition, cross-border electricity trade may be highly valuable from an environmental perspective. This is true both at times of abundant electricity generation from low-carbon electricity and moderate demand, and during situations of high demand. In fact, under high demand, power plants with the highest marginal costs (e.g., oil power plants in Japan and South Korea) generate electricity as well as massive amounts of greenhouse gas emissions. Replacing the output of these power plants by cheaper and less carbon-intensive imports in these two countries, such as the electricity generated from flexible gas power plants rather than coal power plants operated for baseload, may provide substantial environmental benefits. Therefore, the proposed interconnection would also mitigate climate change, which is a goal of both Japan and South Korea, as pledged in the Paris Agreement, in which these countries targeted reductions of 26% in greenhouse gas emissions by FY 2030 with respect to FY 2013 and 37% by 2030 with respect to a business-as-usual scenario, respectively [48].

These findings are consistent with the expectations from a qualitative analysis of the economic efficiency of cross-border electricity trade and its contribution to reduce emissions of carbon dioxide and other air pollutants in Japan and South Korea [49].

4.2 Outcomes for participants

Table 1 lists relevant information regarding a hypothetical electricity trade for Japan and South Korea over 2018 and 2019. First, the day-ahead half-hourly electricity prices were more often lower (60% of the time) in JEPX–West than in KPX–Mainland, resulting in possible higher export volumes from JEPX–West to KPX–Mainland. Second, the value of exports from JEPX–West to KPX–Mainland would be higher than that of imports. Therefore, electricity trade would have resulted in a positive commercial balance for JEPX–West and a negative one for KPX–Mainland. Thus, the position of Japan EPCOs against an interconnection with South Korea for electricity trade that would benefit their businesses seems unjustified.

Table 1 Hypothetical electricity trade outcomes between JEPX–West and KPX–Mainland over 2018 and 2019 [39], [40]

	Number of periods with lower prices	Number of periods with higher prices	Export amount (TWh)	Import amount (TWh)	Export value (USD million)	Import value (USD million)	Commercial balance (USD million)
JEPX–West	21,192	13,848	21	14	1,352	1,072	280
KPX–Mainland	13,848	21,192	14	21	1,072	1,352	−280

Table 2 lists the potential impacts of electricity trade between JEPX–West and KPX–Mainland. The generators would lose and the suppliers would benefit from such trade. This outcome would be exacerbated in KPX–Mainland, were generator losses could have amounted to USD 696 million over 2018 and 2019, against USD 80 million in JEPX–West. In contrast, suppliers would have won USD 416 million in KPX–Mainland and USD 360 million in JEPX–West over the same period. In theory, these results are expected because increasing the competition among generators on both sides of the interconnector would benefit the most competitive ones, leaving the others out of the market. Consequently, the efficiency increases and overall generation costs decrease, thereby deteriorating the economic situation for generators but reducing the procurement costs for suppliers. The suppliers may then decide whether they share these gains with their consumers depending on their business strategies and the competition in the corresponding markets. It is worth noting that the combined market shares of new suppliers reached 16% in Japan in September 2019 [50], and the mostly state-owned Korea Electric Power Corporation monopolizes the supply market in South Korea [51].

Table 2 Potential impacts of electricity trade between JEPX–West and KPX–Mainland over 2018 and 2019 on competitive business segments of EPCOs [39], [40]

	Generator losses from trade (USD million)	Supplier gains from trade (USD million)
JEPX–West	80	360
KPX–Mainland	696	416

5 Further considerations

From the obtained results, several considerations deserve particular attention, especially regarding the low-carbon emission electricity generation with low marginal cost. Investing in increasingly cost-competitive RE systems, which are widely accepted by society, may strengthen the generation segment of Japan EPCOs. In fact, according to recent estimates of the levelized cost of electricity by BloombergNEF for the second half of 2018 [52], most competitive new onshore wind and solar photovoltaic plants in Japan generate at 82 and 67 USD/MWh, respectively, being not only competitive with the power exchange prices in the two countries but also notably below the levelized cost of electricity of these two technologies in South Korea, where onshore wind and solar photovoltaic generation cost 94 and 101 USD/MWh, respectively. The comparative advantage is more evident for photovoltaic generation in Japan and can be explained by the more mature industry for the deployment of the technology and associated economy of scale, which has been historically supported by subsidies [53]. In fact, there was 55.5 GW of cumulative installed capacity in Japan by the end of 2018, being the second largest capacity worldwide (only behind that of China), against only 7.9 GW of capacity in South Korea [43].

Implementing power system interconnections with South Korea may be decisive to maintain Japan positive commercial balance in the future, because cost-competitive, low-marginal-cost technologies are in the economic position of being maximally dispatched. In the next few years, the Japan leadership with nearly zero marginal cost on RE deployment, especially solar photovoltaic and hydropower plants, should remain unchanged even if solar photovoltaic energy grows fast in South Korea. However, this leadership may be counterbalanced by uncertainties related to the operation of low-marginal-cost nuclear power plants in Japan. All the nine restarted reactors in the country now face temporary shutdowns spanning 3 years following a delayed compliance with antiterrorism measures [54], [55]. More generally and over longer time frames, the recurring uncertainties related to nuclear power in Japan are key aspects that cannot be underestimated and impede simple predictions on the future outcome of cross-border electricity trade between Japan and South Korea. More pragmatic low-carbon energy policies in Japan will clarify the perspectives and facilitate reasonable decision-making.

Beyond immediate economic perspectives, realizing a power system interconnection would contribute to reduce electricity generation using imported and highly polluting fossil fuels in the region (particularly due to the lower marginal costs of solar and wind power), which constitutes a persistent energy-security and environmental concern. Increasing electricity generation from RE sources results advantageous and stable compared with the volatile oil and gas geopolitics, and air quality has become a major sociopolitical problem in South Korea given the severe fine dust pollution in the country [56]. Therefore, South Korea will prefer to import low-carbon, low-marginal-cost electricity generated from solar photovoltaic plants by leveraging, for example, curtailment in west Japan [57]. In fact, if the Japanese and South Korean power systems were interconnected [58], South Korea would be able to import the clean and cheap excess of solar power from Kyushu that would otherwise be curtailed.

An international electricity trade based on RE generation may result attractive for consumers on both sides of an interconnector. For instance, Korean residential electricity consumers are willing to increase their electricity consumption from RE sources due to its safety and environment-friendly attributes [59]. In Japan, residential electricity consumers also prefer RE sources for the same reasons [60]. Regarding businesses, several Japanese companies from various areas (e.g., AEON, Daiwa House, Fujitsu, Konica Minolta, Panasonic, Ricoh) have recently announced their commitment for 100% RE usage to conduct their activities given its economic and environmental benefits [61].

Finally, if an international power system interconnection between Japan and South Korea is realized, regulatory decisions may impose electricity trade via the interconnector, like the Nord Pool power exchange in Europe, which imposes cross-border trade [62]. Such regulations may provide multiple benefits, including the increase in power exchange liquidity, stabilization of power exchange prices, stimulation of investments in competitive power plants, and increased competitiveness from new suppliers, possibly reducing the electricity prices for consumers [63].

6 Conclusions

From the analysis and results reported in this paper, we can draw four main conclusions:

1) Various economic opportunities may be available from an electricity trade between JEPX–West and KPX–Mainland, especially for Japan.

2) In both countries, electricity trade via an interconnector would deteriorate the generator situation due to increased competitiveness and efficiency, whereas suppliers and/or consumers would benefit depending on the sharing of gains obtained from cheaper electricity procurement.

3) The competitive segments of Japan EPCOs (i.e., generation and supply), for which the analysis of an interconnector has been detailed, would achieve economic gains from the interconnection with South Korea under the current circumstances. This outcome may foster positive discussions in Japan when considering the economic and business perspectives of a power system interconnection with South Korea.

4) Given their economic, energy-security, and environmental competitive advantages, investment should be directed toward technologies for low-carbon-emission electricity generation with low marginal cost as strategic assets.

Some limitations of this study remain to be addressed. JEPX has a relatively moderate market liquidity, whereas KPX has general participation and imposes pricing rules. Nevertheless, we applied simplifications regarding the exact impact of international electricity trade on the related prices (i.e., selling bids of marginal generation capacity). Therefore, in future work, we will model the interactions between Japan and South Korea power systems under current and medium-term conditions (horizon 2030) to further ensure the correctness of the present analysis and consider foreseeable changes. In addition, we will conduct a more detailed analysis on how generators and suppliers in the two countries may benefit from an international power system interconnection based on both theoretical and practical cases, and we will analyze possible policy implications.

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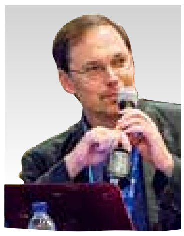

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(Editor Zhou Zhou)