



# Regional Power Grid **Connectivity for Sustainable Development** in North-East Asia

Policies and Strategies



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# Regional Power Grid **Connectivity for Sustainable Development** in North-East Asia

## Policies and Strategies

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# Abbreviations and acronyms

<b>AC</b>	alternating current
<b>ADB</b>	Asian Development Bank
<b>AFTA</b>	ASEAN Free Trade Agreement
<b>AIIB</b>	Asian Infrastructure Investment Bank
<b>APERC</b>	Asia Pacific Energy Research Centre (Japan)
<b>ASEAN</b>	Association of Southeast Asian Nations
<b>ASG</b>	Asian Super Grid
<b>AuES</b>	Altai-Uliastai Electricity System
<b>BAU</b>	business as usual
<b>BIMSTEC</b>	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation
<b>BRI</b>	Belt and Road Initiative
<b>CCGT</b>	Combined Cycle Gas Turbine
<b>CEC</b>	China Electricity Council
<b>CEPRI</b>	China Electric Power Research Institute
<b>CES</b>	Central Electricity System (Mongolia)
<b>CHP</b>	combined heat and power
<b>CSG</b>	China Southern Power Grid
<b>CSGC</b>	China State Grid Company
<b>CSP</b>	concentrated solar power
<b>DC</b>	direct current
<b>DPRK</b>	Democratic People's Republic of Korea
<b>EAEU</b>	Eurasian Economic Union
<b>EBRD</b>	European Bank for Reconstruction and Development
<b>ECT</b>	Energy Charter Treaty
<b>EDF</b>	Électricité de France S.A.
<b>EES</b>	Eastern Electricity System (Mongolia)
<b>EPPEI</b>	Electric Power Planning and Engineering Institute (China)
<b>EPS</b>	Electric Power System
<b>ERINA</b>	Economic Research Institute for North-East Asia (Japan)
<b>ESCAP</b>	United Nations Economic and Social Commission for Asia and the Pacific
<b>ETS</b>	Emissions Trading System
<b>FGC UES</b>	Federal Grid Company of Unified Energy System (Russia)
<b>FiT</b>	Feed-in Tariffs
<b>GCCIA</b>	Gulf Cooperation Council Interconnection Authority
<b>GDP</b>	Gross Domestic Product
<b>GEIDCO</b>	Global Energy Interconnection Cooperation Organization
<b>GTI</b>	Greater Tumen Initiative
<b>HAPUA</b>	Heads of ASEAN Power Utilities/Authorities
<b>HPP</b>	Hydropower Plant

<b>HVAC</b>	High-voltage alternating current
<b>HVDC</b>	High-voltage Direct Current lines
<b>IEA</b>	International Energy Agency
<b>IEC</b>	International Electrotechnical Commission
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>IEEJ</b>	Institute of Energy Economics Japan
<b>IPS</b>	integrated power system
<b>IRENA</b>	The International Renewable Energy Agency
<b>ISO</b>	International Organization for Standardization
<b>JAERO</b>	Japan Atomic Energy Relations Organization
<b>JPEX</b>	Japan Electric Power Exchange
<b>KEA</b>	Korea Energy Agency
<b>KEDO</b>	Korean Peninsula Energy Development Organization
<b>KEEI</b>	Energy Economics Institute of the Republic of Korea
<b>KEPCO</b>	Korea Electric Power Corporation
<b>KEPRI</b>	Korea Electric Power Research Institute
<b>KERI</b>	Korea Electrotechnology Research Institute
<b>KESRI</b>	Korea Electrical Engineering and Science Research Institute
<b>KIC</b>	Kaesong Industrial Complex
<b>KIEP</b>	Korea Institute for International Economic Policy
<b>KOREC</b>	Korea Energy Regulatory Commission
<b>KPX</b>	Korean Power Exchange
<b>LCOE</b>	levelized cost of energy
<b>MEEI</b>	Mongolian Energy Economics Institute
<b>METI</b>	Ministry of Economy, Trade and Industry (Japan)
<b>MOTIE</b>	Ministry of Trade, Industry and Energy of Korea
<b>MoU</b>	Memorandum of Understanding
<b>MUST</b>	Mongolian State University of Science and Technology
<b>NAPSI</b>	North-East Asia Power System Interconnection
<b>NDCs</b>	Nationally Determined Contributions
<b>NDRC</b>	National Development and Reform Commission
<b>NDRC</b>	National Development and Reform Commission (China)
<b>NEA</b>	National Energy Administration (China)
<b>NEA</b>	National Energy Administration (China)
<b>NEAEI</b>	North-East Asia Energy Interconnection
<b>NEAREST</b>	North-East Asian Region Electric System Ties
<b>NEARPIC</b>	North-East Asia Power Interconnection and Cooperation
<b>NEASG</b>	North-East Asian Super Grid
<b>NRA</b>	Nuclear Regulation Authority (Japan)
<b>OCCTO</b>	Organization for Cross-regional Coordination of Transmission Operators (Japan)
<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>PAHs</b>	polycyclic aromatic hydrocarbons

<b>PPP</b>	Purchasing power parity
<b>RAO UES</b>	Unified Energy System of Russia
<b>RCEP</b>	Regional Comprehensive Economic Partnership
<b>REC</b>	Renewable Energy Certificate
<b>REI</b>	Renewable Energy Institute (Japan)
<b>RES-E</b>	renewable energy sources for electricity
<b>RFE</b>	Russian Far East
<b>ROK</b>	Republic of Korea
<b>Rosseti</b>	PJSC Rosseti, Public Joint Stock Company
<b>RPS</b>	Renewable Portfolio Standard
<b>SAPP</b>	South African Power Pool
<b>SB RAS</b>	Siberian Branch of Russian Academy of Sciences
<b>SCADA</b>	supervisory control and data acquisition
<b>SDGs</b>	Sustainable Development Goals
<b>SGCC</b>	State Grid Corporation of China
<b>SIEPAC</b>	Central American Electrical Interconnection System
<b>Skoltech</b>	Skolkovo Institute of Science and Technology
<b>TEC</b>	Total electricity consumption
<b>TEPCO</b>	Tokyo Electric Power Company
<b>TFC</b>	total final energy consumption
<b>TPES</b>	Total primary energy supply
<b>TPP</b>	Thermal Powerplant
<b>TSO</b>	Transmission System Operator
<b>UHV</b>	ultra-high voltage
<b>UNCTAD</b>	United Nations Conference on Trade and Development
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>WAMS</b>	wide-area monitoring systems
<b>WB</b>	The World Bank
<b>WES</b>	Western Electricity Sytem (Mongolia)
<b>WHO</b>	World Health Organization

#### Energy and power units

<b>bcm</b>	billion cubic metres
<b>GW</b>	gigawatt
<b>GWh</b>	gigawatt hour(s)
<b>KW</b>	kilowatt
<b>KWh</b>	kilowatt hour(s)
<b>Mt</b>	megatonnes
<b>MW</b>	megawatt
<b>MWh</b>	megawatt hour(s)
<b>toe</b>	tonnes of oil equivalent
<b>TW</b>	terrawatt
<b>TWh</b>	terawatt hour(s)

## Executive summary

Proposals to interlink the power grids of the countries of North-East Asia<sup>1</sup> stretch back to at least the early 1990s. Since then, multiple shifts in the energy landscape at the global, regional and national levels have taken place, creating a number of drivers for increased cooperation to develop regional power grids. Among the most profound shifts are the rising cost competitiveness of renewable energy sources, such as wind and solar PV; cost and efficiency improvements in long-distance transmission technologies; the establishment of relevant regional and intercontinental integration projects, including the Belt and Road Initiative; and the pressing need to decarbonize the energy sector, in line with the commitments made under the Paris Agreement on Climate Change.

This report examines the opportunity to enhance cross-border power grid connectivity in North-East Asia. Based on a comprehensive literature review of more than 130 studies and contributions by national experts, this report presents policymakers and other stakeholders with an overview of the potential benefits of regional power grid interconnection, with a focus on sustainability. It also describes potential challenges that will need to be addressed to ensure the success of integration efforts and to better link these efforts to the transition to low-carbon power systems. Finally, the report proposes a set of recommendations designed to guide and facilitate cooperation between the Governments of North-East Asia and other stakeholders to advance the process of regional power system integration.

### A. Why North-East Asia should support power system integration

The six countries that make up North-East Asia are collectively endowed with the energy resources, technological expertise, financial resources and human capital necessary to develop a functioning regional power grid. The varying economic, climatic and geographical conditions across North-East Asia create synergies that make regional interconnections an economically and environmentally beneficial option. At the same time, this diversity brings with it challenges that require coordinated interventions to overcome.

Cooperation on power grid connectivity will allow the countries of North-East Asia to leverage regional diversity, and to profit from the economic, environmental and social benefits that interconnected power systems can bring.

For example, power interconnection opens new markets for resource-rich countries, while providing countries with high or growing demand or limited potential to develop renewable resources domestically as well as access to sources of low-cost, low-carbon electricity. Integration allows regions to do more with less – avoiding investments by enabling power systems to serve demand with less generation and transmission than would otherwise be necessary, and improving the economies of scale for projects that are built. Regional integration linked to sustainability efforts can also reduce heavy air pollution – a particular problem in the urban areas of China, Mongolia and the Republic of Korea – and carbon emissions. This, and the economic development associated with the integration process such as the development

<sup>1</sup> Defined, in this context, as the People's Republic of China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea and Russian Federation.

of new transmission lines, also has considerable potential to improve social welfare, raise living standards and contribute to the economic development.

Finally, enhancing regional power grid interconnection can contribute to strengthening regional energy security and the stability of the regional power system. It can increase the overall resilience of the regional power system by reducing reliance on fossil fuel imports and by diversifying the electricity supplies of the interconnected countries. It will also support broader regional integration and peace by providing a new framework for cooperation and creating mutual positive interdependencies between the North-East Asian countries.

## B. How to move forward

Power system integration is a process that requires work across a range of technical, economic, policy and social issues. Based on the research done for this paper, and guided by the draft United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) Electricity Connectivity Roadmap for Asia and the Pacific,<sup>2</sup> this report outlines a series of strategies to advance interconnection in North-East Asia in an efficient and sustainable manner.

The first strategy, “Building trust and political consensus on power grid connectivity”, stresses the importance of political will. Support at the political level is essential, and should be enabled through the establishment of an inclusive governmental dialogue and engagement with national stakeholders.

The second strategy, “Developing a Master Plan for regional power grid interconnection”, builds on the ongoing work of the utilities and other actors to provide a vision for North-East Asia that demonstrates the feasibility and benefits of integration.

The third strategy “Developing and implementing Intergovernmental Agreements, creating a broader institutional framework”, emphasizes that successful cooperation on power grid connectivity requires the presence of transparent and functional institutional frameworks. Appropriate institutional arrangements can be developed through platforms like the North-East Asia Power Interconnection and Cooperation (NEARPIC) Forum, which has been enabling high-level dialogue on this topic since 2016.

The fourth strategy, “Coordinating, harmonizing and institutionalizing policy and regulatory frameworks”, highlights the need for cooperation on relevant policy and regulatory issues, such as harmonization of technology standards and grid codes to ensure efficient and secure integration.

The fifth strategy, “Moving towards multilateral power trade and creating competitive markets for cross-border electricity trade”, suggests the gradual development of regional market frameworks to support the power trade. Short-term steps such as harmonized bilateral trading agreements and a standardized pricing methodology can lay the foundation for the development of full multilateral trading.

2 More details about the nine strategies, included related analyses, can be found in the draft “Electricity Connectivity Roadmap for Asia and the Pacific: Strategies towards interconnecting the region’s grids”. Available at <https://www.unescap.org/publications/electricity-connectivity-roadmap-asia-and-pacific-strategies-towards-interconnecting>.

The sixth strategy, “Coordinating cross-border transmission planning and system operations”, focuses on enabling efficient technical coordination and seamless operations across borders. This includes joint emergency response mechanisms, coordinated ancillary services and the secure sharing of non-sensitive data.

The seventh strategy, “Mobilizing investment in cross-border grid and generation infrastructure”, focuses on the need to develop more cross-border power grid infrastructure and generation assets. A transparent and coherent legal framework for power sector investments, or including power issues in a full multilateral trade agreement, would help to create a favourable investment climate.

The eighth strategy, “Capacity-building and sharing of information, data, and best practices”, points to the benefits of sharing best practices and joint capacity-building. Tools such as ESCAP’s Asia Pacific Energy Portal ([www.asiapacificenergy.org](http://www.asiapacificenergy.org)) can support information sharing, while dialogue with communities and increased public awareness of the benefits of interconnection can help to secure local support.

The ninth, cross-cutting strategy, **“Ensuring that energy connectivity initiatives are compatible with the Sustainable Development Goals”**, stresses the importance of considering cross-border projects holistically. This includes considering the needs of the poorest and most vulnerable population groups, and integrating sustainable energy guidelines into power connectivity projects.

Taken together, these strategies provide a path forward for increased power integration in North-East Asia. Most importantly, they support integration in such a way as ensure alignment with, and even strengthen, national efforts to develop secure, sustainable power sectors and to meet the Sustainable Development Goals.

While much work remains to be done, momentum behind increased integration is building, and the foundation for success is already being laid out. Regional power system integration is a tool, not a goal. Properly guided, increased connectivity will support the development of a secure, sustainable and affordable power system across North-East Asia.

# Introduction

## Towards sustainable energy for all through regional power grid interconnection

### A. Purpose and structure of this report

#### Purpose of this report

Cooperation on power grid connectivity in North-East Asia<sup>3</sup> is a topic that has been the focus of much research for more than three decades. Numerous studies have been conducted, commissioned by research institutions, national Governments and international organizations. However, despite this interest and the obvious urgency of this topic, no consolidated vision for power grid connectivity in North-East Asia has been developed. One major reason is the inherent complexity of the issue of power grid connectivity, given the vast array of aspects involved. Thus, it comes as no surprise that the existing studies, though numerous and very detailed, cover only limited dimensions of the overall issue.

<sup>3</sup> There are numerous definitions of “North-East Asia”, among them those based on physical (geographic), economic, historic and cultural characteristics. For the purposes of this report North-East Asia is defined in line with the regional categorization employed by the United Nations – a subregion of Asia-Pacific consisting of six member States: People’s Republic of China, Democratic People’s Republic of Korea, Japan, Mongolia, Republic of Korea and Russian Federation.

The purpose of this report is threefold. First, it aims to explore and consolidate the abundant yet scattered body of knowledge on power grid connectivity in North-East Asia, in order to create a transparent overview of the existing cross-border interconnections and arrangements in the region, and the interconnection initiatives proposed up to now. This analysis focuses on the benefits that can be gained from cooperation on connectivity and the challenges that have to be addressed in the interconnection process.

Second, based on this overview, this report aims to map the scope for action by the main stakeholders involved, among them member States, subregional organizations, international financial institutions, international organizations, the private sector and academia. In line with the draft Regional Roadmap for Power System Connectivity, developed by ESCAP's Expert Working Group on Energy Connectivity (UN ESCAP, 2019), this report offers policy recommendations for addressing the challenges ahead and for making the most of the benefits that a regionally interconnected power system in North-East Asia has to offer.

Third, in line with the Sustainable Development Agenda 2030, adopted by the United Nations Member States in 2015, this report aims to examine the potential of power grid connectivity in North-East Asia from a sustainability perspective. Research carried out to-date has not focused on the linkages between power grid interconnection and sustainable development. As the review of the existing knowledge database will show, while the economic benefits, technical specifications as well as political and security aspects of cooperation towards interconnected power systems in the region are the central focus for analysis, the sustainability of the envisaged interconnection models is rarely addressed. This report, therefore, attempts to make sense of the results offered by the existing studies and to offer policy advice for cooperation towards a *sustainable* power grid connectivity in North-East Asia.

### Sustainability and power grid interconnection: Conceptual framework of the report

As defined by the Brundtland Commission's report, *Our Common Future*, sustainable development is the "development that meets the needs of the present without compromising the ability of future generations to meet their own need" and, as such, is a highly complex and multidimensional concept. This complexity is best

demonstrated by the seventeen adopted Sustainable Development Goals (SDGs), each of which has several further sub-issues (targets and indicators) to be met. For the purposes of this report, the term "sustainability" will be used as defined by the United Nations through the seventeen SDGs.

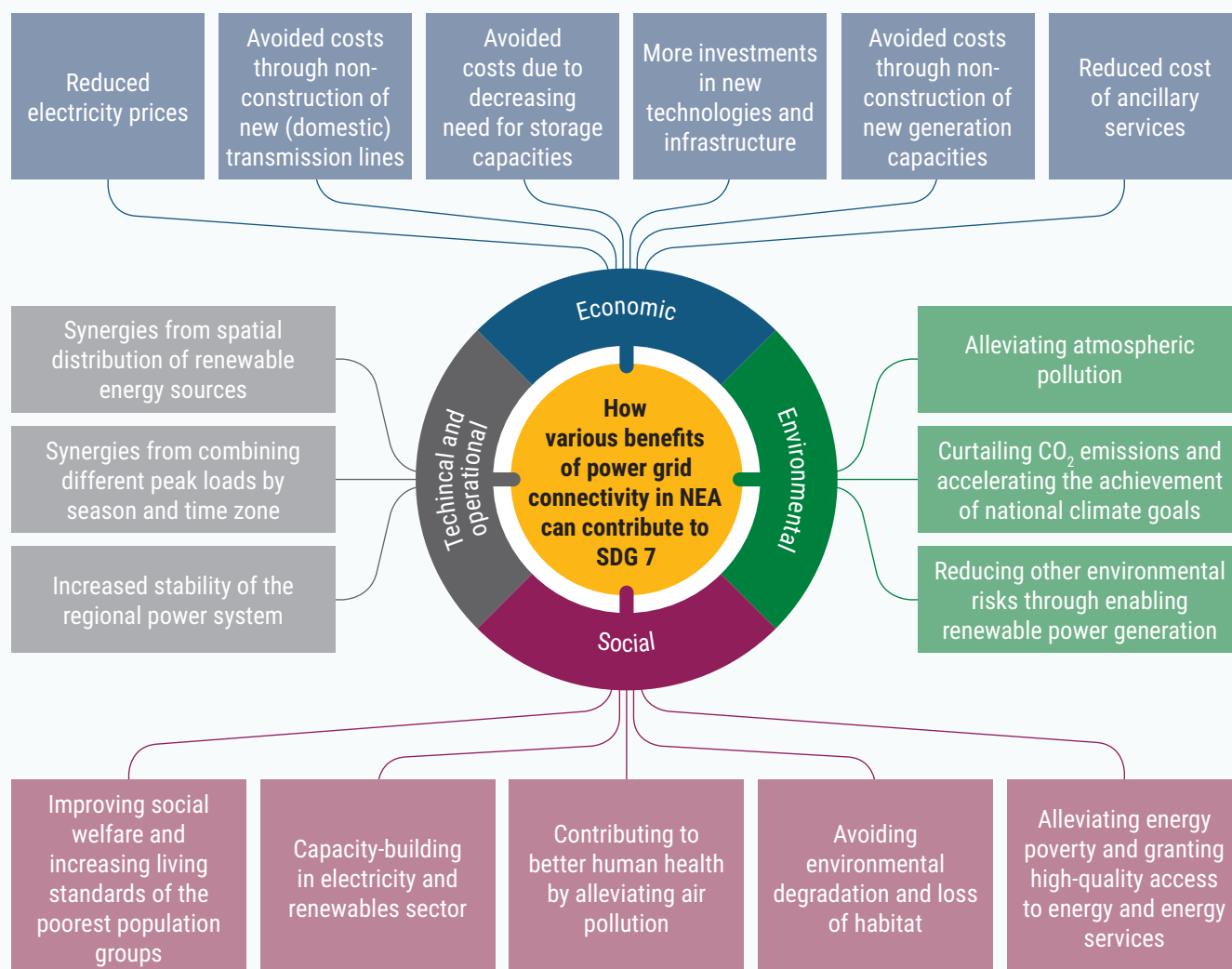
It has become increasingly important to consider changes in global and national energy systems from a sustainability perspective. Aside from the obvious long-term merit of pursuing a sustainable energy system, it allows countries and regions – each of which have their own and often very different policy agendas – to work towards a common vision. Fundamental to economic development and social welfare, energy is perceived to have a strategic value and, as such, is often framed as a matter of national interest. This is reflected in the national energy security agendas, which are based on the economic and political interests of the respective countries and are therefore often very different, or even seemingly conflicting. These perceived differences are one of the major obstacles to cooperation on energy security, be it at the subregional, regional or global scope.

The recently emerged patterns of interstate cooperation on energy transition face the same challenge; there is no universally acknowledged definition of energy transition, and each country has its own preferences for the pathway, means or the desired energy sources towards the future low-carbon energy system. Approaching both issues of energy security and energy transition from a sustainability angle provides national Governments with the necessary common ground for cooperation. Regardless of the political, economic or even geographic conditions of the respective countries, the aspirational future energy system is one which provides universal access to affordable, reliable, sustainable and modern energy (Pastukhova and Westphal, 2020). This has been encapsulated as the Sustainable Development Goal on Energy (SDG 7) within the Sustainable Development Agenda, adopted by the Governments of 193 United Nations Member States.

In a similar manner, approaching cooperation on power grid connectivity from this perspective does not only allow the national Governments and other stakeholders to contribute to a sustainable future. It also provides them with the foundation on which they can build a universally agreed, common vision on power grid connectivity.

Figure 1

Possible contributions of increased power grid connectivity in North-East Asia to SDG 7

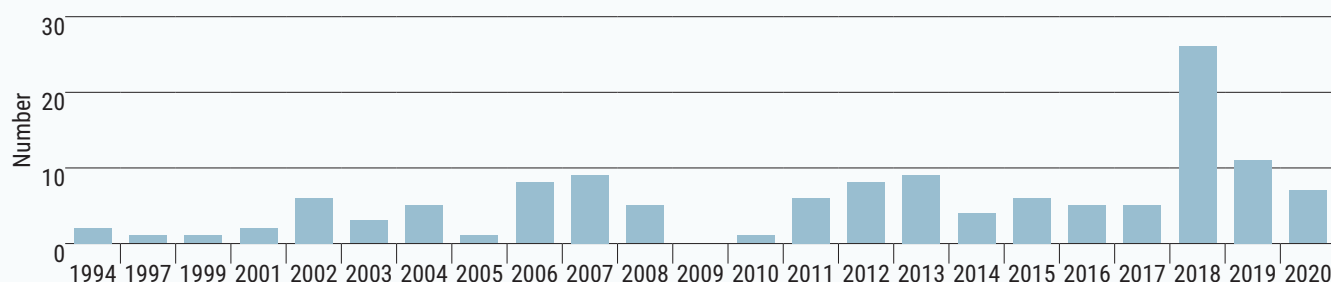


The review of the benefits and challenges of the regional power grid interconnection in North-East Asia will therefore be structured along four thematic pillars (figure 1). The first three are generally acknowledged to be the three main pillars of sustainability – economic, environmental and social. The fourth will address technical benefits and challenges of such interconnection. Due to the fact that a sustainable power system of the future is universally acknowledged to be based on new, low-carbon technologies as well as increasingly interconnected and digitalized means of operation and control, this report deems the pillar on technical aspects to be necessary for a comprehensive picture.

## B. Studies on power grid interconnection in North-East Asia: A review

This report is based on 129 region-specific studies conducted on power grid connectivity issues for the past three decades (figure 2). While certainly not exhaustive, the list of the analysed studies represents a solid knowledge base which, when consolidated, offers a comprehensive overview of the interconnection initiatives proposed up to date, the benefits and challenges of these specific initiatives as well as the general desirability of a regional power interconnection.

With first studies being published in the mid-1990s – the “oldest” in the list of reviewed papers was published in 1994, by researchers from the Melentyev Energy

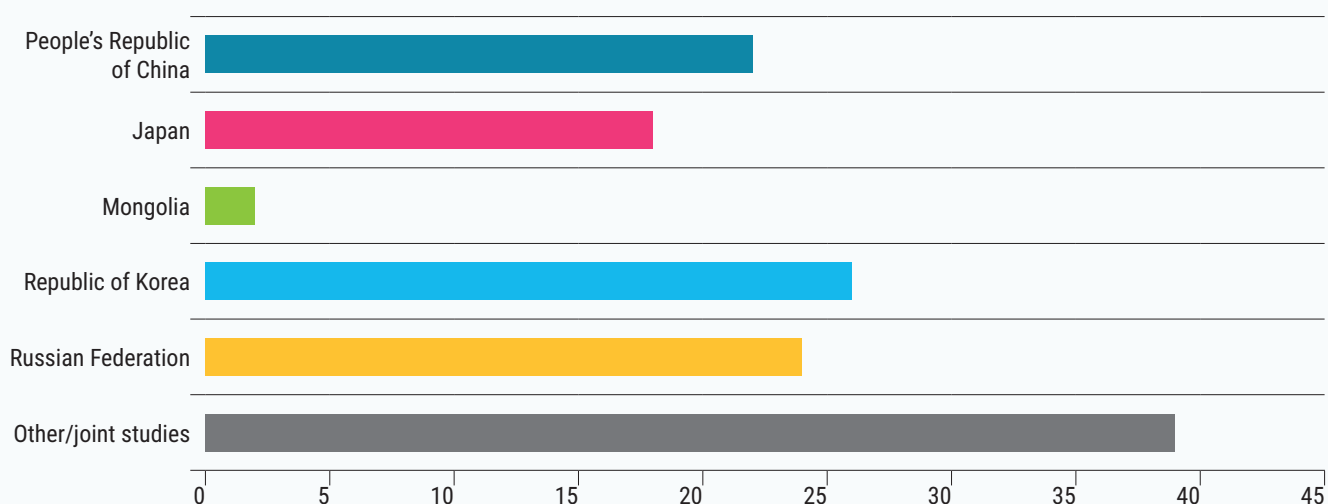
**Figure 2** \_ Studies by year of publication, 1994-2020

Systems Institute (Belyaev et al., 1994) – the knowledge base on power grid interconnection for North-East Asia has been accumulating for nearly three decades. As is demonstrated by the timeline representing the number of studies published in various years, research work on power grid interconnections surged in 2018, which might be related to several factors. Among these are: changes in the political and economic environment increasing urgency of the issue of connectivity; intensified international discussions on the issue, i.e., within the framework of the yearly North-East Asia Power Interconnection and Cooperation (NEARPIC) Forum; and the emergence of the *Global Power Grid Interconnection*, a journal issued by the GEIDCO featuring studies on connectivity. Compilation of the database was completed by late September 2020. Consequently, this report cannot make an accurate statement on the number of studies published in 2020. However, given the fact that the latest studies available

at that time were dated summer 2020, it is safe to assume that research activity on this issue has remained on a level comparable to that of 2019.

Although about one third of the studies have been the result of international cooperation between experts from several institutions, the majority of the reviewed research has been commissioned by and/or conducted under the auspices of the research institutions based in China, Japan, Mongolia, the Republic of Korea and the Russian Federation (figure 3).

In China, the research is led within the China Electric Power Planning and Engineering Institute (EPPEI), Global Energy Interconnection Development and Cooperation Organization (GEIDCO), China Electric Power Research Institute (CEPRI), In Tech China, China Datang Corporation and State Grid Energy Research Institute as well by the experts representing

**Figure 3** \_ Studies by the country of the issuing institution

several universities – among them Dalian University of Technology, Tsinghua University, Xi'an Jiaotong University and Lingnan University (Hong Kong).

Among the Japanese institutions actively engaged in research on these topics are the Renewable Energy Institute (REI), Economic Research Institute for North-East Asia (ERINA), Institute of Energy Economics Japan (IEEJ) and the affiliated Asia-Pacific Energy Research Centre (APEREC), Mizuho Information and Research Institute, TEPCO Research Institute, Tohoku University and Nagaoka University of Technology.

In Mongolia, primarily the Mongolian Energy Economics Institute (MEEI) and the Mongolian State University of Science and Technology (MUST) are working on the issue of power grid connectivity. Although only one study published by researchers from MUST is reviewed within this report, presentations on the national power grid situation and the Mongolian vision of the regional power grid interconnection by the MEEI experts on numerous occasions, during the NEARPIC events, have been taken into account when drafting the country's power system profile.

Experts studying power grid connectivity in Republic of Korea represent Energy Economics Institute of the Republic of Korea (KEEI), The Korea Electrotechnology Research Institute (KERI), Korea Institute for International Economic Policy (KIEP), KEPRI/KEPCO research institute, Korea Electrical Engineering and

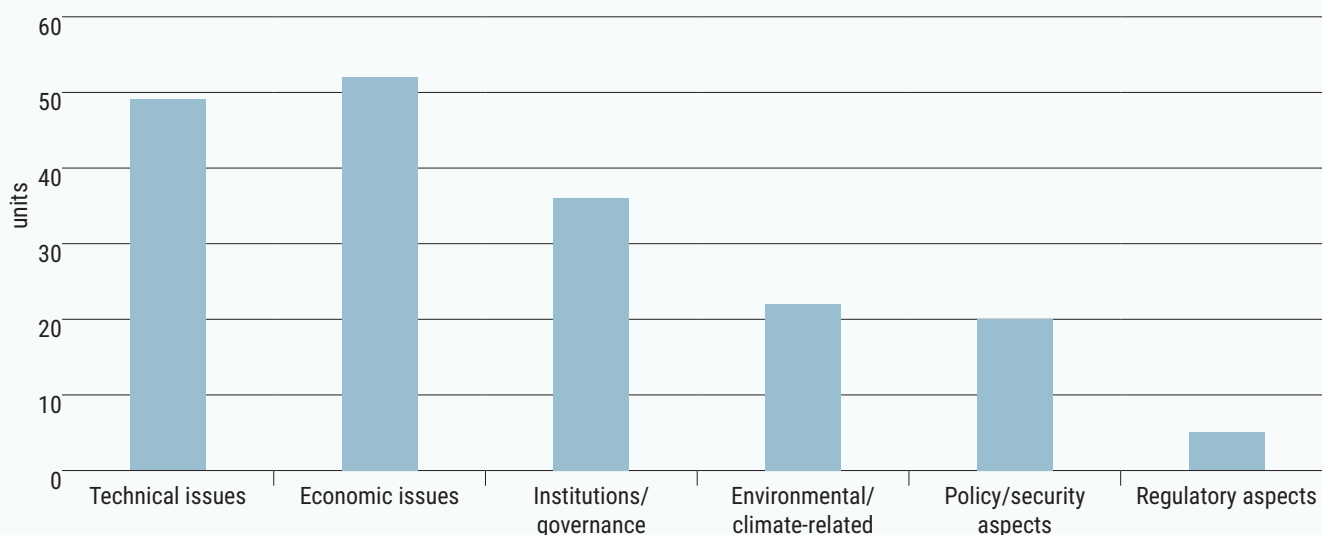
Science Research Institute (KESRI), Samsung Economic Research Institute, Seoul National University, Silla University, Daejin University and Gyeongsang National University, Hongik University

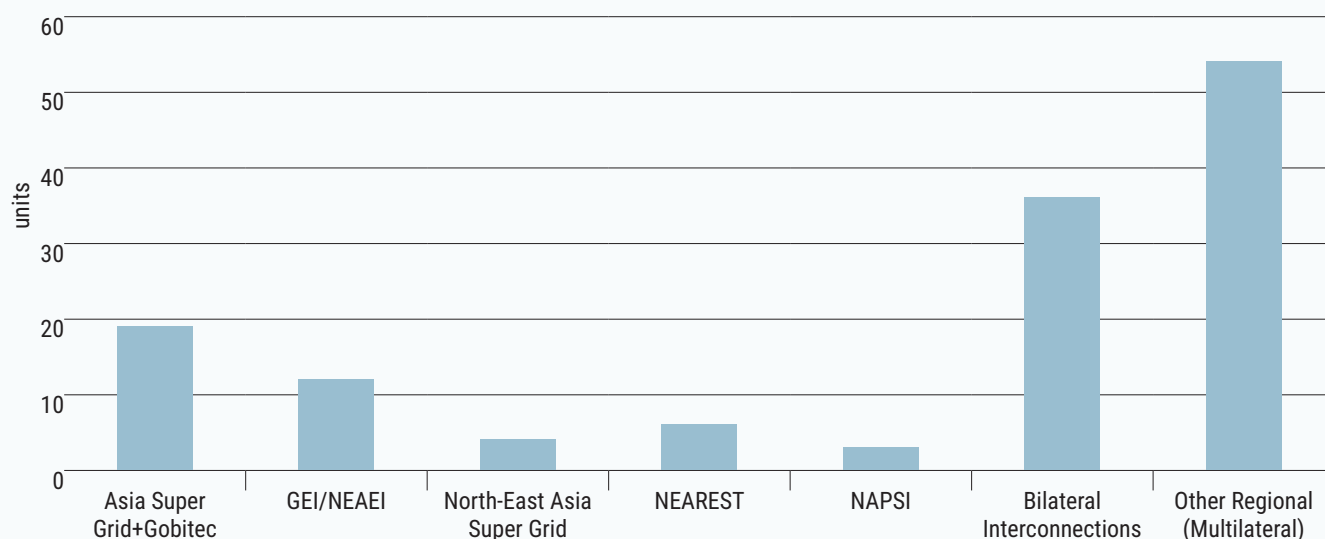
In the Russian Federation, the main body of research is being published by experts from the Melentiev Energy Systems Institute (SO RAN), while other research institutes, among them Skolkovo Institute of Science and Technology and Khabarovsk Economic Research Institute, are addressing the issue.

The international organizations and research institutions from outside the region that are working on the issue include the Institute of Electrical and Electronics Engineers (IEEE), Energy Charter, the Asian Development Bank (ADB), the International Energy Agency (IEA), and the International Electrotechnical Commission (IEC). The issues addressed by the studies on North-East Asia connectivity are shown in figure 4.

When it comes to the thematic scope, technical and economic issues dominate the analysis. The inherent question addressed by the majority of studies is related to the integrated value of enhancing cross-border transmission links or developing a regional power grid interconnection. Various power interconnection initiatives are analysed regarding their potential to contribute to a wide array of issues, such as reducing electricity cost, improving energy infrastructure, improving energy security, driving economic growth,

**Figure 4** – Issues addressed by the studies on North-East Asia connectivity



**Figure 5** \_ Interconnection projects in focus

reducing environmental emissions and creating new employment opportunities.

It is important to note that the issues under focus differ among the research institutes of the different North-East Asian countries, which is an indication of the differences in the respective energy policy agenda of these countries. While Japanese and Korean research institutes pay more attention to electricity cost, design of the power system and security of energy supply, the Russian Federation and Mongolia focus on the potential to boost economic growth and the creation of employed positions. Another focus of studies led by Korean experts are environmental concerns together with the issue of emissions reduction, which are also the major focus of the research conducted by Chinese institutions. Figure 5 illustrates the Interconnection projects now in focus

A review of the interconnection projects in focus of the respective studies shows that, rather than a concrete vision for regional power grid interconnection, the existing research addresses various aspects of power grid connectivity applied to the North-East Asian region. In contrast to that, another major part of the studies presents more detailed estimations and feasibility studies of concrete bilateral interconnection projects. Although studies of concrete regional interconnection initiatives – including the North-East Asia Super Grid, North-East Asian Region Electric System Ties (NEAREST), North-East Asia Power System Interconnection (NAPSII), Asian Super Grid

and Gobitec as well as the North-East Asian section of the Global Energy Interconnection (NEAEI)<sup>4</sup> – have been published, particularly in the recent years, the dominant focus on general issues of connectivity and bilateral interconnections demonstrate the current lack of a common vision on power grid connectivity among North-East Asian countries.

### C. Regional specifics of North-East Asia: Inherent obstacles and new stimuli for cooperation on power grid connectivity

There are many examples of successful integration of the power markets on the regional scale, with the most prominent examples being the European and the North American power grids. These experiences cannot, however, be directly transferred to North-East Asia, where several region-specific factors have long impeded cooperation on regional power grid connectivity.

First, geographic constraints have long been, and still remain, a major obstacle to the development of regional interconnection ties. For example, building a regionally interconnected power system would inevitably

<sup>4</sup> Focus on one of these interconnection initiatives is, to a large extent, predetermined by the institute of origin of the respective initiatives. For example, the NEAREST initiative has been developed by KERI, GEI by GEIDCO and the Asian Super Grid by the Renewable Energy Institute.

involve construction of submarine transmission lines, which, until very recently, have not been considered cost-efficient. Long distances between major power generation centres and load centres as well as rough terrain in many parts of continental North-East Asia are further complications that require implementation of technically complex solutions in order to enable power exchange between the countries. Lack of the infrastructure necessary for the construction of transmission lines in the less populated areas adds another challenge that even further increases the upfront cost of power interconnection projects.

Second, the perceived need for cross-border interconnections has not been very pronounced in the past three decades. Until recently, electricity demand in the North-East Asian countries has been largely met by domestic power generation (with the exception of Mongolia).

Finally, political tensions in the region remain the biggest obstacle for the cooperation on regional power grid connectivity. Although there have been no large military conflicts in the region since the end of the Korean War, historical sentiments, multiple territorial disputes and geopolitical rivalries impede regional cooperation. The countries of North-East Asia will have to overcome past political disagreements in order to move towards regional cooperation on power grid connectivity. Once the first step has been taken, cooperation on power grid connectivity itself could become a central impetus towards deeper political integration, contributing to peace and security in the region.

Despite the aforementioned challenges, momentum to begin cooperation has been building up for about a decade and recent political and economic developments, both on the regional and the global scale have added a new sense of urgency to the issue of power grid connectivity. Notwithstanding their different climate and energy agendas, all member States in North-East Asia have committed to the climate agenda introduced by the Paris Agreement on Climate Change in 2015. As of October 2020, China, Japan and the Republic of Korea have raised their climate ambitions even further by setting net-zero emission targets. Coal-fired power generation has been the central source of electricity for the most energy-hungry countries of the region, China, the Republic of Korea and Japan; this remains as the main contributor to the region's heavy air pollution and a major source of carbon emissions. However, since

the past decade a major transformation of the regional energy system has begun to take place. Low-cost renewable generation technologies have entered the market and are being increasingly deployed in the North-East Asian countries. Domestic grids cannot adequately respond to these profound changes, which necessitates the development of regional power interconnections.

After the Fukushima Daiichi nuclear disaster, skepticism with regard to nuclear energy as a source of low-carbon electricity has risen in many countries, including some in North-East Asia. The current Government of the Republic of Korea has introduced plans to phase-out nuclear energy over 60 years. In Japan itself, although nuclear power plants have been gradually re-started and nuclear power generation reintroduced into the national power mix, public acceptance remains relatively low (JAERO, 2017; ERIA, 2018). Renewables (solar and wind) have become an increasingly attractive and cost-effective option. Under these circumstances, strengthening and enhancing the power transmission system beyond national borders gains additional importance as the means of enabling further deployment of variable renewable energy sources.

Meanwhile, regional demand for electricity has dramatically risen in recent decades, mainly due to China's economic growth, and is projected to rise even further due to, among other reasons, the continuing efforts to further electrify national economies, in particular the transport sector. To meet this rising demand in a sustainable way, the share of electricity from renewable sources will have to grow in all North-East Asian countries. A regional power grid interconnection is therefore not only necessary in order to enable a bigger share of renewable energy to be introduced into the power systems. It would provide critical infrastructure that enables power flows between areas with high renewable energy potential and areas with high electricity demand, which are not necessarily always located within the same national borders.

Finally, institutional changes have been taking place on the regional scale that create favorable environment for the cooperation on power grid connectivity. In 2016, SoftBank Group, the State Grid Corporation of China (SGCC), Korea Electric Power Corporation (KEPCO), and PJSC ROSSETI, the operator of the Russian Federation's energy grid, signed a Memorandum of Understanding (MoU) on joint research and a plan to promote an interconnected electric power grid in North-East Asia

(Soft Bank Group, 2016). A year later, SGCC and KEPCO proceeded with the partial implementation of this connectivity vision by drafting an agreement on China-Republic of Korea power interconnection in late 2017. The construction of the interconnection is planned for 2022. Furthermore, in 2019, Mongolia's largest state-owned mining company, Erdenes Mongol LLC, signed an MoU with ROSSETI on joint research and development of integration links of North-Eastern Asia's power grids, including the necessary primary efforts to enhance and improve reliability of Mongolia's power system (Rosseti, 03.09.2019).

More broadly, the Regional Comprehensive Economic Partnership (RCEP) Agreement is a proposed free trade agreement (FTA) between 15 countries, three of which are in North-East Asia. At present, there is no common regulatory framework for trade among the three countries, and although RCEP does not cover energy issues, it could nevertheless potentially serve as a stepping stone towards a regional framework for energy exchange in North-East Asia and beyond. Since 2003, China, Japan and Republic of Korea have been negotiating a separate free trade agreement. This agreement, if adopted, would take the RCEP Agreement as its baseline, and would therefore be considered a "RCEP Plus" free trade agreement (Ministry of

Commerce, 4/17/2019). As such, it could also include agreements on energy trade if, in the end, they are not included in the RCEP Agreement.

## D. Structure of this report

The remaining sections of this report are structured as follows. Chapter II offers an overview of the energy situation in North-East Asia on the regional level as well as on the level of national energy systems. In particular, the chapter focuses on the renewable potential of the region, and the progress on the sustainable goal on energy (SDG 7) of the respective Member States. The specifics of their respective power systems are included in the Appendix. Chapter III offers an overview of the existing interconnections, as well as the regional power grid interconnection projects currently under discussion. Chapter IV reviews potential benefits resulting from and challenges that need to be addressed on the way towards a regional power grid interconnection. Chapter V suggests policy options to be considered by the national governments and other relevant stakeholders, in order to develop and pursue a common vision on regional power grid interconnection in accordance with Sustainable Development Goals. Chapter IV concludes.

# Background

## Energy systems in North-East Asia

**N**orth-East Asia is a key global player when it comes to energy and shifts in subregional energy demand and supply have a significant impact on global energy balance (table 1 and figure 6). The subregion is home to the world's top three natural gas importing countries, three out of the top five crude oil importing countries, one of the world's major leaders in the production of natural gas and crude oil, and four out of the 10 leading countries in terms of electricity production. In line with its global energy footprint, North-East Asia is also the region responsible for more than one third of global carbon emissions.

During the past three decades, rapid economic growth in North-East Asia quickly increased regional demand for energy. Total primary energy supply in the region, which amounted to 2,330 Mtoe in 1990, grew almost twofold to 4,695 Mtoe in 2018 (IEA, 2020). Today, North-East Asia is a dominant player in global energy markets, with a total primary energy supply (TPES) in the region amounting to approximately 32.9% of the global energy supply (14.279,5 Mtoe).

Table 1

Key energy statistics for North-East Asian economies, 2018

	Total primary energy supply (TPES) (Mtoe)	TPES per capita (toe per capita)	Total final energy consumption (Mtoe)	Total energy production (Mtoe)
People's Republic of China	3,210.7	2.3	2,066.7	2,570
Democratic People's Republic of Korea	14.3	0.6	5	14.3
Japan	426	3.4	283	52
Mongolia	5.6	1.8	3.9	26.6
Republic of Korea	278	5.5	182.2	61
Russian Federation	760.4	5.3	514.5	1,477
Total	4,695	-	3,055.3	4,200.9
Global Share of NEA (%)	32.8	-	30.7	29.1
World	14,279.5	1.9	9,937.7	14,421

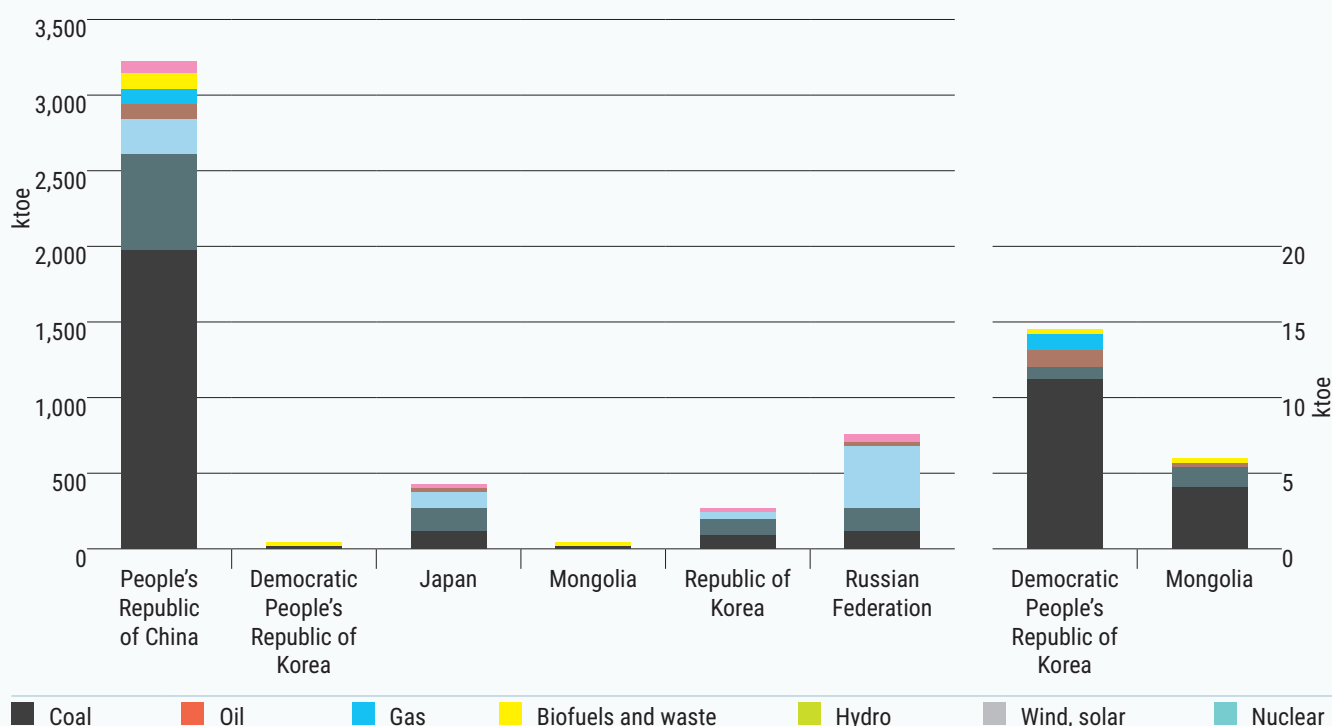
Source: Yearbook Enerdata, IEA 2020a, IEA 2020b

China accounts for two-thirds of the regional TPES (68.4%), with the Russian Federation, Japan and the Republic of Korea occupying second, third and fourth place (16.2%, 9% and 5.9%, respectively). The Democratic People's Republic of Korea and Mongolia account for less than 1% of the regional TPES each (0.3%

and 0.1% respectively). Source-wise, coal dominates the regional energy mix with 49% of TPES, which is almost two times more than the global average (26.8%). Oil is the second-biggest energy source (22%), followed by natural gas (17%).

Figure 6

Total primary energy supply by source, 2018 (Mtoe)



Source: IEA 2020a.

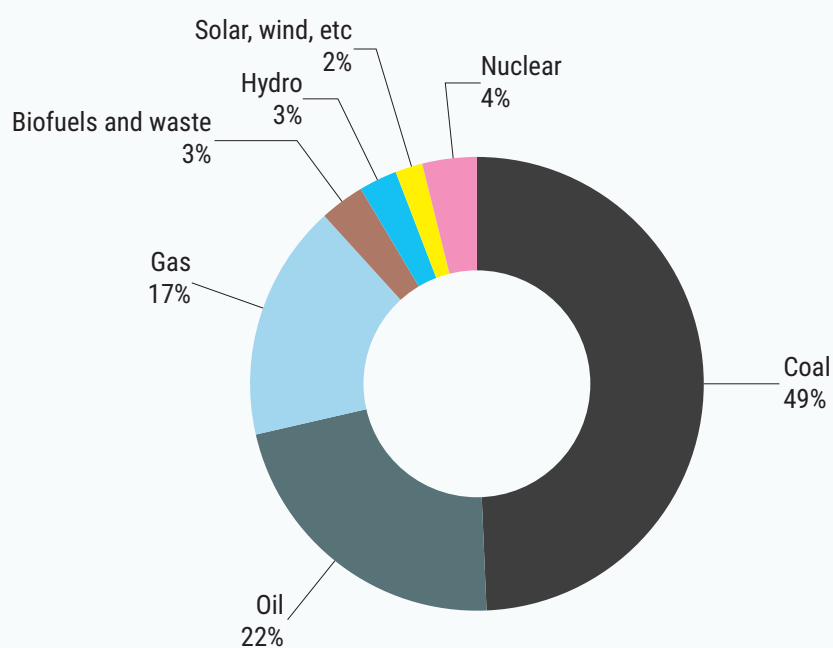
Electricity consumption (TWh)	Energy intensity (toe/ thousand) 2015 US\$ (PPP)	Total CO <sub>2</sub> emissions (Mt)	CO <sub>2</sub> emissions from heat and power generation (Mt)	CO <sub>2</sub> intensity of energy mix (t CO <sub>2</sub> /toe)
6,880	0.13	9,570.8	4,890.3	3.0
13	0.13	15.3	2.9	1.1
1,012.8	0.08	1,080.7	500.6	2.5
7.3	0.14	21.1	13.5	3.7
572	0.13	605.8	328.3	2.2
999.4	0.21	1,587	778.2	2.1
9,484.5	-	12,880.7	6,513.8	-
38.3	-	38.4	47	-
24,738.9	0.12	33,513.3	13,823.7	2.4

Hydropower and further modern (non-combustible) renewable energy sources, such as wind and solar energy, account for 3% and 2% of the total energy mix, respectively. According to most energy outlook analyses (e.g., BP, IEA, IEEJ, Shell, Skolkovo, World Bank), at least until 2040 coal will remain one of the major

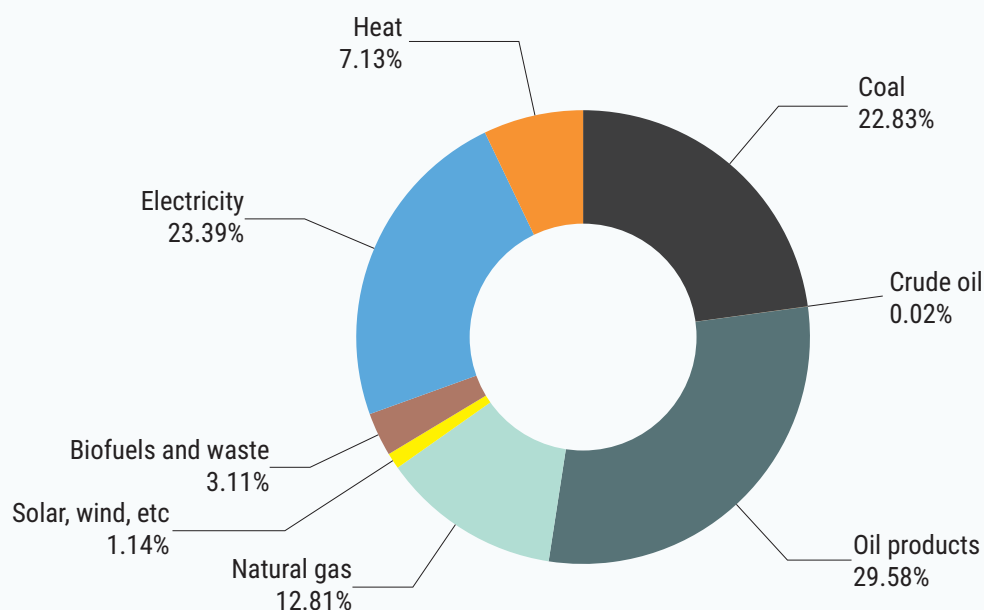
sources of primary energy in the subregion, despite legitimate concerns about air pollution and greenhouse gas emissions. Greater efforts are needed by the Governments of this subregion to embrace less polluting and more efficient power generation technologies if this outlook is to be improved.

Figure 7 \_

TPES, Regional Energy Mix (2018)



Source: IEA 2020a.

**Figure 8** Total final energy consumption in NEA by source (2018)

Source: IEA 2020a.

## A. Total final energy consumption

Coal is also the primary source for total final energy consumption (TFC) in the subregion, accounting for 22.8%, which is more than twice the global average (10.5%). On the positive side, the share of electricity in the total final energy consumption in the subregion (23.9%) is considerably higher than the global average (18.9%), while the use of oil products is more than one-fourth lower (NEA, 29.5% and global, 40.9%). In absolute terms, the share of coal in the subregional energy mix has been decreasing for the past several years (e.g., 28.3% in 2015 as opposed to 22.8% in 2018) (figure 8), mainly due to China's decarbonization efforts and countermeasures against air pollution. As China expands its coal-to-gas and coal-to-electricity measures to enable cleaner heating options for Chinese households, the share of natural gas in its energy mix is expected to grow by 166% until 2040, accounting for 14% of the total energy mix (BP, 2019a).

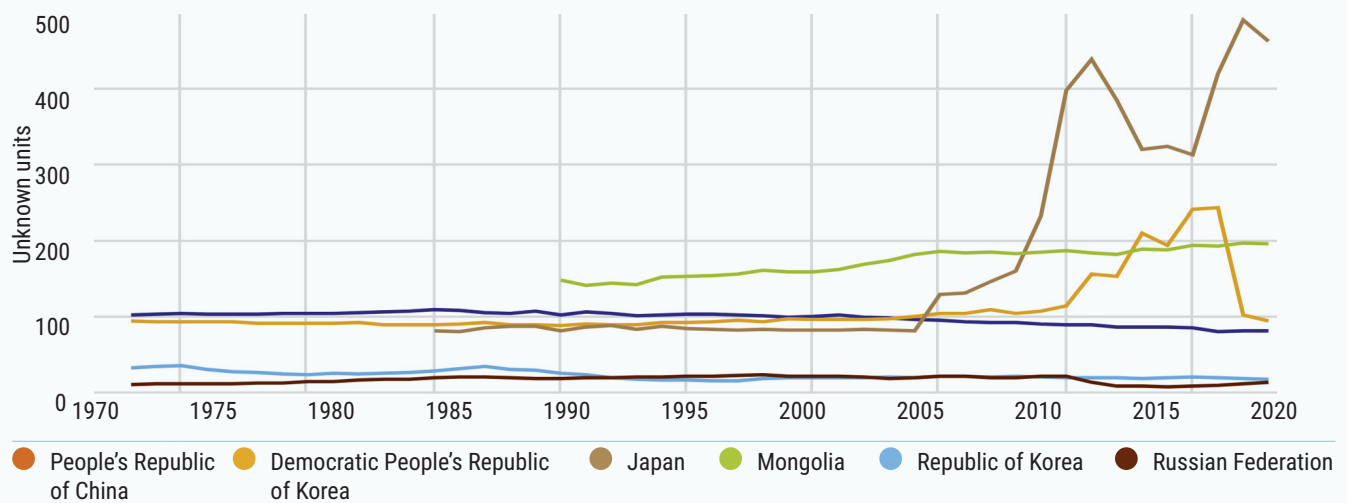
### Energy production and energy self-sufficiency

Natural energy reserves are distributed unevenly among North-East Asian countries, causing national energy production volumes to differ significantly. In addition, the self-sufficiency levels in the subregion vary greatly, and the countries could be roughly divided into two

groups – energy exporting (Russian Federation and Mongolia) and energy importing countries (China, Japan and the Republic of Korea). As demonstrated in figure 9, the Democratic People's Republic of Korea produces nearly 100% of its domestic energy demand and is formally self-sufficient. However, given the low levels of energy access in the country, it is safe to assume that, should larger shares of the population get access to energy, the current domestic levels of energy production would not suffice to cover the domestic energy demand.

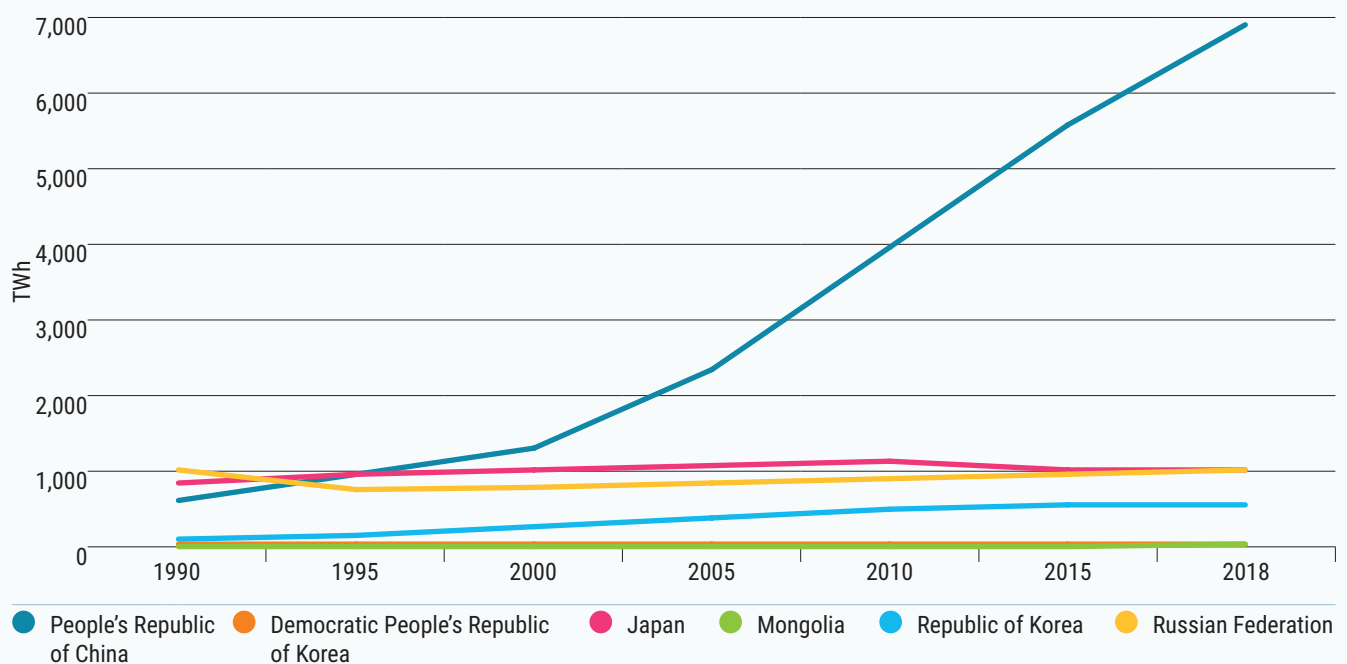
Among the energy-exporting countries, the Russian Federation is a major global player – in 2018, the Russian Federation remained the second largest gas, and the third largest oil producer, accounting for 17% and 12% of the global output, respectively (BP, 2019b). Export of energy resources dominates the Russian Federation economy and accounted for 54.5% of total export in 2018 (Ru-Stat, 2019). Mongolia exports about 73% of its annual coal production and is dependent on revenues from coal export that constitute about 33% of country's total exports (OEC, 2020).

As of 2018, Japan and the Republic of Korea had to import 88% and 84 % of their primary energy supply and are thereby among the most import-dependent countries in the world. Japan's historically low self-sufficiency ratio abruptly decreased even further after

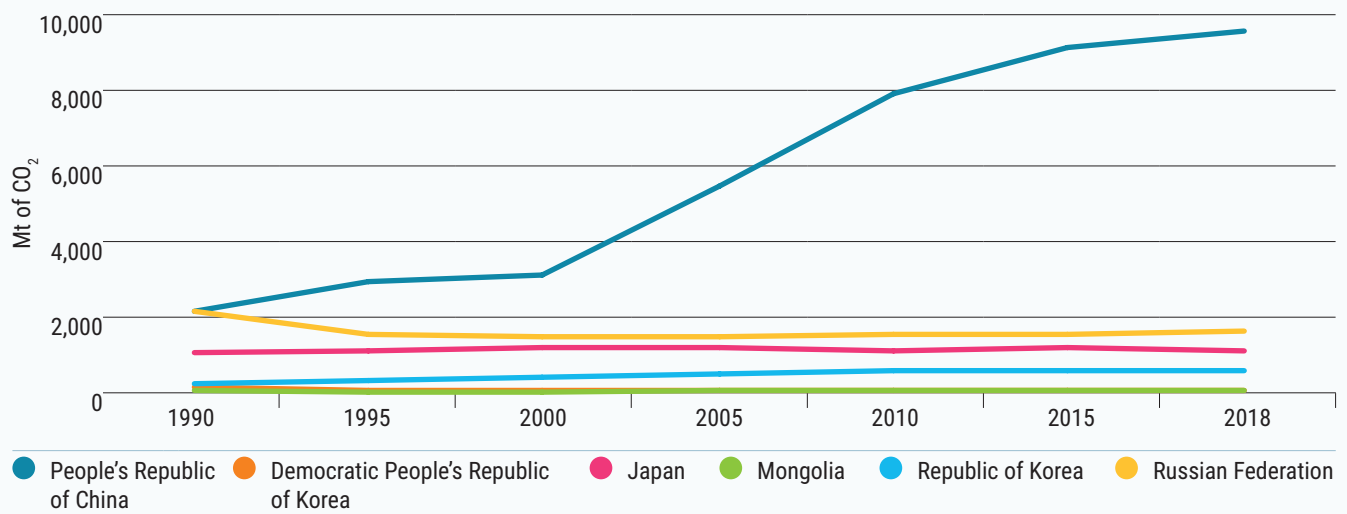
**Figure 9** – Self-sufficiency (total energy production/TPES, %), 2018

the Fukushima nuclear disaster (from 19.9% in 2010 to 6% in 2014) and the following phase-out of the country's nuclear power plants. Although some of the power plants were put back online, their output is not sufficient to cover any significant share of the domestic energy demand (METI, 2016). With the major share of

their crude oil imports coming from the Middle Eastern countries, most notably Saudi Arabia, the United Arab Emirates, Kuwait and the Islamic Republic of Iran, both Japan and the Republic of Korea are highly sensitive to the political situation in the region (EIA, 2018).

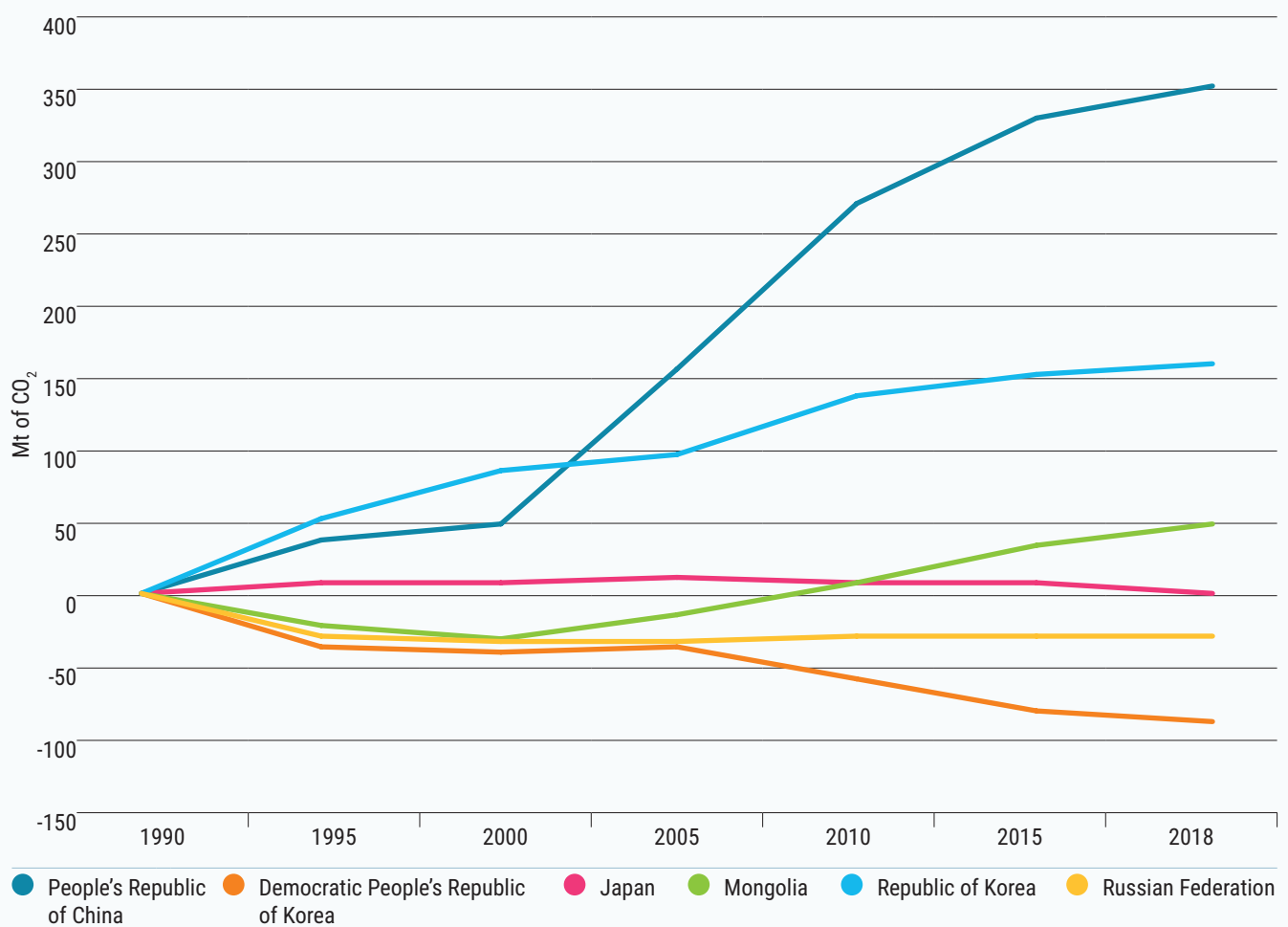
**Figure 10** – Electricity consumption in North-East Asia, 1990–2018, TWh

**Figure 11\_A** Total CO<sub>2</sub> emissions by country, 1990-2018 (Mt of CO<sub>2</sub>)



Source: IEA 2020a.

**Figure 11\_B** CO<sub>2</sub> emissions growth by country, compared to the 1990 level, 1990-2018 (%)



Source: IEA World Energy Balances 2019.

China imports about 20% of its primary energy supply and covers the rest through domestic production. China had been self-sufficient until the early 2000s, but shortly afterwards domestic energy production could no longer keep up with country's rapid economic growth. Consequently, China began importing crude oil, coal and gas, in order to supply the energy-thirsty economy. Natural gas imports have gained particular importance in recent years, as China attempts to decarbonize its economy and replace some of its coal consumption with this less carbon-intensive fossil alternative. As of today, China is the world's largest natural gas and oil importing country.

North-East Asia is home to four out of the 10 largest electricity consuming countries (China – 27.8%, Japan – 4%, Russian Federation – 4%, the Republic of Korea – 2.3%), (figure 9). Altogether, North-East Asian countries account for more than one third of global electricity consumption (38.3%). The total volume of electricity consumption in the region has grown considerably since the 1990, which is primarily due to China's rapid economic development and the rise of national electricity consumption by more than 10 times from 1990 (603 TWh) to 2018 (6880 TWh) (figure 10).

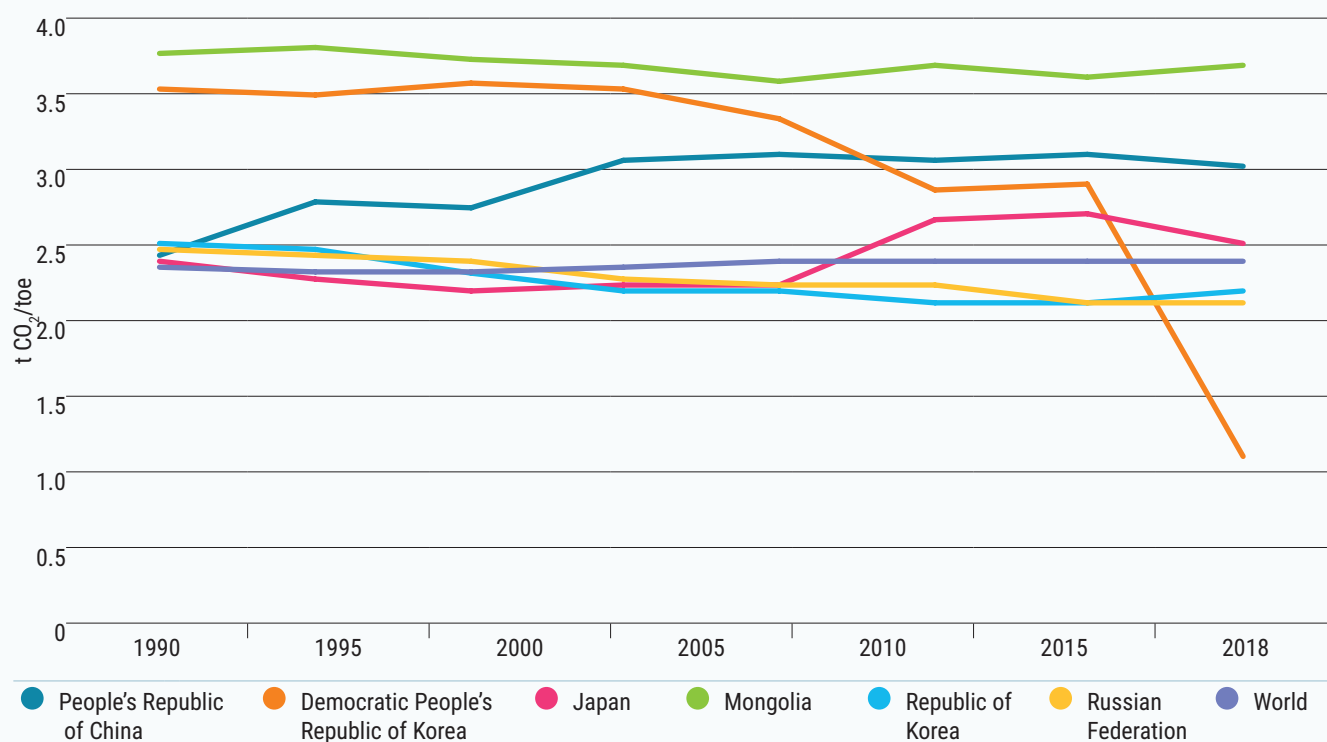
### CO<sub>2</sub> emissions

Energy consumption in the region has dramatically increased over the last two decades, primarily due to China's economic development and the consequent rise in energy demand. The increase in energy consumption, dominated by coal and other fossil fuels, has been accompanied by soaring carbon emissions, particularly in China (figure 11a).

The share of North-East Asia in the world's carbon energy emissions grew from 26.7% in 2000 to 38.4% in 2018, whereas China is responsible for 74.3% of the subregional and more than 25% of global carbon emissions (figure 11b) (IEA 2020, author's calculations).

Emission levels increased by more than 350% in China, by ca. 160% in the Republic of Korea and by 48% in Mongolia since 1990, driven by economic growth and increased energy consumption (figure 12). Emission levels in Japan have been holding at the approximately same level for the last 30 years and have been about 2.5% over the 1990 level in 2018, while the emission levels in the Russian Federation and the DPRK have dropped significantly since 1990 (26.6% and 87%,

**Figure 12** CO<sub>2</sub> intensity of the energy mix by country, 1990–2018 (t CO<sub>2</sub>/toe)



Source: IEA Data Services 2020 (available online).

respectively), mainly as the result of the economic downturn.

The energy sector is by far the biggest source of CO<sub>2</sub> emissions in the subregion, with emissions from electricity and heat generation accounting for 47% of the total CO<sub>2</sub> emissions (see table 1 for country details). Aside from the Democratic People's Republic of Korea, the Republic of Korea and the Russian Federation, the CO<sub>2</sub> intensity of the national energy mixes in North-East Asia is well above the world average.<sup>5</sup> Both indicators (CO<sub>2</sub> emissions of the energy sector and CO<sub>2</sub> intensity of the energy mix) point to the dominance and even further growth of the role of coal as the primary fuel in the subregional energy mix, and signify the dire need to decarbonize the energy sector.

Reducing CO<sub>2</sub> emissions is among the core goals of the sustainable development agenda, and a central part of the Paris Agreement on Climate Change. All countries in the subregion have either ratified (China, DPRK, Mongolia and the Republic of Korea) or accepted (Japan and the Russian Federation) the Paris Agreement and presented their own Nationally Determined Contributions (NDCs) until 2030. By 2030, China pledged to peak CO<sub>2</sub> emissions, while reducing the carbon intensity of its economy by 60% to 65% below the 2005 level. Japan has committed to reducing CO<sub>2</sub> emissions by 26% below 2013 levels (UNFCCC, 2015a), and the Russian Federation by 20-30% below the 1990 levels (Climate Action Tracker, 2020). The Republic of Korea, Mongolia and DPRK pledged to reduce CO<sub>2</sub> emissions, compared to the projected emissions level under a business-as-usual (BAU) scenario, by 30% (UNFCCC, 2015b), 14% (UNFCCC, 2015c), and 8%, respectively. While the 8% reduction is an unconditional contribution pledged by the DPRK, there is another, conditional contribution – up to 34% below BAU, given the international cooperation on the implementation of the Paris Agreement, including financial support, is in place. China, Japan, and the Republic of Korea have further raised their climate ambitions in autumn 2020, by setting net-zero emission goals. China and the Republic of Korea pledged to achieve carbon-neutrality, i.e. net-zero CO<sub>2</sub> emissions, by 2060 and 2050, respectively (Hook, 2020 and Gerretsen, 2020).

5 The CO<sub>2</sub> intensity of Japan's energy mix has significantly risen after the Fukushima nuclear disaster and the consequent reduction of the share of (low-carbon) nuclear power and the increase of coal and gas in the total primary energy consumption.

Japan pledged to become climate-neutral, i.e. to achieve net-zero greenhouse emissions, by 2050 (Kankyo Business, 2020). With these recent net-zero pledges set by its largest economies, North-East Asia has become a subregion with one of the most ambitious climate targets worldwide.

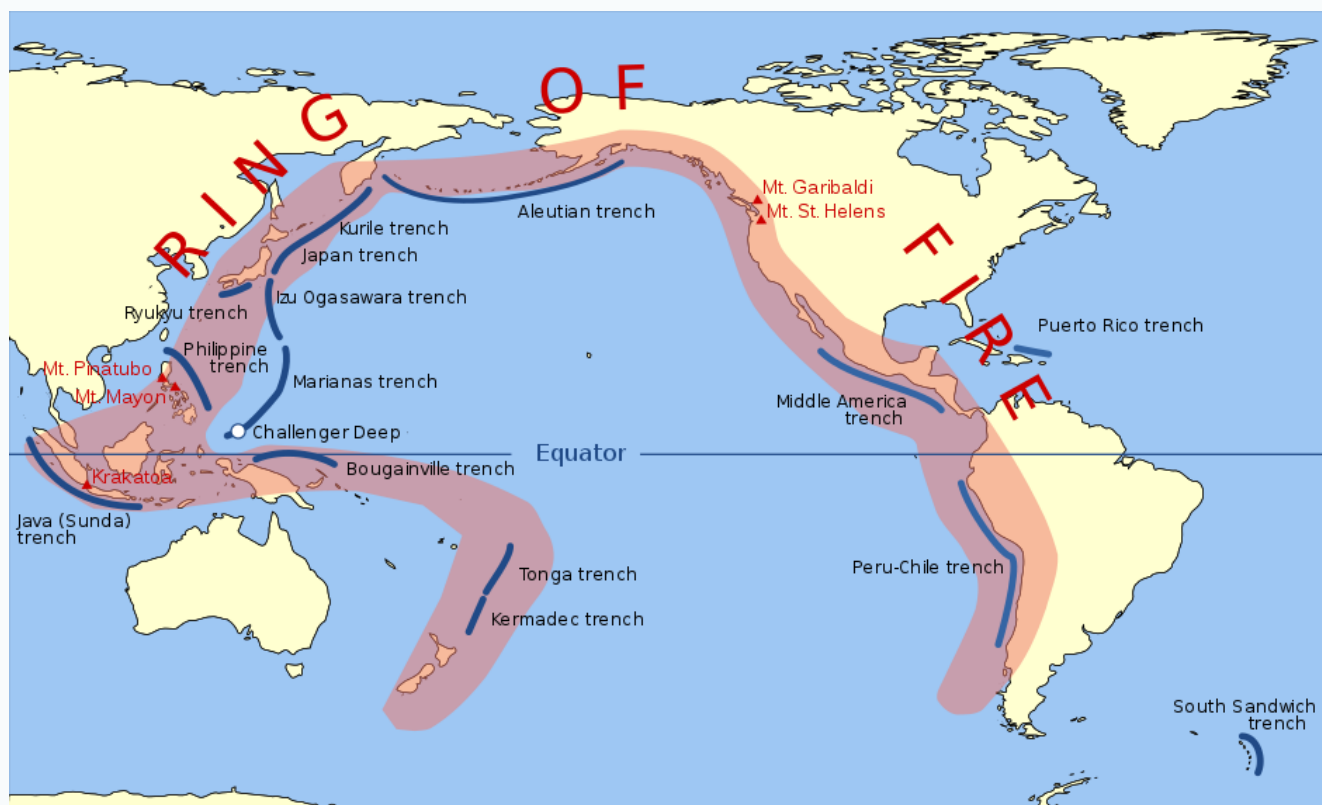
## B. Renewable potential of the region

North-East Asia is a region richly endowed with renewable energy resources that are used for electricity generation, particularly hydropower, solar, wind and geothermal (see the maps in Appendix II). These resources are distributed unevenly between North-East Asian countries, with photovoltaic power output being the highest in the central and southern parts of Mongolia as well as in Tibet and the northern provinces of China. Areas in Mongolia's Gobi Desert and the northern and north-eastern parts of China have the largest technical potential, given their relatively flat landscape and low level of urbanization. These areas are also very rich in wind resource. While theoretical onshore wind potential in the Russian Far East (Kamchatka, Magadan and Primorye) and Japan's northern island Hokkaido is very high, the technical potential is lower given the steepness and roughness of terrain.

Offshore wind potential is generally very high in the coastal areas of the region, while areas along the shores of the Russian Far East (Kamchatka, Sakhalin and Primorye), and Japan's Hokkaido island are among areas with the world's highest potential for offshore wind installations. There, mean wind speed ranges between 8.5 and 9.75 m/s and the average wind density is between 700 and 1300 W/m<sup>2</sup>.<sup>2</sup> Aside from Mongolia, North-East Asia is very rich in hydropower resources. China has the world's highest hydropower potential of up to 2,474 TWh per year, while the Russian Federation possesses the world's second-largest hydropower potential of up to 1670 TWh per year (Belyaev et al., 2015).

As the region is located along the collision lines of tectonic plates (the so-called Pacific Ring of Fire; figure 13), the physical potential for geothermal power generation is considerable, especially in the outer areas of the Kamchatka peninsula (IEG RAS (2015) and in Japan (IRENA, 2017b). Despite Japan's considerable geothermal potential, further development of these resources is difficult, given that most undeveloped

Figure 13 \_ The Pacific “Ring of Fire”



Source: Wikimedia Commons

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

geothermal resources are located in national parks and protected areas.

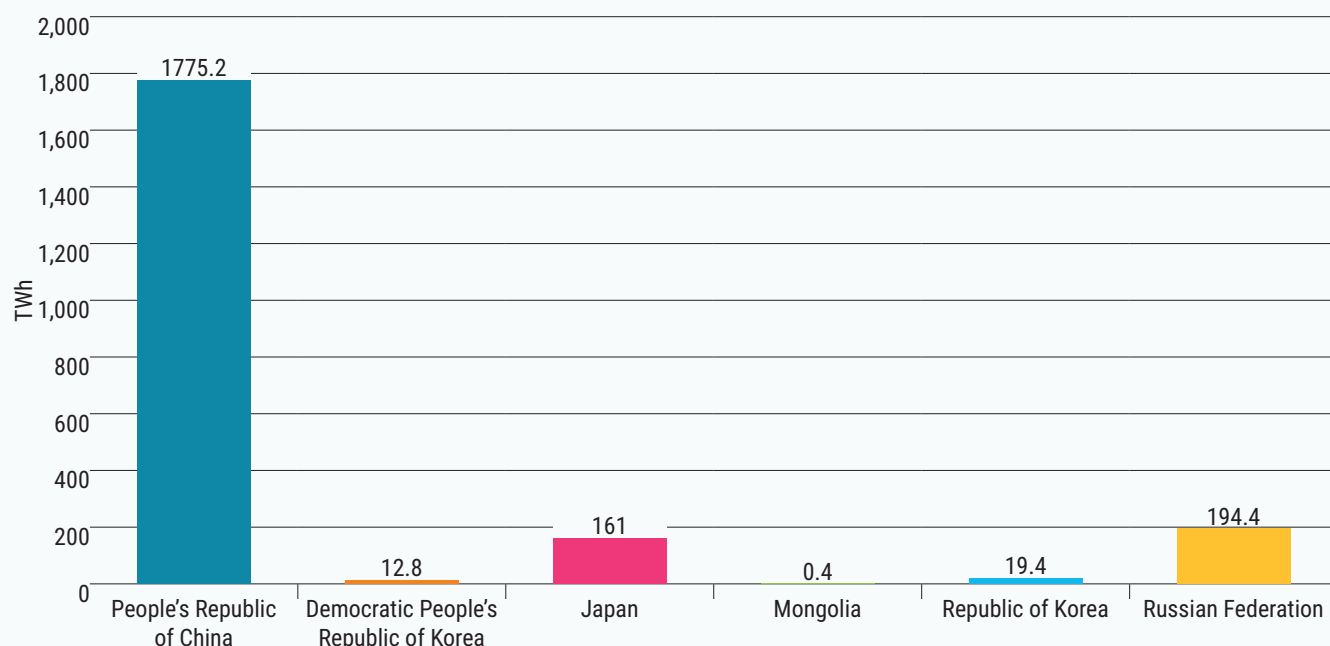
Despite the vast renewable energy resources available, only a fraction has been exploited up to now. While China actively develops solar generation capacities in its northern provinces, Mongolia's solar and wind potential remains practically untouched due to low domestic power demand, the remote location of the areas with high solar and wind potential from Mongolia's load centres, and the inability of Mongolian economy to fund the costly required infrastructure. While the gross hydropower potentials of the rivers in the Eastern Siberia and Far East regions account for 41.4% and 42.1%, respectively, of the national hydropower potential, one-fifth of the potential in Eastern Siberia and only 3% of the Far East has been tapped so far. Some areas in the Far East are already at overcapacity compared to local demand, in particular because domestic electricity demand in the area grows very slowly. Although domestic demand is expected to grow due to increased activity of the railway, oil transport and

coal mining sectors, plans to install new capacities are currently contingent on exporting the excess electricity to China (Interfax, 12/30/2014).

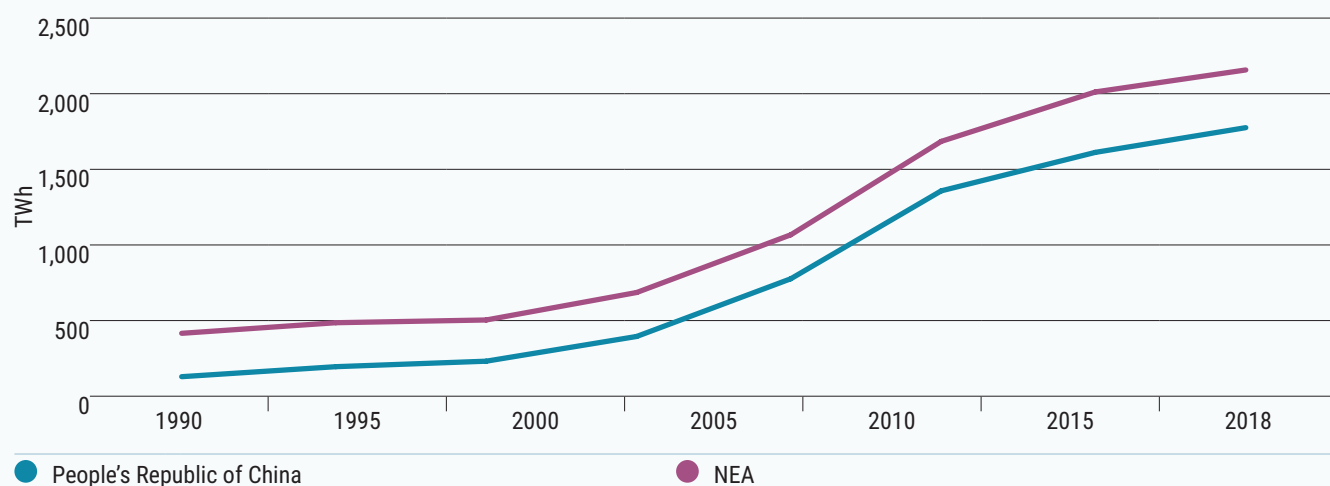
#### Renewable energy sources and power generation in North-East Asia

In the past three decades, renewable energy generation in North-East Asia has risen from around 413.5 TWh to a soaring 2163.2 TWh (2018), an increase of 523%. The lion share of this contribution belongs to China, whose renewable energy generation has grown tenfold and, with 1775.2 TWh, constituted about 82% of the total renewable electricity generation in the region as of 2018 (figures 14a and 14b).

Japan and the Republic of Korea have also recorded a considerable increase in their share of renewables in the electricity generation mix (twofold and threefold, respectively). Mongolia introduced its first renewable (hydropower) generation facilities in 2000 and, a decade later, introduced its first wind power plant; this

**Figure 14\_A** Renewable electricity generation by country, 2018 (TWh)

Source: IEA 2020a.

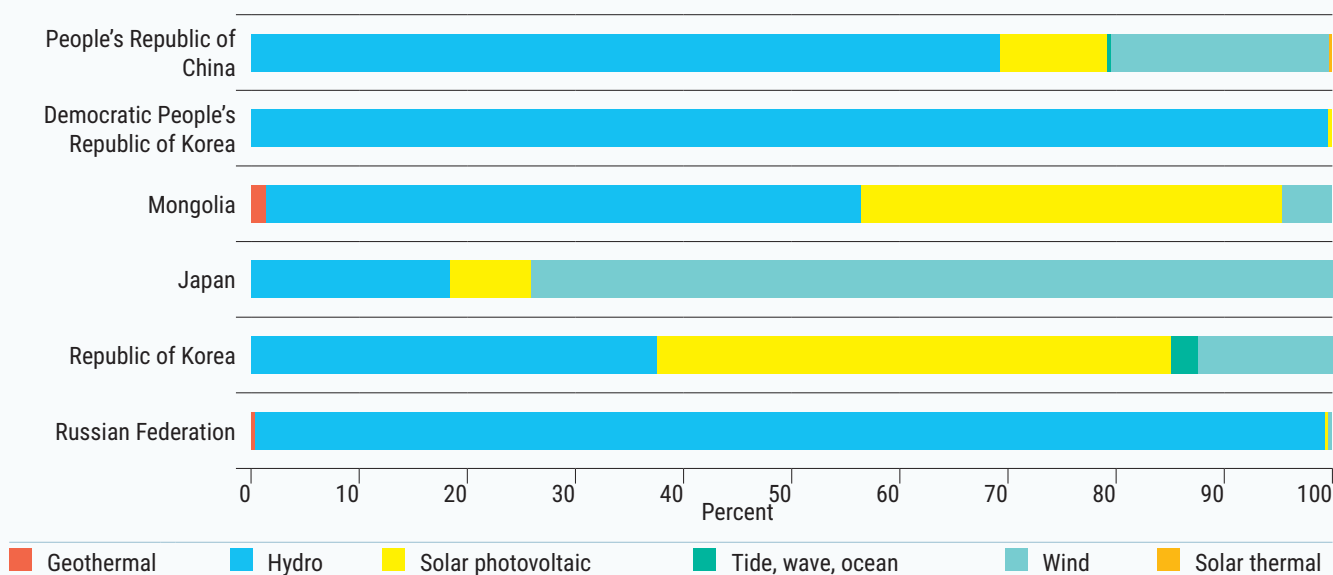
**Figure 14\_B** Renewable electricity generation in NEA, 1990–2018 (TWh)

Source: IEA 2020a.

increased the country's renewable electricity generation almost a hundredfold, from 0.004 TWh in 1990 to 0.458 TWh in 2018. Although this is a very impressive growth, in absolute terms this number is still rather modest in the regional perspective.

In the Russian Federation, construction of several large-scale hydropower plants in East Siberia and the Far East regions and, to a much lesser extent, the introduction of first solar and wind capacities contributed to a 13% increase in renewable energy generation, from 166 TWh in 1990 to 194.4 TWh in 2018.

6 Solar thermal generation is limited to China, where it makes up 0.01% of the RES-E power mix.

**Figure 14 \_C** Renewable power generation mix by country and source, 2018 (%)<sup>6</sup>

Source: IEA 2020a.

Hydropower dominates the regional renewable energy mix due to the maturity of hydropower technology. Particularly widespread are reservoir hydropower plants, due to the relative stability and controllability of their generation output; this makes them a dispatchable power source, similar to the fossil power plants (IRENA, 2015). While the first large hydropower plants in the region were constructed as early as the first half of the twentieth century, variable renewable energy sources began to be exploited on a large scale only a couple of decades ago. As of 2019, solar PV and onshore wind power were the fastest growing renewable energy sources, both globally and in North-East Asia, and are expected to lead the future growth in renewable electricity generation.

#### Solar and wind: Growing potential due to technology advancements and lowering costs

Due to rapid technological progress, coupled with economy of scale and the introduction of policies supporting deployment of renewable energy, renewable power generation technologies have entered a virtuous cycle of falling costs, increasing deployment and accelerated technological progress.

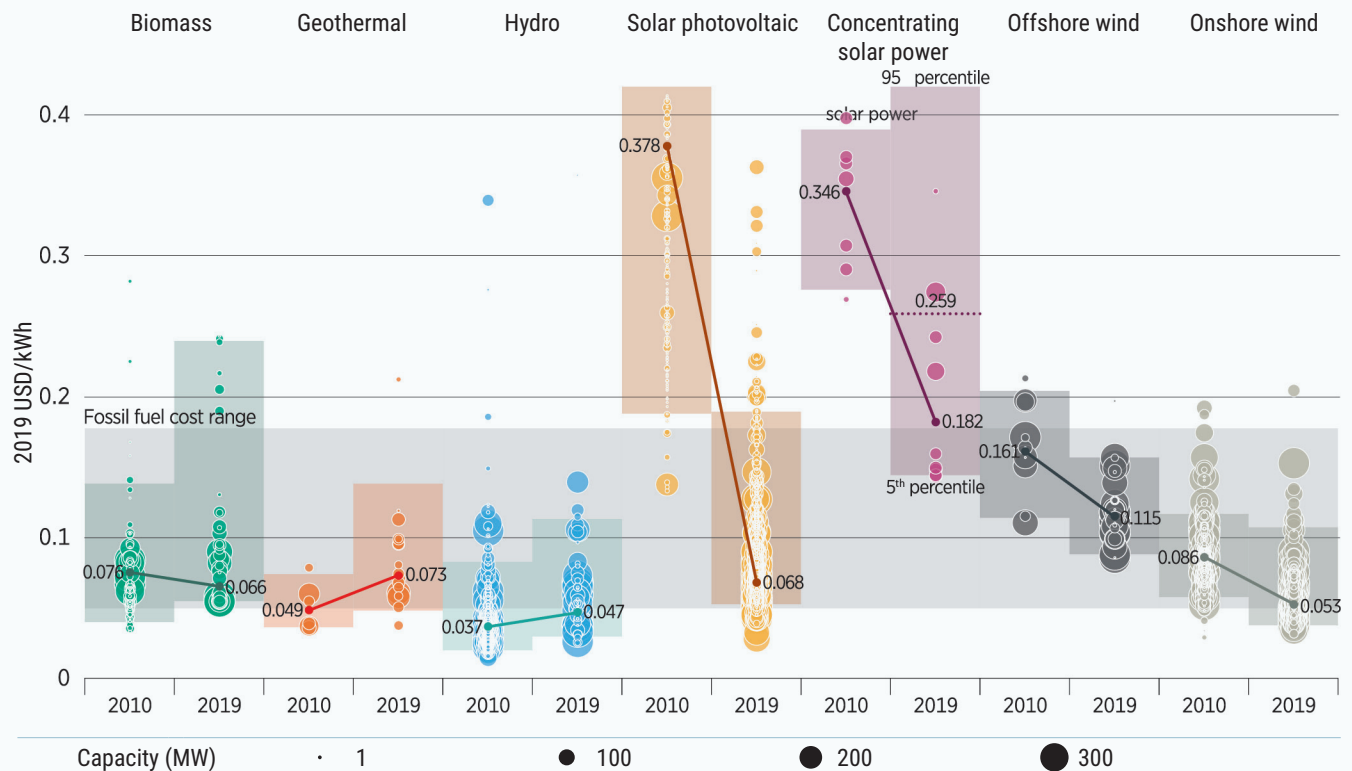
Globally, solar PV module prices have fallen by around 90% since the end of 2009, while wind turbine prices have fallen by 55-60% (IRENA, 2020). The global

levelized cost (LCOE)<sup>7</sup> of utility-scale renewable power generation technologies has dropped significantly in the last decade and is currently well within fossil fuel cost range for most major technologies. As demonstrated in the Figure S1, the fuel cost (light grey stripe) ranges between ca. 0.05 and 0.18 USD/kWh. In comparison, the average LCOE of utility-scale PV plants is estimated to have fallen by 82% between 2010 and 2019, from around USD 0.378/kWh to USD 0.068/kWh, while auction and tender results suggest they will fall to between USD 0.08/kWh and 0.02/kWh until 2030. Recent record low auction outcomes for solar PV in Abu Dhabi, Chile, Dubai, Mexico, Peru and Saudi Arabia have shown that an LCOE of \$0.03/kWh is already possible in a wide variety of national contexts (ibid.,26). By 2050, solar PV is expected to be among the cheapest sources of power available, particularly in areas with excellent solar irradiation, with 2050 costs in the range of USD 0.014–0.05/kWh.

Together with significant cost reductions, improvements in the performance of solar systems were achieved and losses reduced. For example, the average efficiency of

<sup>7</sup> The levelized cost of energy is the present value of the total cost of construction and operation of a power plant over an assumed lifetime. It is one of the most important indicators of economic viability, as it allows the comparison of different technologies (e.g., wind, solar and natural gas) of unequal life spans, project size, different capital cost, risk, return and capacities.

**Figure 15** \_ Global LCOE from newly commissioned utility-scale renewable power generation technologies, 2010–2019



Source: IRENA, 2020, Renewable power generation database, costs in 2019, figure 1.2.

Note: This data is for the year of commissioning. The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted-average LCOE value for plants commissioned in each year. Real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the world. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represents the 5th and 95th percentile bands for renewable projects.

mono- and polycrystalline silicon PV modules between 2006 and 2018 grew by ca. 22% and 28%, respectively (Fraunhofer Institute, 2020). Total installed costs for large-scale solar generation facilities have dropped significantly in all major countries, especially in China, 77% and Japan, 74%. All these developments have created considerable improvement in the economic competitiveness of solar PV and wind power (IRENA, 2019a).

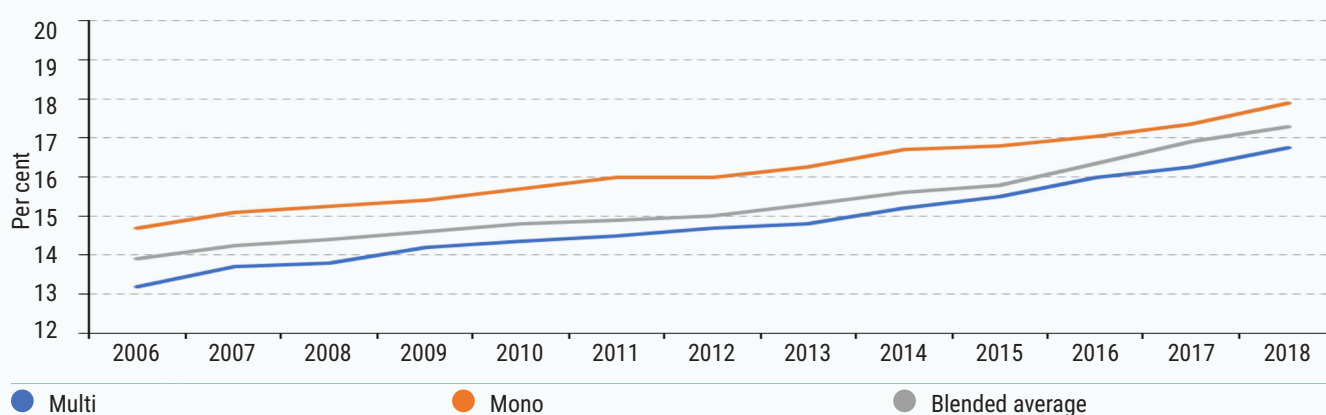
### Evolution of storage and transmission technologies

Progress has been made not only in renewable generation technologies, but also in storage and transmission systems that are essential to giving the power system the necessary flexibility (batteries for local/short-term issues, and expanded grid on a large

scale) to accommodate large amounts of variable renewable energy. The costs of battery storage technologies continued to decline in 2018 and by some estimates, costs of utility-scale storage technologies decreased 40% during that year. For lithium-ion batteries, which remain the leading battery storage technology, the cost per unit of storage (US\$/kWh) dropped 80% between 2010 and 2017.

Transmission technologies are also evolving, with the emergence of economically feasible ultra-high voltage (UHV) transmission lines and digitalization of the grid, including smart metering, smart sensors, automation and other digital network technologies (World Economic Forum, 2017). High- and ultra-high-voltage transmission lines enable bulk power transfer over long distances and are therefore an indispensable

8 The Russian Federation's renewable target excludes hydropower, which currently makes up approximately 17 percent of generation (BP Statistical Review, 2019, p.56).

**Figure 16** – Average crystalline-silicon PV module efficiency, 2006–2018

Source: Fraunhofer Institute, 2020.

**Table 2** – Renewable energy targets of NEA countries for 2030 and progress to date.

	China	Democratic People's Republic of Korea	Japan	Mongolia	Republic of Korea	Russian Federation
<b>2030 Target</b>	20% of non-fossil fuels in primary energy consumption by 2030	100 MW of grid-connected solar PV, 500 MW of offshore and 500MW of onshore wind power plants	22-24% of electricity generation from RES-E by 2030	20% of electricity generation from RES-E by 2020 and 30% by 2030	20% RES-E in electricity generation by 2030	At least 2.5% RES-E <sup>9</sup> in total electricity generation by in 2020 and 4.5% - by 2024
<b>Progress (year in brackets)</b>	14.7% (2018)	No data available <sup>9</sup>	18% (2018, BP)	6.5% (2017, IEA)	3.2% (2018, IEA)	1.3% (2018, BP)

Source: METI, 2015; BP, 2019b; IRENA 2017c; IEA, 2018.

component of a regional power system. Since the first high-voltage direct current transmission line was constructed in Sweden in 1954 (100kV), the feasible voltage of the DC power lines has increased dramatically, with power transmission lines of more than 1000 kV being constructed in several countries, most notably China (CEPRI, 2018). Progress has also been made in implementing UHV AC technologies, which enable construction of interconnectors with higher capacity

and lower transmission losses, while reducing the total construction cost.

### Renewable energy policy and targets in North-East Asia

The international community as well as the overwhelming majority of nation states acknowledge the key role renewable energy will play in curtailing CO<sub>2</sub> emissions and creating a sustainable, low-carbon energy system. In North-East Asia, all countries have introduced their own

<sup>9</sup> The Democratic People's Republic of Korea's target is only for wind and solar PV. While data is available regarding power generation from other renewable sources (in this case, hydropower), there are currently no data available on installed wind and solar power capacities.

**Table 3** \_ Renewable energy policies in place in North-East Asia

	China <sup>10</sup>	Democratic People's Republic of Korea	Japan	Republic of Korea	Mongolia	Russian Federation
Current RES-E Legislation in force since	2016	2013 <sup>11</sup>	2012	2009	2019	2009
FIT/ premium payment	● <sup>12</sup>		● <sup>13</sup>		●	●
El. utility quota obligation/ Renewable Portfolio Standard (RPS)	●		● <sup>14</sup>	●		
Net metering				●		
Tradable Renewable Energy Certificate (REC)			●	●		
Tax incentives	●		●	●	●	●
Investment or production tax credits	●			●		
Energy production payment	●			●		
Public investment loans, grants, subsidies etc.	●		●	●		●

Source: REN21, 2019, Renewables 2019: Global Status Report.

targets for renewable energy and mechanisms to support further deployment of renewable energy sources.

Although the policies and their implementation vary considerably, each of the North-East-Asian countries have introduced support schemes to foster the development of renewable energy, with feed-in tariff being in force in China, Japan, Mongolia and the Russian Federation, Renewable Portfolio Standard in China and the Republic of Korea, and various tax incentives in all countries except Mongolia and the Democratic People's Republic of Korea.

It is not possible to elaborate on the quality and success rate of renewables-related policies in North-East Asia within the scope of this report. It is nevertheless evident that although countries' efforts contributed significantly to the deployment of renewable energy, problems remain.

As the share of variable renewables in a power system increases, the need for the power system flexibility increases as well. The generation output of wind, solar PV and, to a lesser extent, hydropower varies depending on the time of the day, weather patterns and the season. Without sufficient flexibility to balance the variations in renewable energy production, during times of surplus production it becomes necessary to curtail generation in order to avoid grid congestion. To avoid wasting this surplus electricity, countries have made an effort to develop storage solutions and have expanded the grid. In China, for example, many of the country's wind projects are in remote areas in the north-western provinces that have weak grid links and are often unable to dispatch the whole output. Construction of ten AC and 27 DC ultra-high voltage (UHV) transmission lines by 2020 have been planned to solve this problem. Although due to the expansion of the grid, the average curtailment rate of wind power in China fell to 7% in 2018, it is still around 25% in the major wind generating provinces of Xinjiang and Gansu in the north-west of the country. In late 2018, Japan's first curtailment of solar PV and wind generation occurred on the island of Kyushu (*Wind*

10 REN21, 2019, Renewables 2019: Global Status Report; DPRK – News, translated by NK Econ Watch.

11 According to the report of Korean Central News Agency (KCNA) of September 2, 2013, country's first Renewable Energy Act was adopted at the Presidium of the Supreme People's Assembly, consisting of the following six chapters: (1) definition and mission of renewable energy; (2) research and development of renewable energy resources; (3) basic principles in the usage; (4) planning and encouraging the development of renewable energy; (5) enforcement of the materials and technical sectors of renewable energy; and (6) legal requirements to guide the renewable energy sector projects.

12 Revised in 2018.

13 Revised in 2019.

14 Although the RPS Act (電気事業者による新エネルギー等の利用に関する特別措置法 or RPS法) officially abolished the introduction of the Feed-in Tariff system in 2012, the RPS certification system remains in effect until 2022 and applies to companies certified for RPS before the introduction of FIT. This decision has been taken in order to counter the perceived risk that the RPS-certified companies would not be able to recover their investments in the renewable power generation facilities. After the start of the Feed-in Tariff, most of the RPS-certified facilities have been transferred to FIT (METI, 2016).

*Energy and Electric Vehicle Magazine*, 21 June 2019) due to periodical high shares of variable renewable output combined with inflexible nuclear generation, which also increased its share in the electricity mix.

Insufficient interconnections not only cause curtailment losses in the already installed renewable generation capacities (mainly in China, but also in other parts of the region – e.g., within the power system of Kyushu, Japan), but also prevent new plants from being constructed. The substantial hydropower potential of the Russian Far East cannot be fully developed without new transmission lines connecting the potential hydropower plant sites to the load centres (the closest ones being in China). Similarly, Mongolia's enormous solar and wind potential (2.6 TW), (IRENA, 2016) will remain largely unexploited until infrastructure is in place to supply the power to the neighbouring countries that have a demand for such vast amounts of electricity.

While weak grids and insufficient demand are limiting the potential of renewable energy resources in the Russian Federation and Mongolia, further deployment of variable renewable energy is becoming increasingly difficult in Japan and the Republic of Korea, due to high urbanization rate and not many available sites remaining on land for new large-scale installations. Japan has considerable and practically untapped offshore wind potential, 99.5% of which, however, is in deep water and cannot be harnessed by the currently mature (fixed-bottom type) technologies (IEA 2019a). Given the successful development of floating wind turbines in

the future, and the regional power grid interconnection in place, Japan's offshore wind resources could cover the national power demand nine times over and make Japan a net exporter of electricity.

The policies and instruments implemented by the countries of North-East Asia to-date, although commendable, are not enough to give credit to the enormous renewable energy potential of the region. With a growing share of variable renewables in national energy mixes, a system-wide approach is necessary to ensure the development of a flexible, cost-effective and stable power system. Increasing the regional power grid connectivity through cross-border interconnections may prove to be the key element of such an approach.

### C. Sustainable Development Goal 7: State of play in North-East Asia<sup>15</sup>

As one of the global centres in terms of energy demand and consumption, North-East Asia's performance with regard to the Sustainable Goal on energy will be pivotal for the global progress towards a sustainable energy system that ensures universal access to affordable, reliable and modern energy services. Efforts by North-East Asia's countries to foster transformation of their energy systems will also have

<sup>15</sup> The indicators in table 4 correspond to indicators for SDG 7 as defined within the Global indicator framework for the Sustainable Development Goals and the targets of the 2030 Agenda for Sustainable Development.

Table 4 \_

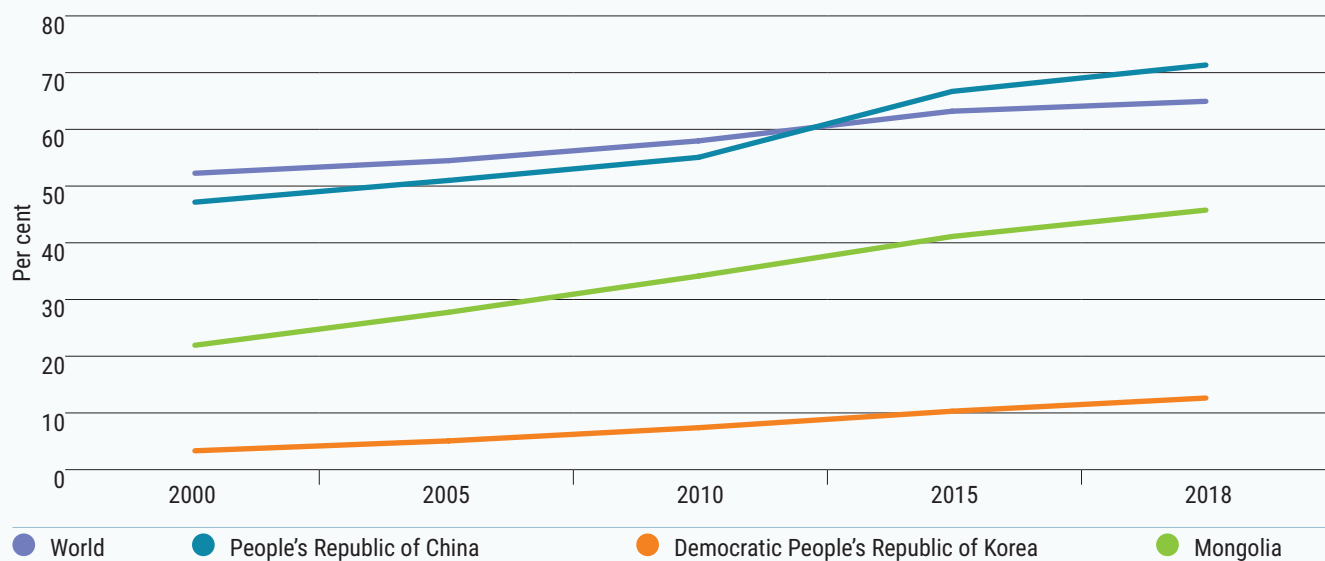
Indicators of SDG 7, by country, in North-East Asia

	China	Democratic People's Republic of Korea	Japan	Mongolia	Republic of Korea	Russian Federation
Access to electricity	100%	56% (urban) 40% (rural)	100%	100% (urban) 95% (rural)	100%	100%
Access to clean cooking fuels and technology	64%	10%	100%	50%	100%	90%
Share of RES-E in total final energy consumption	12.8%	27.4%	6.9%	3.5%	2.8%	3.3%
Energy intensity of GDP (toe/1000 USD GDP, 2010 PPP)	0.15	0.15	0.09	0.15	0.15	0.23
Investment in energy efficiency measures (billion US\$), 2017	65	n.a.	9	n.a.	n.a.	4

Source: IEA 2020b, Yearbook Enerdata 2020, IEA/OECD World Energy Investment 2018, Tracking SDG 7 2020.

Figure 17

Proportion of population with primary reliance on clean cooking facilities in China, DPRK and Mongolia, 2000–2018 (%)



Source: IEA, 2019c. SDG 7: Data and Projections, Flagship Report.

a considerable impact on the global performance for related SDGs, particularly those concerning climate, human health, sustainable cities and resilient infrastructure. More intensive cooperation on energy and environmental issues is required at the subregional level in order to efficiently address the challenges faced on the path towards a sustainable energy system.

#### Proportion of population with access to electricity

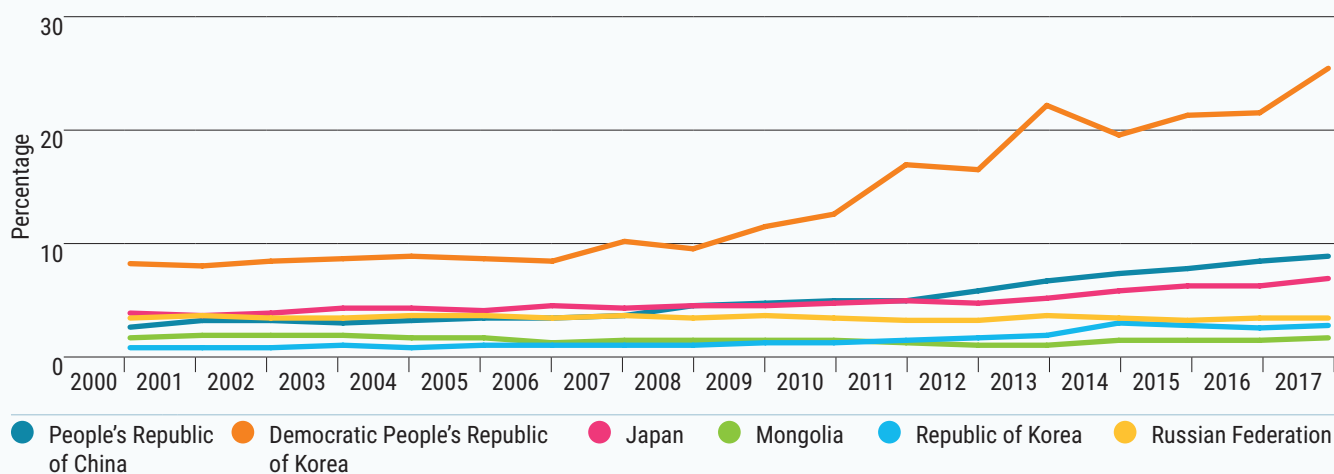
As of 2018, North-East Asia became the subregion with the highest average electrification rate in Asia (86.5%), where the populations of China, Japan, the Republic of Korea and the Russian Federation is granted universal electricity access, and all North-East Asian countries except for the DPRK are above the global average of 88.7%. Despite gradual improvement over recent years, the electrification rate in the DPRK is still very low (48%), with 56% of urban and 40% of rural population having access to electricity. Mongolia has demonstrated some significant progress in closing the gap between the urban and rural electrification rates, which in 2018 grew to 100% and 95% respectively.

#### Proportion of population with primary reliance on clean fuels and technology

Notwithstanding the high electrification rates in the subregion, only households in Japan, the Republic of Korea and the Russian Federation have access to clean cooking fuels and technology. A large share of biofuels and biomass, which constitute 13% of the TPES in North-East Asia, consists of solid biofuels such as fuelwood and charcoal, both extensively used for heating and cooking. When used indoors without venting, these fuels produce particulates as well as polycyclic aromatic hydrocarbons (PAHs), causing heavy air pollution and endangering human health, particularly of women and children.

Although there has been significant progress in enabling access to clean cooking in the subregion, 38.5%, 54.3% and 87.7% of population have to cook with polluting fuels in China, Mongolia and the Democratic People's Republic of Korea, respectively (IEA, 2020). In absolute numbers, China and the DPRK are among the 20 countries with the largest deficit in access to clean cooking fuels and technology (399.3 million and 22.5 million people, respectively).

Access to clean heating fuels has also been a problem, particularly in Mongolia, where winter temperatures can go below -40°C. Households and low-pressure boilers burning raw coal cause about 80% of the air pollution

**Figure 18** – Share of modern renewables in total final energy consumption by country (%), 2000–2017

Source: IEA, 2019, SDG 7: Data and Projections, Flagship Report.

in the capital, Ulaanbaatar, where more than 46% of country's population reside (WHO, 2019). As of May 2018, the Government of Mongolia had introduced a ban on burning raw coal in the city and started to work on policy measures to replace the polluting fuel with alternatives.<sup>16</sup> In addition, it is working on plans to expand the city infrastructure to enable better energy services for the poorest population groups (Kwong, 2019).

Access to clean fuels for further energy services has also been lacking in countries where the population has nearly universal access to clean cooking and heating fuel. Among others, fuel used in transportation have been one of the major causes of heavy air pollution in metropolitan areas of the Republic of Korea, which ranks last among the OECD when it comes to air quality (OECD, 2017).

### Share of renewable energy in the subregional energy mix

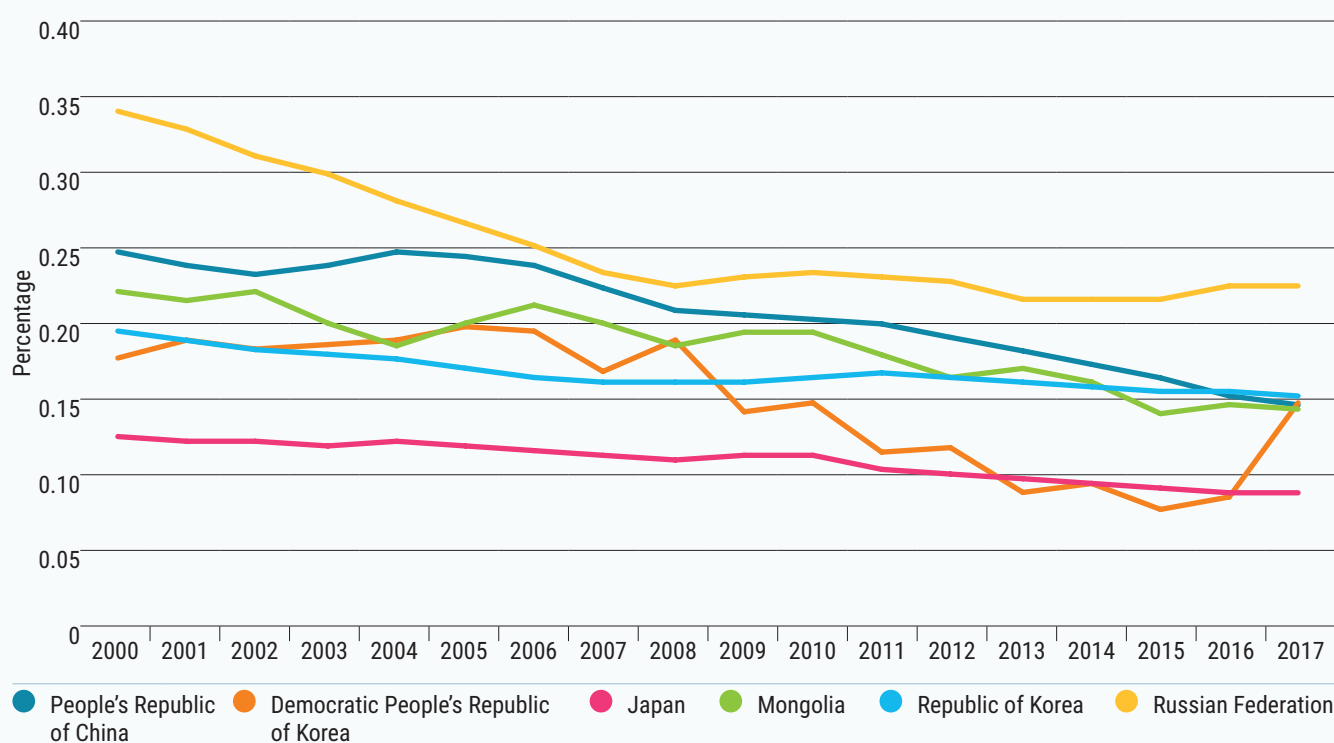
The share of renewables in total final energy consumption has been growing in North-East Asia together with the global trend since 2000, and in 2017 amounted to 12.8%, 27.4%, 6.9%, 3.5%, 2.8%, 3.3% in China, DPRK, Japan, Mongolia, the Republic of Korea and the Russian Federation, respectively. This growth has mainly been due to the rapid deployment

of solar and wind generation capacities in China and, to a much lesser extent, in Japan and the Republic of Korea. DPRK's sole modern renewable energy resource is hydropower, which accounts for 12.7% of final energy consumption. However impressive, this number must be considered against the background of a low electrification rate, both for urban and rural areas (56% and 40%, respectively) (IEA, IRENA, UNSD, WB, WHO, 2020) as well as the high share of combustible renewables (solid biofuel), accounting for 14.7% of the total final energy consumption. In addition, the Russian Federation's main renewable source in the TFC mix is hydropower. Although wind generation capacities have been developed in the Russian Federation since 2000 and the connection of the first solar generation facilities to the grid has occurred in 2015, in 2017 they accounted for only 0.1% and 0.3%, respectively, of non-combustible renewables<sup>17</sup> in the total final energy consumption (IEA, 2020).

In the regional mix of modern renewables, hydro is the dominant source of energy, with 74.2% mainly consisting of large hydropower plants in China and the Russian Federation.

<sup>16</sup> Coal sellers should be provided with briquettes of semi coke, a less polluting alternative with higher energy density compared to coal. While more expensive, this fuel will be subsidized by the Government

<sup>17</sup> Renewables from which energy can be extracted without combustion (as opposed to biomass or waste). These include hydropower, tidal and ocean energy, geothermal energy, solar and wind energy (Eurostat, 2019), available at [https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Renewable\\_energy\\_sources](https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Renewable_energy_sources).

**Figure 19** \_ Energy intensity measured in terms of primary energy and GDP, 2000–2017

Source: IEA, 2019, SDG: Data and Projections, Flagship Report.

### Progress on energy efficiency

Energy efficiency is central to the achievement of a range of policy goals, including energy security, economic growth and environmental sustainability (IEA, 2017a). The improvements in energy intensity, that is the amount of energy needed to produce one unit of GDP, are one of the central instruments for enabling sustainable economic growth while levelling of CO<sub>2</sub> emissions. Furthermore, improvements in energy efficiency help to reduce consumer expenditure on energy as well as balance out the growing energy demand, thus contributing to energy equity.

Energy efficiency in the North-East Asian subregion varies among countries. Although the energy intensity of the economies of North-East Asian countries have decreased significantly since 2000, the level of energy intensity is considerably higher than the global average in all countries of the subregion except for Japan and the DPRK (figure 19).

While the relatively low energy intensity in Japan's economy is due to political efforts at the national level to improve energy efficiency, the decreasing level of

energy intensity in DPRK's economy can be attributed to lower living standards and the country's poor economic performance. With 0.227 toe/US\$ 1,000 GDP, the Russian Federation's economy is the most energy-intensive in the subregion. The energy intensity of the Russian Federation's economy increased by 1.9% in 2018, versus a decline of 0.7% per annum over the past 10 years, with the main reasons being an increase in energy consumption (primarily in heating) versus slow economic growth and comparatively weak energy efficiency policies (Bogoviz et al., 2018).

### Investments in energy efficiency

The investments in energy efficiency have grown strongly in recent years, with North-East Asia being the leading subregion in Asia and the Pacific. In 2017, China was leading the global effort, accounting for US\$65 billion, or more than a quarter of total global investments in energy efficiency.<sup>18</sup> Japan has been the leader in the

<sup>18</sup> This estimate of energy efficiency spending stems from IEA's World Investment Report 2018 and corresponds to the incremental spending on equipment that consumes less energy than would have been used had the purchaser opted for a less efficient model or, in the case of building refurbishments, not undertaken the efficiency improvement (IEA 2018).

OECD Asia-Pacific, accounting for approximately half of the total investments in energy efficiency among the OECD countries in the region (US\$9 billion out of US\$18 billion). Russian Federation investments in energy efficiency have also been growing, and amounted to US\$ 4 billion; although that is a considerable amount, more efforts on the Russian Federation side are needed given the high energy intensity of its economy (IEA, 2018).

#### D. Power sectors in North-East Asia

Although diverse in terms of regulatory frameworks, policy agenda and (to a large extent) power market design, the national power systems in North-East Asian countries have several common traits. While nominally unbundled in most countries, the power sector is dominated by the vertically integrated state-owned enterprises – particularly evident in the power transmission sector (Japan is the only exception). Rapid growth in power demand is a trend that can be observed in most North-East Asian countries, due to their electrification efforts, and in the case of China due to the country's continuing economic growth. All North-East Asian countries rely on coal for a significant (and in most cases dominant) share of power generation. Finally, most countries have to address the challenge of enhancing and, furthermore, integrating the national

power grids. Aside from the DPRK and Mongolia, the absolute majority of the population in the region has access to the centralized power grid.

The frequency of the grid in North-East Asia differs by country, with 50Hz networks being used in China, Republic of Korea, Mongolia and the Russian Federation. Japanese power grid is divided into two frequency zones, the frequency in east Japan being 50Hz, and in west Japan, 60Hz. Nominally, the DPRK also has a 60Hz grid while the de-facto frequency varies and is mostly close to 50Hz.

North-East Asian countries have different approaches regarding international cooperation in the power sector, whereas most of them strive to strengthen regional efforts in this field. China pursues its goal of establishing an intercontinental power grid with its Global Energy Interconnection Development and Cooperation Organization (GEIDCO) project, and development of cross-border power interconnections and the regional power market is one of its focus areas for international cooperation. Republic of Korea has expressed its interest in a regional power grid interconnection in North-East Asia as one of the strategic directions of its Energy Strategy and is working on a joint development of China-Korea power interconnection since 2017. Similarly, the establishment of a power grid interconnection in North-

**Table 5 \_** Power sectors in North-East Asia: Key figures

	China, 2019	DPRK, 2017	Japan, 2019	Mongolia, 2017	Republic of Korea, 2018	Russian Federation (Siberia/ Far East)
Total electricity consumption (TEC), TWh	6,349	13	1,026	7	526	210.2/34.2
TEC per capita, MWh per capita	4,6	0.5	8.1	2.2	10.2	9,5
Total electricity production, TWh	6,671.9	15	1,026	6	593.5	205.3/37.6
Total installed generation capacity, GW	2011	9.5	298	1.3	123	51.8/9.6
TPP	1,190.5		174	1.11	79.1	26.5/5.9
HPP	356		49.5	0.02	6.5	25.3/3.7
NPP	48.7		38.5	-	21.8	-
Solar PV	204.7		42.8	0.05	8	0.05/ -
Wind	210		3	0.15	1.3	-
Geothermal	-		0.02	-		
Oil	16.25 (included in TPP)			0.04		

Source: EPSIS, 2020; SO UES, 2019; JIEPIC, 2019; IEA, 2017b, 2018; CEC, 2019; KESIS, 2019.

**Table 6** – Power generation resources, by country, in North-East Asia<sup>19</sup>

	China	DPRK	Japan	Mongolia	Republic of Korea	Russian Federation (Siberia/Far East)
Coal <sup>20</sup> (bln T)	5,191	10.6	13.9	41	1.7	2,694
Gas (bcm)	72,076	No country data available	26	133	55	188,050
Hydro (TWh/yr) <sup>21</sup>	2,474 <sup>22</sup>	>26.0	135.8	22	26.4	75/684
Solar PV (GW)		No country data available	255	1,500	3.6	24,965 <sup>23</sup>
Wind (GW)		No country data available	267.56 (onshore) 1,303 (offshore) <sup>24</sup>	1,100	0.85	4,145 <sup>25</sup>
Oil (bln T)	23	No country data available	-	1	-	46.6
NPP	48.7		38.5	-	21.8	-
Solar PV	204.7		42.8	0.05	8	0.05/ -
Wind	210		3	0.15	1.3	-
Geothermal	-		0.02	-		
Oil	16.25 (included in TPP)			0.04		

Source: Belyaev et al., 2018; Asia Pacific Energy Portal; Popel et al., 2015; MOE, 2013; IRENA, 2016; BGR, 2013.

East Asia is one of the major policy directions for the Government of Mongolia, which strives to become a net power exporter upon the construction of large-scale renewable power facilities in the Gobi Desert (Gobitec) and an Asia Super grid interconnection. For

the Russian government, expansion of electricity exports to neighbouring countries, i.e. from the Far Eastern region, is one of the strategic goals of its energy policy. The DPRK does not have a pronounced policy towards regional power grid interconnection but is nevertheless maintaining a dialogue with the Russian Federation on possible cooperation in the power sector. Japan also has no official policy regarding cross-border interconnections and the possibility of power import/export.

Further information on power systems of the North-East Asian countries is presented in the Appendix I of the present report.

19 Natural reserves for coal and gas, and maximum technical potential for hydro, solar and wind.

20 Hard coal (bituminous and anthracite)

21 Technically exploitable resources (Belayev et al., 2018).

22 The major share of these potential hydropower resources are located in south-west China.

23 Calculations are based on the data from the Atlas of Renewable Energy Resources on the territory of the Russian Federation (Popel et al., 2015), which estimates the solar potential of Siberia and the Russian Far East at 32,454 TWh/year, and assumes the average capacity factor of 0.15 for conversion into GW.

24 Including areas around small islands.

25 Calculations are based on the data from the Atlas of Renewable Energy Resources on the territory of the Russian Federation (Popel et al., 2015), which estimates the wind potential for Siberia and the Russian Far East at the height of 100 m to be 8291 TWh/year, and assumes the average capacity factor of 0.23 for conversion into GW.

Table 7 \_

## Overview of power system structure, by country, in North-East Asia

	Generation	Transmission	Distribution	Sales: Retail market	Sales: Wholesale market	Power import/export
China	State-owned enterprises, private-owned companies (small portion)	Two State-owned TSOs	State-owned (state and provincial level)	State-owned TSOs, private-owned retailers (small portion)	30% of total demand	State monopoly (SGCC, CSG)
Democratic People's Republic of Korea	Large generation capacities state-owned, growing decentralized generation	State-owned	State-owned	Regulated prices	Regulated prices	-
Japan	834 power producers (METI, 2019)	Regulated, legal unbundling to be completed by 2020	Regulated, unbundling to be completed by 2020	Fully liberalized – 634 retailers (METI, 2020)	20% of total demand (JPEX, 2018)	-
Mongolia	State-owned enterprise – over 60%, private companies	State-owned TSO	State-owned and private distribution and retail companies	State-owned and private distribution and retail companies	-	State monopoly (vertically integrated Power System Companies – CES, WES, AuES, EES)
Republic of Korea	Partially liberalized - 6 subsidiaries of KEPCO, 17 major private generators	State-owned (KEPCO) has monopoly	KEPCO has monopoly	Prices determined by KEPCO, vary among nine categories	KPX, daily price-building based on SMP and capacity markers, price cap for baseload generation appr. 95% of total demand	-
Russian Federation	Partially liberalized – 60% of generation capacity – state-owned enterprises, rest – private-sector companies	State-owned (Rosseti)	Both state-owned (subsidiaries of Rosseti) and private sector distribution companies	Both state-owned (subsidiaries of Rosseti) and private sector distribution companies. Market-based pricing in Siberia IPS, regulated pricing in Far East IPS and isolated regions of Far East	Both power and capacity, Market-based pricing in Siberia IPS, regulated pricing in Far East IPS and isolated regions of Far East	State monopoly (Inter Rao)
NPP	48.7		38.5	-	21.8	-
Solar PV	204.7		42.8	0.05	8	0.05/ -
Wind	210		3	0.15	1.3	-
Geothermal	-		0.02	-		
Oil	16.25 (included in TPP)			0.04		

# Power grid connectivity in North-East Asia

## Current status and possible ways forward

### A. Existing cross-border power grid interconnections in North-East Asia

As of 2020, power grid connectivity in North-East Asia is at a preliminary stage, with several grid connections constructed for bilateral cross-border electricity trade between the Russian Federation, China, Mongolia and DPRK.

The main electricity exporting countries in the region, currently the Russian Federation and China, export power to the Central Grid and the Western power system of Mongolia and import some of the electricity in periods of minimum loads in Mongolia. Russian Federation exports have been growing for several years and increased from 300 GWh in 2016 to 416 GWh in 2019. Exports from Mongolia are modest, 27 GWh in 2018. The Russian Federation also exports electricity to China via four cross-border lines. Since the bilateral trade agreement was signed in 2009, Russian Federation electricity exports have grown almost fourfold, from 854 GWh to 3,319 GWh in 2017 (Inter RAO, 2020).

**Table 8** Existing cross-border interconnections in North-East Asia

Countries involved	End points	Voltage	Transmission capacity (MW) <sup>26</sup>
Russian Federation, Mongolia	Gusinozerskaya TPP (RUS) - Darhkan (MNG)	2*220 kV	250
	Kharanorskay TPP (RES) - Choibalsan (MNG)	110 kV	n.a.
	Chadan (RUS) - Khandagaity-Ulanngom	110 kV	90
Russian Federation, China	Blagoveshensk (RUS) - Heihe (China)	110	95
	Sivaki (RUS) - Sirius/Aigun (China)	110 kV	90
	Blagoveshensk (RUS) - Sirius/Aigun (China)	2*220 kV	300
	Amurskay (RUS) - Heihe (China)	500 kV	750
China, Mongolia	Oyu Tolgoi-Inner Mongolia	2*220 kV	300
China, DPRK	66kV	2*66kV	n.a.
DPRK-ROK interconnection (not operating)	ROK-KIC	154kV	100

The Chinese power grid is connected to the mining facilities located in the southern Gobi Desert (Mongolia) by a 220 kV overhead transmission line, which was commissioned in 2013 and currently operates separately from the Mongolian grid. China's electricity exports to Mongolia amounted to 1,200 GWh in 2018, which accounts for about 15% of electricity supplied through Mongolia's Central Grid (Tumenjargal, 2018).

There is also a cross-border link connecting the DPRK to China's grid. Both countries jointly operate four hydropower dams with installed capacity ranging from 190 MW to 630 MW, on the shared Yalu river. Two additional dams with installed capacity 40 MW each are under construction and were planned for completion in 2019-2020. The total installed capacity of the jointly-operated hydropower plants is estimated to be about 2.4 GW.

Finally, the DPRK is interconnected with the Republic of Korea through a 154kV cross-border cable line that has, however, not been in operation since 2016. The interconnection was constructed as a part of the Kaesong Industrial Complex (KIC) project, aimed at strengthening economic cooperation and contribute to reconciliation between the DPRK and the Republic of Korea. The industrial complex built on DPRK territory and interconnected by infrastructure with the Republic of Korea, was supposed to enable Republic of Korea

businesses to manufacture products in the DPRK as well as boost DPRK's economic development and ease tensions across the demilitarized zone. The power line interconnecting the KIC and the Republic of Korean power grid, commenced operation in 2007, and was put out of commission in 2016 together with the KIC, which was shut down after the DPRK nuclear bomb test in 2016.

Overall, the existing cross-border interconnections in North-East Asia are small in scale and, aside from the electricity mix in Mongolia, do not have any significant impact on the energy situation in the region.

## B. Proposed power grid interconnection projects

Within the studied literature, 11 interconnection proposals<sup>27</sup> of regional and interregional scale as well as 30 interconnection routes<sup>28</sup> of intraregional scale could be identified. The first of these interconnection routes was proposed in the late 1990s and early 2000s. At that time, particular focus was placed on the

<sup>26</sup> Approximate numbers resulting from cross-checking the data available in the analysed studies.

<sup>27</sup> Four interregional interconnection proposals are listed in the overview table for the sake of completeness, but not explicitly covered in this report.

<sup>28</sup> Another set of nine different "loop routes" was proposed by Lee (2000), including various variations of cross-border interconnections between three up to all six countries of North-East Asia. Lee analysed possible power flows for each of the interconnections but did not discuss their feasibility. Nevertheless, these routes are listed in the overview table for the sake of completeness.

interconnections between the Russian Far East, the DPRK and the Republic of Korea, modelled around the Shinpo Light-Water-Reactor (LWR). This reactor was, at that time, constructed in the DPRK in cooperation with the Korean Peninsula Energy Development Organization (KEDO), an international consortium comprising the Republic of Korea, the United States, Japan, the European Union and eight United Nations member countries, including Canada, Australia, New Zealand, Finland, and Indonesia (KEDO, 2020). The LWR project was suspended together with the six-party talks, and terminated in May 2006. Nevertheless, conducting transmission lines through the DPRK played a key role in many interconnection proposals that emerged later, particularly those involving the Republic of Korea, since any on-land routes from the Republic of Korea to the Russian Federation or China had to pass through DPRK territory.

Another set of cross-border interconnections that, in different versions, has also been proposed since the late 1990s is the so-called “power bridge” between the Russian Far East and Japan. Ranging from a submarine link between Sakhalin island and Hokkaido, the northern island of Japan, to a set of submarine cables connecting the Russian Federation mainland with Japan’s main island, Honshu, these interconnections are aimed at solving several issues at once:

1. Provision of a market for the existing Russian surplus generation (from a TPP on Sakhalin or thermal and hydro energy from the mainland) and the yet-to-be constructed gas and coal-based thermal power plants on Sakhalin;
2. Supplying comparatively cheap electricity to the Japanese power market;
3. Fostering economic development on Hokkaido, and, more importantly, on Sakhalin island; and
4. Improving bilateral relations between the Russian Federation and Japan.

Although all variations for the interconnection between the Russian Far East and Japan are still on the table and a subject of modelling studies and estimates, the preliminary results show that the link between Sakhalin and Hokkaido alone will not bring large economic benefits. The electricity demand on the northern island is not sufficient for such an interconnection to be

economic – therefore, the “power bridge” between the Russian Federation and Hokkaido only makes sense if the load centres on Honshu have access to this imported electricity.

The first attempts to assess the benefits of a cross-border interconnection between China and the Russian Federation were made in the late 1990s. However, a recession hit the Russian economy and the idea was suspended and then revived in the early 2000s, when research institutes in the Russian Federation and China started to look into the bilateral interconnection potential beyond the existing cross-border lines. As China began to recover from the 1998 Asian financial crisis, the electricity demand in the country grew rapidly, which presented an opportunity for expansion of electricity trade with Russian Siberia. Given that the peak loads in the two countries differ by season (winter in Siberia, summer in China’s load centres), the core idea was to send the surplus electricity from the already operational Siberian thermal (TPP) and hydropower plants (HPP) to China in summer, and to import electricity generated by Chinese coal-fired TPPs in winter (Belyaev, 2002). As these proposals feature interconnections that do not require construction of any additional generation capacities, but which derive benefits of synergies between the power systems of Siberia and China, their economic feasibility has been generally estimated as high. More recent proposals expand the scope of the Russian Federation-China interconnections to the Republic of Korea, assuming construction of new thermal and hydropower plants in Far East.

It is noteworthy that an absolute majority of the studies on bilateral and trilateral cross-border interconnections suggests cross-border electricity supply and exchange based either on conventional thermal (coal and gas-fired) or large-scale hydropower generation. The only interconnection implying exchange in electricity generated from variable sources would be the one between the Republic of Korea and Japan, and it is being studied as one link in the regional power grid. The marginal role of variable renewables in the cross-border trade is not surprising; on the one hand, the competitiveness and practicality of variable renewable technologies only began to grow by the time the first cross-border interconnections had been developed. On the other hand, as already mentioned in the previous section, accommodating large amounts of variable power generation requires a flexible power system,

Figure 20 – Proposed course of the Asian Super Grid



Source: Energy Charter et al. (2014). Gobitec and the Asian Supergrid for Renewable Energy Sources in Northeast Asia. Energy Charter (978-905948-144-2).  
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

which none of the bilateral cross-border ties alone can provide.

This need for a systemic approach to regional connectivity has spurred the development of new, region-wide interconnection proposals. Most of them have been put forward in the past decade and are the result of cooperation between:

1. Various research institutions, such as the Melentiev Energy System Institute, SB RAS (ESI SB), Korea Electrotechnology Research Institute (KERI), Electric Power Planning and Engineering Institute (EPPEI), the Renewable Energy Institute Japan (REI), Japan Policy Council and Skolkovo Institute of Science and Technology (Skoltech);
2. International organizations, among them the Energy Charter, the Asian Development Bank,

Global Energy Interconnection Development and Cooperation Organization (GEIDCO), International Electrotechnical Commission (IEC); and

3. Companies from the regional industry sector, such as State Grid Corporation of China (SGCC), KEPCO, Softbank, Marubeni and Daesung Energy Company.

Of the studied interconnection proposals, only one presents an expansion of the conventional power system, based on large-scale hydropower (NEAREST); the rest stress the importance of the interconnection for increasing the flexibility of national power systems, in order for them to tap the regional potential of variable renewable energy sources. With the exception of two proposals that do not include the Russian Federation in the original design – i.e., Gobitec + ASG by the Energy Charter, NEASG by Bogdanov and Breyer, 2016 – all interconnection studies encompass the whole of North-

Figure 21 \_ Proposed North-East Asian Power System Interconnection by 2036



Source: Asian Development Bank (ADB)/ Électricité de France (EDF) (2019). Mongolia: Strategy for North-East Asia Power System Interconnection. Final Draft. Technical Assistance Consultant's Report, ADB Project Nr 48030-001. Map is adapted by ESCAP.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

East Asia, and underline the importance of including the DPRK in the regional connectivity initiatives, both for economic and security reasons (see Section B below on challenges and opportunities). In addition, Mongolia plays the key role as the future regional powerhouse, providing the energy-hungry economies such as China, the Republic of Korea and Japan with affordable low-carbon electricity. Most of the proposals are still at the conceptual stage and do not provide many technical details, such as the length of the transmission lines, generation capacities to be included etc. The most advanced proposals in terms of technical design are the Asian Super Grid (ASG) initiative, the North-East Asian Power System Interconnection (NAPSI) initiative and the North-East Asian Energy Interconnection (NEAEI). The ASG aims to interconnect all six countries of the region, supplying them with electricity from wind and solar power-rich areas of Mongolia's Gobi Desert. It has been proposed that large-scale solar PV arrays and wind turbines be installed on 2,500 km<sup>2</sup> and interconnected with ultra-high-voltage (min. 1,000 kV) direct current

lines to the national power systems of the region. The cost of the project is estimated to be between US\$ 294.6 billion (ECT, 2014) and US\$ 550 billion (Van de Graaf and Sovacool, 2013), while the major share of the total cost will have to be invested in the renewable generation capacities and a much more modest sum in the transmission lines.

NAPSI covers approximately the same geographic area, and has the expansion of the renewable power generation base in Mongolia at its core, which is similar to the ASG. NAPSI, however, offers a different power grid model, focusing more on bilateral back-to-back HVDC (500kV, and 800/1,100 kV at later stages), interconnections between Mongolia's renewable base and the main load centres in NEA countries as well as on the existing power grid interconnections that will have to be reinforced by lines of higher voltage and transmission capacity. NAPSI proposes the development of the regional power grid interconnection in three stages, starting with deployment of 5 GW of renewable power

**Figure 22** – Proposed North-East Asia Energy Interconnection by 2050



Source: GEIDCO (2018). North-East Asia Energy Interconnection. Global Energy Interconnection Development and Cooperation Organization. October 2018. Map is adapted by ESCAP.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

generation in the Gobi Desert, and the addition of new interconnections as the renewable base expands – up to 100 GW by 2036. The total investment cost is estimated to be US\$ 148 billion, while the main investment (US\$ 129 billion) will be required at a later stage. Development of a 5 GW renewable power generation base in Mongolia and interconnecting it with the first few load centres (Stage 1) would cost about US\$ 12.9 billion (ADB/EDF, 2019).

As part of the Global Energy Interconnection, proposed by GEIDCO, NEAEI aims to interconnect all six North-East Asian countries in a “three-ring and one line” grid interconnection pattern through five corridors. The first corridor would interconnect Mongolia, China, the Republic of Korea and Japan. The second one would connect China and the Russian Federation. The third would connect the Russian Federation and Japan. The fourth would connect China, the DPRK and the Republic of Korea, and, finally, the fifth would connect the Russian Federation, the DPRK and the Republic of Korea. In addition, 18 high voltage (500-800kV) interconnections,

ca. 990 GW of new renewable generation, would be developed by 2050, including about 430 GW off- and on-shore wind power generation capacities distributed over the Sea of Okhotsk, Sakhalin Island, south-east Mongolia, north and north-east China as well as five solar power generation bases in Mongolia’s Gobi Desert area, with total capacity of ca. 510 GW, and two new hydropower plants with ca. 54 GW total capacity on the Lena (Russian Federation) and Heilongjinag-Amur (Russian Federation/China) rivers. To implement this project by 2050, US\$ 2,100 billion of investment in the above-mentioned renewable generation capacities and US\$ 600 billion in the construction of transmission lines will be needed.<sup>29</sup>

Development of critical infrastructure such as the power grids, whether “only” between two countries or on a regional scale, inevitably will involve significant amounts of investment as well as technical and regulatory coordination, and have implications for national energy

<sup>29</sup> GEIDCO, 2018.

security as well as social welfare. In the next section, this report presents an overview of challenges and

opportunities that such interconnections present in North-East Asia.

# Sustainable power system development in North-East Asia

## Benefits of cooperation and challenges

**W**hichever of the region-wide power grid interconnection project proposals is implemented, there is solid scientific evidence that increased power grid connectivity between the countries of North-East Asia has great potential for (a) providing consumers everywhere in the region with cheaper electricity, (b) increasing the overall reliability of national power systems, and (c) contributing to the alleviation of air pollution and the reduction of carbon emissions. As with every large-scale endeavour, however, the regional power grid interconnection may have negative externalities and become a driver of environmental degradation and loss of social welfare in the region.

In order to ensure that regional cooperation on power grid connectivity develops in a sustainable way, the feasibility of interconnection projects should be assessed from a more holistic perspective. The focus of the existing studies has usually been on aspects of the chosen interconnection project such as the total cost of the interconnection, environmental risks and damage, opportunities for cooperation on energy security or the potential for modernizing the regional infrastructure fleet and power systems with new technologies. This issue-specific approach has facilitated

the emergence of in-depth analyses of the various aspects relevant to the respective interconnections, which together build an extensive knowledge pool. Combining the insights from these numerous studies enables the focus to be shifted from specific issues to the systemic changes that an increase in the regional power connectivity will trigger for economies and societies of the countries in North-East Asia. In other words, it enables the assessment of the existing interconnection proposals from a viewpoint of their overall sustainability.

Cooperation on the regional connectivity in North-East Asia will face some challenges common to any of the multilateral interconnection proposals. However, some opportunities and challenges are specific to different interconnection initiatives, or are existent only under certain conditions. Therefore, although this report aims to summarize the challenges and opportunities for regional power grid interconnectivity in general, remarks are made on any aspect that is valid only for a particular interconnection design.

## A. Economic aspects

### Overview

Opportunities/benefits	Challenges/threats
Avoided costs through non-construction of new generation capacities.	Size of the Chinese power market and cross-border interconnections, and possible implications for the regional power system.
Avoided costs through non-construction of new (domestic) transmission lines.	Attracting investments for cross-border and regional power grid interconnections.
Avoided costs due to decreasing need for storage capacities.	Inconsistent power market liberalization in the region.
Increased cost-competitiveness of HV transmission technologies due to long transmission distances.	Fair distribution of benefits and of the financial burden.
Cheaper electricity for power markets with high electricity prices, reduction of electricity prices due to region-wide competition.	Potential opposition from domestic power business.
Reduced cost for ancillary services due to an increase in the scope of the power system.	Operationalizing the electricity trade in an interconnected power system.
More investments in new technologies and infrastructure.	

### Possible benefits

Varying economic, climatic and geographical conditions in the countries of North-East Asia create synergies that make regional interconnections an economically beneficial option. In the region where central electricity consumption areas (e.g., Tokyo and Beijing) are far from resource fields (e.g., the Gobi Desert, and large rivers in the Russian Far East), a power interconnection opens new markets for the resource-rich countries and areas, and for the areas with high and/or growing electricity demand – i.e., access to new, cheap electricity. Numerous models and scenarios of regional and transregional interconnections have demonstrated that a regional power interconnection would bring the average price of electricity down compared to the isolated

national power markets (Podkovalnikov et al., 2018; Podkovalnikov, 2011; Podkovalnikov 2002; Rafique et al., 2018; Otsuki, 2015; Bogdanov and Breyer, 2016; Chung and Kim, 2007).

Although the distribution of economic benefits is likely to be uneven between the countries, depending on the size of their national power markets, and their location and position in the regional power system (importer/exporter/transit country), the overall economic effect of the power grid interconnection on the region is assessed to be positive. In the case of a region-wide interconnection, China and Japan will receive the greatest effect of participation. As the two largest participants in the regional power system, their economic gains would correspond to more than two-

## Benefits of cooperation and challenges

thirds of the total system (Podkovalnikov et al., 2018; Voropai et al., 2019). Compared to an isolated scenario/status quo, China will benefit from the interconnection mainly due to the size of its market and lesser need to install new generation capacities. By comparison, Japan's high electricity prices are the major reason behind the high profitability of the regional interconnection for the island state.

Economic benefits can be captured from several aspects of an increased regional power grid connectivity. First, it is generally acknowledged by those studies focusing on economic feasibility of regional power interconnections that the total cost calculation for any of the initiatives should include the "avoided" costs:

### Avoided costs due to less need for construction of new generation capacities

Connecting power systems with seasonally different maximum loads such as, for example, the Siberian EPS and the Chinese EPS, is economically effective. The need to build new generation capacities is lesser in an interconnected system since the combined annual load maximum of consumers in an interconnected power system is less than the sum of the power systems' annual maxima at their separate operation. Although the interconnected system will have additional transmission costs as well as possibly increased fuel costs<sup>30</sup> for higher utilization of existing facilities, these are estimated to be far below the expenses otherwise created for the construction of new generating facilities in the respective independent systems (Belyaev et al., 2006; Chung and Kim, 2007; Podkovalnikov, 2011; Breyer et al., 2015). Saving investment for generation capacities due to the interconnection of power systems results, in turn, in recovering less investment and interest from electricity tariffs, resulting in lower electricity tariffs (Podkovalnikov 2002).

### Avoided costs due to less need for enhancing the domestic transmission lines

Cross-border interconnections that link the generation facilities directly with the metropolitan load centres (such as in the case of the interconnection routes between the Russian Far East, DPRK and the Republic of Korea) may save investments in domestic transmission lines that otherwise needed to be developed to transfer

power to the load centres (ibid., 12). This might be particularly important when considering sections of the regional power grid that go through less interconnected power systems, such as that of the DPRK or Mongolia.

### Avoided costs due to decreasing need for storage capacities

Surplus electricity must be either re-directed, e.g., through demand management mechanisms, stored, curtailed by cutting the generation facility off the grid, in order to avoid grid congestion. This is particularly true for power systems accommodating an increasing share of variable renewable energy. Unless there is an interconnection to enable integration of significant volumes of renewable generation capacity, countries will have to resort to building up higher-cost storage capacities or to increasing curtailment rates. Therefore, costs for additional high-voltage transmission lines will be compensated by a decrease in generation and storage capacities (Otsuki, 2017a; Bogdanov and Breyer, 2016). An additional benefit that is derived from a regional power grid interconnection could be the ability to store the generated power that national power systems cannot accommodate by utilizing storage capacities in neighbouring countries. The large reservoir hydropower plants operating in Siberia and the Russian Far East, for example, might have a considerable seasonal potential that can be used to balance variable electricity generated by renewable generation facilities in China (Voropai et al., 2019).

Given the gradual cost reduction of storage technologies, maintaining regional independent systems while increasing the share of variable renewable generation will eventually be cost-effective as well. It can, however, take up to a decade until a set of independent power systems have managed to decrease the cost of electricity to the level that they would have had in a regionally interconnected system (Breyer et al., 2015; Chung and Kim, 2007).

### Benefit of scale: Increased cost-competitiveness of high-voltage transmission technologies due to long transmission distances

When it comes to constructing transmission lines between different countries in North-East Asia, significant distances have to be covered – from several hundred to more than 1,000 kilometres per interconnection. In order to reduce transmission

<sup>30</sup> Fuel costs are more likely to increase on the exporting side.

losses for long-distance interconnections, high-voltage transmission cables have to be used, with either direct (HVDC) or alternating current (HVAC). HVDC transmission lines, which are proposed as the key transmission technology by most studies, are more costly than the HVAC equivalent, since they necessitate construction of high-cost converter stations. However, from a so called “critical length” that lies between 600 and 1,000 km (depending on the difficulty of the route), the total cost of HVDC transmission lines decreases compared to the HVAC alternative.<sup>31</sup> Given that the length of interstate transmission lines in North-East Asia usually exceeds this critical length, HVDC technology is the most cost-competitive solution. For interconnections involving submarine cable lines the critical length of a transmission system does not exceed 80 km (Koshcheev, 2001) – a distance most interconnection routes in the region exceed.

#### Cheaper electricity for power markets with high electricity prices, and general reduction of electricity prices due to region-wide competition

Integration of national power markets brings the cost of regional interconnection projects down – if the national grid is already in place, less transmission lines have to be constructed. However, even with fragmented national markets, a regional power grid interconnection creates a considerable decrease in electricity cost (Bogdanov and Breyer, 2016; Breyer et al., 2015; ADB/EDF, 2019) due to economic efficiency through international competition. A country with a high electricity price could import cheaper power from another country at a lower price. A country may supply electricity at a lower price in a set period and offer a higher price in another period. When two countries connect their markets to trade electricity on a larger scale, competition between them drives down power prices in both countries (a win-win relationship) (REI, 2017).

In the initial stages of cooperation, however, the primary benefits will be related to the increased stability of the power grid, not the decrease in electricity prices. Given the limited scale and capacity of the first cross-border interconnections, their impact on the electricity prices will be marginal.

#### Reduced cost for ancillary services due to an increase in the power system scope

One benefit of increasing connectivity in the region is to lower the cost of ancillary services.<sup>32</sup> Costs for the provision of large amounts of ancillary services capacity tend to be higher in small systems than in large systems, in part because of the economies of scale that large systems are able to take advantage of, including the availability of more, and more diverse, generating resources. Regional integration further allows for joint optimization of system operations, which can improve overall operating efficiency of the generating fleet and reduce operating costs, such as the cost of fuel (Podkovalnikov, 2011; Neuhoff, 2001).

Trading ancillary services within a regional market also enables increased flexibility of the interconnected transmission systems. This can be seen, for example, in the European power market, where national regulatory authorities and TSOs are developing a set of rules to enable cross-border trading between so-called balancing markets.

In the medium term, as the share of variable renewable generation in the national power systems of North-East Asian countries continues to grow, innovative solutions will be necessary to support system balancing. Enhancing access to balancing resources through regional power grid interconnection may not only contribute to the overall system stabilization and decrease costs, but could also drive the participation of renewable generation facilities in the provision of ancillary services (e.g., inertial response provided by wind turbines, or voltage support provided by solar PV inverters), in particular by offering them additional markets and a greater pool of demand to provide these services.

#### Increased benefits to power grid integration due to reduction in LCOE of variable renewable technologies and high-voltage transmission technologies

Cost reductions of electricity are likely to be even more significant than proposed by existing studies due to falling costs of renewable generation and long-distance transmission technologies. The first modelling exercises

<sup>31</sup> See the next section on technology aspects.

<sup>32</sup> Ancillary services run regulatory operations in the background that perform multiple functions – monitoring, balancing and repairing the energy infrastructure (DENA, 2019).

on cross-border interconnections in North-East Asia with the integration of variable renewable generation date back to the mid-2000s. Consequently, many of the available economic estimates were made with the back-then soaring costs of solar PV and wind technology. Even the most recent analyses (Otsuki et al., 2016; Khamisov and Podkovalnikov, 2018) assume the cost of electricity generated from solar PV to be US\$ 0.05-0.066 per kWh. Meanwhile, reductions in LCOE of solar electricity as well as the recent auction and tender results suggest that by 2030, the prices will fall to between US\$ 0.08/kWh and US\$ 0.02/kWh (IRENA 2019). It is therefore safe to assume that the economic benefit of the proposed interconnection models would be even greater than suggested by many studies. The cost of UHVDC transmission lines is also rapidly going down (Liu et al., 2016), which creates a larger profit margin for electricity trade in the region, given differences in the national electricity tariffs.

#### Even more economic benefits with right policies - regional energy system based on low-carbon energy generation and carbon policies

Economic estimates published in recent years have started including the carbon emission cost in their analysis (Fan et al., 2019; Otsuki et al., 2016; Otsuki, 2017a; Zhang et al., 2016; Podkovalnikov et al, 2020). The economic benefits of an interconnected regional power system are particularly evident when climate and energy goals of the respective countries in North-East Asia are considered. Increasing the flexibility of thermal power plants and developing cross-regional interconnection ties are among the most cost-effective methods of integrating larger shares of renewable generation capacities and hence of increasing renewable energy consumption. Although the studies have proven most interconnection proposals to be cost-effective under present conditions, coordinated national climate and energy policies could give these projects a major impetus.

In particular, the interconnection promotes the cost-effectiveness of energy systems under stringent conditions such as, for example, nuclear phase-out in Japan. In such a scenario, the interconnections diminish the replacement cost of phased-out nuclear power plants by reducing the need for constructing new thermal power plants. On the regional scale, countries would benefit from lower levels of CO<sub>2</sub> emissions, due to lesser need to construct new coal- and gas-fired power

plants, thus contributing to their respective national climate goals (Zhang et al., 2018; Kanagawa and Nakata, 2006). In view of these considerations, interconnection projects that propose connecting the already existing low-carbon generation capacities, such as the hydro power plants in the Russian Far East and southern Siberia, appear to be the most economically attractive in the short term. Interconnections of the regional scope that involve the construction of large-scale variable renewable generation capacities are, on the other hand, a viable option in the medium term.

#### Possible challenges

There is more than enough evidence that developing power grid connectivity in North-East-Asia makes considerable sense from an economic perspective, and a large share of the proposed interconnection projects is cost-efficient. There are, however, factors that can affect the economic efficiency and/or contribute to a redistribution of benefits between the participating countries:

#### Size of the Chinese power market and possible implications for the regional power system

Being responsible for more than three-quarters of the regional electricity consumption, China will have a major influence on the state of the regional power system. When fully interconnected, the North-East Asian countries will, to a certain extent, become interdependent in terms of power supply. Consequently, any major disturbances in the Chinese power market (e.g., blackouts) or abrupt changes in Chinese consumption patterns may affect the regional power market. The scope of such an effect depends on, among other reasons, the transmission capacity of the cross-border interconnections and the volume of power traded over the border, and may be minimal in the initial stages of regional power grid development. Indeed, most commonly proposed are back-to-back, cross-border interconnections with transmission capacity between 0.4 GW and 4 GW, which are not likely to be able to spread any major disturbances in the Chinese power market to other interconnected power systems. Nevertheless, an assessment of such a risk and the development of risk management and emergency cooperation mechanisms are necessary, particularly as the integration of the power systems in North-East Asia is deepening (Bogdanov and Breyer, 2016).

### Attracting investments for cross-border and regional power grid interconnections

As the overview table with proposed interconnections demonstrates, implementing cross-border and regional interconnection projects requires substantial investments of up to several hundred billion United States dollars. The initial costs for the installation of renewable generation capacities and for the construction of transmission lines account for the major share of the total cost, and they make such interconnection projects less attractive for investors (Otsuki, 2017b; Otsuki et al., 2016.; Voropai et al., 2019; Podkovalnikov et al., 2015).

Therefore, particularly when it comes to large-scale multilateral interconnection projects in North-East Asia, the relevant stakeholders need to carefully consider how to secure large investments, taking into consideration long-term energy prices, capital costs and environmental policy trends. This involves, for example, the development of mechanisms for risk reduction. Additional factors, such as the impact of the capacity factor on the transmission price (particularly relevant to the transmission of variable renewables-based electricity over long-distance transmission lines) may also need to be considered depending on the interconnection design. As financial markets are usually not able to underwrite this kind of debt, loan guarantees or special state-sponsored financing mechanisms should be offered by the involved Governments. Involvement of multilateral (e.g., international or regional investment) banks that would adopt policies for compensating stranded costs in the event of project failure would also be helpful in attracting private investors (Cooper and Sovacool, 2013, Voropai et al., 2019; Wang, 2007).

In view of the high upfront cost of regional interconnection projects, several studies have suggested that securing the financing through investments from national network companies seems to be the most practicable solution (Belyaev and Podkovalnikov, 2007; Voropai et al., 2019). However, in North-East Asia, where the network companies have monopolies on transmission in most countries, it remains questionable how eager they will be to invest in projects that might eventually lead to competition in the transmission sector. Some recent studies have suggested that transmission can derive more opportunities than threats from Japan-Russian Federation power grid interconnection (Kimura and Ichimura, 2019) and

Japan-Republic of Korea power grid interconnection (i.e, Zissler and Cross, 2020). In any case, the central role of state-owned transmission operation companies in the national power sectors has to be taken into account and their potential contribution to financing cross-border interconnections has yet to be estimated.

Additional financing for variable renewable generation capacities in Mongolia might come from development aid, since Mongolia has access to such international resources, including technical support that is not available to developed nations. The World Bank, ADB, Asian Infrastructure Investment Bank (AIIB) and the European Bank for Reconstruction and Development (EBRD) are well-positioned to lend financial support to Mongolia, and clean energy projects as the deployment of wind and solar capacities in Mongolia are exactly the type of win-win climate mitigation solution that the World Bank has prioritized as part of its climate strategy (Borgford-Parnell, 2011).

### Considering the additional costs of maintaining renewable generation capacities due to geographical and climate specifics

Southern Mongolia's Gobi Desert is arguably the single best location for solar power generation in the region; the more than 300 days of sunshine per year, little humidity and low average temperatures seem to be the perfect conditions for deploying large-scale solar PV generation capacities.

Nevertheless, maintenance of such facilities in the Gobi Desert might prove to be more challenging, leading to additional costs. In particular, the dust storms that regularly occur in the desert could reduce solar insolation and thus lessen the efficiency of the solar panels. Therefore, the cleaning measures will need be developed and considered when estimating the overall cost of the project. In this regard, the stakeholders might consider solutions used by the countries of the Arabic Peninsula, where climatic conditions are similar to those of the Gobi Desert and north-east China.

### Market liberalization at different stages in North-East Asian countries as a potential obstacle to effective cooperation on connectivity

A large portion of scenarios and connectivity models has been analysed under the assumption that, by the time regional interconnections are established, there

### Benefits of cooperation and challenges

will be a liberalized wholesale market in the region. The economic benefits of these project proposals should be estimated for the case of partial liberalization of the power market in the region (Lee et al., 2011). Advancing liberalization of the national power markets significantly can increase the economic benefits of a regional power interconnection. While different levels of liberalization are not a fundamental obstacle to the establishment of regional power trade, in the long-term further liberalization and subsequent creation of the competitive regional power market can allow North-East Asia to derive the full benefits of regional integration.

#### Distribution of benefits and the financial burden

Although a regional power interconnection will most likely contribute to the reduction of the average electricity price in North-East Asia, it is important that participating countries be aware of the fact that the economic benefits will likely to be distributed unevenly. Furthermore, when securing financing for a region-wide interconnection project, the participating parties should ensure that weaker economies which lack strong debt repayment and technical capacities (e.g., Mongolia and DPRK) are assisted through concessional or grant funds (Bhattacharyay, 2012; Cooper and Sovacool, 2013).

#### Potential opposition from domestic power business

A regionally interconnected power system would grant the North-East Asian countries numerous benefits, such as lower electricity prices and a boost in investments. Nevertheless, one of the central stakeholders – domestic power industry of the net importing countries – may

oppose the connectivity vision, fearing profit losses due to increased competition from abroad. National Governments should engage in dialogue with national generation and transmission companies from the earliest stages of planning.

#### Conducting electricity trade

Finally, trade mechanisms for electricity trade on the regional level have to be developed. One decision that has to be decided upon is the currency used for the transactions. After the Global Financial Crisis, China and the Russian Federation would use their national currencies in power trade settlement to save the transaction cost compared to the use of United States dollars. However, usage of the respective national currencies will lead to an exchange rate risk if the exchange rate mechanism of the two sides is different (as is the case with the Russian rouble and the Chinese renminbi) (Wang et al., 2012; Kalashnikov, 1997). The national currencies of the Russian Federation, China and the DPRK do not belong to the freely convertible – a fact that creates difficulties in organizing electricity exchange (especially with the DPRK), which requires special discussion when determining a form of payment. The following solutions (or their combinations) can be used for regional electricity trade. Payment in hard currency, the most probable choice being the Japanese yen as the only freely convertible currency in the region; payment in national currencies; or a barter form of payment, when in exchanges for electricity, goods and services are provided. While the last two solutions may be acceptable to more participating countries than the first one, they would complicate the procedure of mutual payments.

## B. Technical/operational aspects

### Overview

Opportunities/Benefits	Challenges/Threats
Increased stability of the regional power system (higher capacity of the system to absorb variable renewables).	Choosing the most appropriate transmission technology and power grid design for the needs of North-East Asia. Long distances, difficult routes and high cost.
Synergies from combining different peak loads by season.	Strengthening domestic power infrastructure and ensuring the stability of weaker grid links.
Synergies from combining different peak loads in different time zones.	Harmonization of grid codes and technical standards.
Synergies from spatial distribution of renewable energy sources and the resulting smoothing effect.	Harnessing the solar and wind potential of Mongolia under harsh climatic and geographic conditions.
	The need for innovative ancillary service solutions, including coordination, to enable region-wide power system management.
	Data sharing for reliable operation of the interconnected grid.
	Capacity-building for faultless operation of the grid.
	Developing transport infrastructure to support the development of variable renewable generation capacities and the construction of transmission lines.

With the emergence of a large, interconnected regional power system, innovative solutions will be essential to avoiding congestion and improving the system stability. One of the key challenges related to deployment of renewable energy resources is that they are, to a large degree, constrained both in time and space. The best wind and solar resources are often located far from centres of energy demand and vary in output based on weather conditions or time of the day. Spatial constraints also exist for hydropower as well as for geothermal, wave or tidal power. Expansion of transmission lines is often the only possible way to efficiently utilize the most attractive renewable resources (IEC, 2016; Podkovalnikov et al., 2020).

### Increased stability of the regional power system and smoothing

There are several mechanisms that can help to add flexibility to a power system and allow for accommodation of large-scale renewable generation capacities. Among them are raising the efficiency of existing thermal power plants, building additional flexible power capacities and expanding transmission

lines, both domestically and through interconnections with neighbouring countries. The latter option is, as demonstrated in the previous section on economic aspects, not only the most cost-effective, but also highly efficient since an integrated grid of several countries has a much higher capacity to absorb variable renewable energy than separate national grids (Zhang et al., 2018, Li and Kimura, 2016; Lee et al., 2007b; EC, 2014). Several simulations demonstrate, that, even if the power interconnection does not significantly improve the reliability of the power supply, the required capacity reserve is decreased with the same reliability (Podkovalnikov et al., 2002; Podkovalnikov, 2011; Belyaev et al., 2002).

Furthermore, transmission interconnection can become a valuable flexibility tool for facilitating the integration of variable renewable resources, as it allows the smoothing of national renewable generation profiles (IEC 2016). Increasing the spatial extent of an interconnected power transmission grid smooths the feed-in by the exchange of excess energy over long distances, and therefore supports renewable power integration (Krutova et al, 2017).

### Synergies from combining different peak loads by season

Establishing a regional power interconnection can effectively take advantage of the seasonal differences in electricity demand between the different areas and countries by shaving peaks, thus optimizing the distribution of the generated electricity. In regions such as the Russian Far East, Siberia, north-east China and Mongolia, the peak load normally emerges in winter, while electricity demand in Japan, the Republic of Korea, north (particularly the Beijing area) and eastern China peaks in summer. Interconnections between these areas will lead to a more balanced distribution of loads during the whole year, thus reducing the need for installing new generation capacities (Liu et al., 2016; Voropai et al., 2019; Yilmaz and Li, 2018; IEC 2016). Interconnections enabling Russian electricity export to Japan and the Republic of Korea would have the most potential to utilize the seasonal difference in peak loads (Voropai et al., 2019a; Park et al., 2004).

The overall reliability of the regional power system may also be enhanced by connecting areas with abundant storage capacities to areas with a high share of variable power generation. One such example is an interconnection between Siberian hydropower reservoirs and renewable generation capacities in northern China. The surplus electricity could be stored in the reservoirs of the hydropower plants and sent back to China during the period of load increase.

### Synergies from combining different peak loads by the time zone

Some studies argue that the wide geographical spread of the North-East Asian countries causes them to have differing peak hours, which is why the daily peak load can also be rebalanced through regional interconnections (Li and Kimura, 2016). It is, however, important to note that despite the impressive geographic spread of the region, it covers only four different time zones. Japan, the Republic of Korea and the Siberian region are all in the same time zone and have one-hour difference with China as well as two to three hours difference with areas in the Russian Far East. Consequently, the potential benefits from time zone difference can only be harnessed by interconnecting the Russian Far East to Japan or north-eastern China (Otsuki et al., 2016).

### Technical challenges

Next to the poor level of institutionalization and political tensions, insufficiently developed green energy infrastructure is the major obstacle to creating a regional power grid based on variable renewable power generation. The existing power systems were built and optimized for a fossil fuel-based power generation and need to be adjusted to grant the regional power system more flexibility (Frick and Thioye, 2018). Low levels of population density in the regions with abundant resources for power generation as well as difficult terrain on some interconnection routes add further technical challenges.

### Choosing the most appropriate transmission technology and power grid design for the needs of North-East Asia: Long distances, difficult routes and high cost

The necessity to cross large rivers (like the Amur, for example, in the Russian Far East) and sea straits (to connect Japan with the Russian Far East or with the Republic of Korea) makes several routes for interconnections in the North-East Asian region very challenging. Nevertheless, technological progress in transmission technologies and electronics as well as the scale effect can provide a sustainable solution. High-voltage DC lines (HVDC) are acknowledged to be the optimal technology for power transmission over long distances, while implementing DC submarine cables allows crossing wide rivers and sea straits. The higher cost of HVDC cables levels out starting from a “critical distance” of 600 km for overhead and 80 km for submarine cables, since the higher cost of converter stations is being compensated by the lower cost of the transmission cable, compared to other technologies. Given that most projected interconnections in North-East Asia are significantly longer than the “critical distance”, the higher cost of HVDC transmission lines is a lesser challenge (Podkovalnikov, 2011).

### Strengthening domestic power infrastructure and ensuring the stability of weaker grid links

The extent to which national power grids in North-East Asian countries are integrated as well as the design of the power grids varies greatly – from the centralized power grid system in the Republic of Korea through integrated grids at prefectural or provincial levels in Japan, China and Mongolia, to the poorly integrated

grid in the DPRK. If a regional power interconnection should involve large-scale variable renewable generation capacities, the ability to accommodate bulk variable power transmissions of regional grids in their current state should be examined (Podkovalnikov, 2002). The smaller scale of transmission capacity of the Mongolian and DPRK domestic grids makes them particularly vulnerable to any shortages, fluctuations and disruptions of supply. Furthermore, Mongolia has long-term power purchase agreements with the Russian Federation, which leaves little room for integration of alternative forms of generation into the Mongolian grid in its current state. On the Russian side, strict provisions regarding variability and load-frequency control pose a challenge for integrating new renewables. Consequently, if the regional power system based on variable renewable electricity should be interconnected with the Russian Federation, specific agreements for potential variability will likely need be negotiated (Cooper and Sovacool, 2013; Churkin et al., 2019; Song, 2013). In any case, deployment of the variable renewable potential of the Gobi Desert would require immediate interconnection of the generation capacities with neighbouring countries.

China's eastern grid is likely to play a central role in supporting the North-East Asian power grid interconnection. China is actively developing ultra-high voltage domestic power links, and plans to establish the eastern and western synchronized grid within service areas of the State Grid Corporation of China (SGCC) (Liu et al., 2016). On the other hand, interconnecting Japan might prove to be a challenge. In order to enable bulk electricity transmissions from the mainland to the Tokyo area, Japan's main load centre, interconnection links between Japan's islands as well as between different service areas will most likely need be strengthened.

While strengthening the domestic power grid is a task that needs to be addressed by all North-East Asian countries, it is not a prerequisite for pursuing cooperation on regional power grid connectivity. Even if the domestic power grid is not fully developed, countries in the subregion can secure some benefits from cross-border interconnections. Undoubtedly, for an integrated regional power grid to be fully functional, the domestic power grids of the member countries will also need to be highly integrated. However, the initial stages of cooperation towards regional power connectivity (e.g., bilateral cross-border interconnections) should not be hindered by this.

### Harmonization of grid codes and technical standards

Grid codes set the rules for the power system and energy market operation, ensuring operational stability, security of supply and well-functioning wholesale markets. As such, they are essential both for the smooth functioning of the multilateral power trade and the successful integration of large shares of variable renewable energy sources. Therefore, harmonization of grid codes, in particular those related to transmission capacity allocation and the secure operation of the grid, is among the prerequisites for the regional power grid integration, which is already in its initial stages (IEA 2019f). The harmonization of regional grid codes comes with the necessity to share data on national power systems, parts of which – particularly if related to grid planning and capacity calculation methodologies – are often considered sensitive. However, the data required as a minimum for enabling cross-border power trade, however, does not fall into this category, and therefore poses no obstacle for the harmonization of the grid code. At the initial stage of grid code harmonization, it may take place in the bilateral or multilateral format, where specifics of each country's power system are taken into account.

Among the concrete technical challenges for the initial stage of regional power grid interconnection are the different frequencies of the domestic grids in North-East Asian countries. The frequency of alternating current is 50 Hz in the Russian Federation, Mongolia, China and northern Japan. In the Republic of Korea and southern Japan it is 60 Hz, while in the DPRK the actual operating frequency varies and has been closer to 50 Hz (Hippel, 2001; Podkovalnikov, 2011). The most feasible solution among those suggested by various studies for interconnecting non-synchronized power systems in the region are direct current interconnection ties with AC/DC/AC back-to-back converters (Giri, 2019; Podkovalnikov, 2011).

Finally, even in power systems with the same frequency, there are different approaches to maintaining power quality and control. Although technical cooperation is required in achieving the long-term goal of a harmonized regional power system, implementing DC interconnections is considered to be the most practical solution in the initial stages (Podkovalnikov, 2011).

## Benefits of cooperation and challenges

### Harnessing the solar potential of Mongolia under harsh climatic and geographic conditions

While the operation and maintenance of large-scale PV installations appears to be less problematic, even under the climatic conditions of the Gobi Desert, the installation of concentrated solar power (CSP) facilities – another technology considered for the Gobitec project – may prove to be a challenge. The dust storms, whose obscuring effect on the PV panels can be redressed by introducing dust-removing solutions, may cause permanent damage to mirrors in CSP installations, should this solar power technology be chosen for this project (Cooper and Sovacool, 2013). Moreover, although low temperatures are known to increase the efficiency of solar panels, they might appear problematic in the case of a CSP installation. Molten salt, which is used as a thermal energy storage method in CSP facilities, has a melting point of 221 °C and freezes at temperatures of 120-220 °C. As temperatures in the Gobi Desert can go well below -30°C in winter, the Gobitec design will need to include a sustainable method to keep the transfer fluid liquid (Cooper and Sovacool, 2013).

Also, large-scale wind power installations will have to face these challenges, in particular the problem of de-icing the turbine blades in winter as well as the potential effect of dust on the performance of wind turbines.

### Innovative technologies for better ancillary services

Innovative design and introduction of wide-area monitoring systems (WAMS) will be necessary to enable efficient ancillary services in a region-wide power system. Synchrophasors, a new grid measurement technology that is being used worldwide, could dramatically increase the capabilities of the energy management system. In contrast to the conventional phasor measurement units, each measurement of a synchrophasor is precisely time-stamped, which allows several synchrophasors from across the grid to be synchronized and monitor the power system more efficiently (Giri, 2019; IEC, 2016).

### Data sharing for reliable operation of the interconnected grid

Sharing real-time information from neighbouring countries' major substations, such as information on

voltage and power flows on lines, transformers or generators, is necessary for safer and more efficient coordination of the grid as well as its operation in an effective and secure manner (Giri, 2019; Cooper and Sovacool, 2013). This is especially beneficial with the growth of cheap renewable resources in different countries. Some studies have expressed doubts about the readiness of North-East Asian countries to share such information, since it might be perceived as revealing their security vulnerabilities (Cooper and Sovacool, 2013). In order to overcome political mistrust and de-securitize the issue of power grid cooperation – i.e., to stop regarding this issue solely through the prism of national security – the establishment of a regular dialogue on the working level with subsequent development of an institutionalized platform for such data exchange is advisable. Clarifying what data need to be shared for what type of interconnection will be a necessary first step; as international experience shows, data needed for the coordination of a regional power grid are not as sensitive as is often perceived, and even less so for bilateral cross-border interconnections.

### Capacity-building for faultless operation of the grid

Operation and maintenance, both of the large-scale renewable generation facilities and the nodes of a region-wide power system, are highly complex tasks requiring well-trained personnel on the ground. This might prove to be a challenge in the case of Gobitec. While it is a globally unprecedented project, both in scope and implementation, Mongolia has not yet gained enough experience in operating large-scale renewable generation facilities and ultra-high voltage transmission grids. Cooperation in the development of the regional power interconnection should go hand-in-hand with regional capacity-building programmes.

### Developing infrastructure to support the development of variable renewable generation capacities and the construction of transmission lines

Construction of large-scale renewable generation facilities and long-distance transmission lines requires sufficient infrastructure to transport the necessary materials and components to the construction site. Transporting enormous wind turbines from the manufacturer to the project site can present a challenge even in countries with modern infrastructure, let alone

unpopulated areas such as the Gobi Desert. There are paved highways to Mongolia's Oyu Tolgoi mine, constructed with support from the Government of China on the Sino-Mongolian border; however, additional

transportation infrastructure will be necessary for the construction of Gobitec and the transmission lines in less populated areas of the region (Borgford-Parnell, 2011.).

## C. Environmental and climate aspects

While most of the proposed interconnection projects are profitable from the economic perspective (lower electricity price), it is also important to consider their implications for environmental sustainability. Depending on implementation, cross-border and regional power interconnections may significantly contribute to the improvement of the environmental situation in the region, or to further exacerbate it.

### Overview

Opportunities/benefits	Challenges/threats
Alleviating atmospheric pollution.	Damage to habitat and environment due to large-scale construction works.
Curtailing CO <sub>2</sub> emissions and accelerating the achievement of national climate goals.	
Reducing other environmental risks through enabling renewable power generation.	

### Opportunities

There appears to be a general agreement in the expert community that an interconnection of North-East Asian power systems has strong potential for improving the environmental situation in the region (Hammons, 2011; van de Graaf and Sovacool, 2014; Streets, 2003).

#### Alleviating atmospheric pollution

Air pollution is one of the most serious environmental challenges in North-East Asia, with populations in China, the Republic of Korea and Mongolia being particularly affected. Enhanced power grid interconnections can contribute to better air quality in North-East Asia in at least two ways. First, air quality at the main load centres can be improved with the spatial separation of generation sources and points of electricity use. In most of the region, the major pollution sources, i.e., coal-fired power plants, are located in urban areas. The population in these areas is therefore exposed to high ambient pollutant concentrations, with resulting damage to human health. A cross-border interconnection enables electricity supplies from generation sources located far from urban areas, thus improving the air quality in the

load centres. This effect would take place even with non-renewable generation sources, as long as they are located far from the populated areas (e.g., cross-border interconnection linking the existing coal-fired TPPs in Siberia or the Russian Far East with Chinese urban areas). The environmental benefit of power grid interconnections is estimated to be highest during periods of maximum load, when thermal power plants have to operate at full capacity and produce greater pollution (Podkovalnikov, 2002; Podkovalnikov, 2011).

Second, regional and cross-border interconnections could improve the air quality by replacing coal-fired power generation with cleaner sources, such as hydropower, variable renewable energy sources and natural gas. Doing so would contribute to a substantial decrease in volatile chemical particulate matter, carbon emissions and other polluting emissions, including SO<sub>2</sub> and NO<sub>x</sub>, not only in the singular load centres, but on the regional scale (Cooper and Sovacool, 2013; Liu et al., 2016; Rafique et al., 2018; Streets, 2003; Yoon et al., 2004; Energy Charter, 2014; Podkovalnikov, 2002; Voropai et al., 2019; Churkin et al., 2019; Lee et al., 2011).

### Curtailing CO<sub>2</sub> emissions and accelerating the achievement of national climate goals

Curtailing CO<sub>2</sub> emissions to an extent that would at least correspond to the nationally determined commitments (NDCs), let alone UNFCCC's 1.5 scenario, is a task of scale. North-East Asia is, on the one side, home to some of the world's most energy-hungry economies, and on the other side, to countries with enormous potential for low-carbon energy deployment, but with economies not large enough to harness this potential. A regional power grid interconnection could help to connect these two extremes and create a low-carbon regional power system (Borgford-Parnell, 2011; ADB/EDF 2019). According to one of the most recent studies on the North-East Asian Power System Interconnection (NAPSI) performed by EDF and ADB (2019), the implementation of the interconnection would, depending on the design, result in an additional 17 Mt to 210 Mt of CO<sub>2</sub> emissions in North-East Asia in 2036 (ADB/EDF 2019).

Furthermore, once established, power exchange via regional power grid interconnections can, in the long term, foster the establishment of an emission trading market among the countries of North-East Asia. It could also encourage the harmonization of environmental regulations and lead to a more efficient environment and climate policy overall (Yoon et al., 2004; Hippel, 2001; Streets, 2003). Once bilateral power exchange via cross-border interconnections has evolved into a functioning regional power market, the market mechanism itself could well contribute to the further reduction of carbon emissions, by giving preference to the electricity source of the lowest marginal cost, which is increasingly becoming renewable energy. Should the competitiveness of renewable energy sources be further enhanced through the introduction of a carbon pricing mechanism, the regional power market could become an even more effective tool for reducing carbon emissions. A precondition for such developments is, however, continuous and intensive dialogue on climate policies between the North-East Asian countries.

Although the potential for regional power grid interconnections to curtail carbon emissions in North-East Asia is considerable, studies addressing environmental issues give a word of caution. Cross-border and regional interconnections are only mitigating regional carbon emissions if they enable the transfer of electricity generated by low-carbon sources or if they

help to avoid construction of new coal-fired power plants by transferring supply surplus electricity from the already existing coal-fired power plants in the neighbouring countries. In the latter case, reduction of the carbon emissions happens due to the displacement of coal generation near the load centre. If, however, the respective interconnection project includes construction of new coal-fired generation capacities, a transfer of the carbon burden occurs and an increase of carbon emissions at the regional level happens. In other words, carbon emissions that would have been produced by the coal-fired generation facilities near a populated area are instead produced in the distant generation facility, now interconnected with the populated area. Thus, this would have zero, or even negative effect on regional efforts to reduce carbon emissions (Hippel et al., 2011).

Transfer of the carbon burden may even gain interregional dimensions, as coal-fired generation in the region is increasingly replaced by the low-carbon generation sources. For example, Japanese, Korean and Chinese companies are now actively investing in newly commissioned coal-fired power plants abroad (primarily in South-East Asia), where the demand for cheap and reliable electricity is best met by coal (Bengali, 2019), by trying to make use of equipment that will lose its value in the coming years. These investments are much needed in cross-border interconnections and the national Governments should strive to redirect them through climate and environment policies.

### Reducing other environmental risks by enabling renewable power generation

A regional power system based on renewable generation sources is considered to be a possible solution with a generally lower risk for the environment compared not only to coal, but also to other low-carbon sources. Among the threats – including fossil and other low-carbon sources, such as nuclear, natural gas with carbon capture and storage technologies – are nuclear melt-down, nuclear terrorism, unsolved nuclear waste disposal, remaining CO<sub>2</sub> emissions of power plants with CCS, a diminishing conventional resource base and high health costs due to heavy metal emissions from coal-fired power plants (Bogdanov and Breyer, 2016).

### Challenges

It is evident that cross-border interconnections in the region could have a major positive effect on the

air quality and environment in general, particularly in areas of high electricity use such as metropolitan areas. Nevertheless, the environmental impact caused by the construction and operation of transmission lines, particularly ones that may have to pass through environmentally fragile areas, should be taken into account. Also, depending on the generation source, the positive effect created for the load centres might be the opposite in the sites of electricity generation.

#### Damage to habitat and the environment due to large-scale construction work

Access to clean water is a major issue in Mongolia, where approximately half of the country's population has no access to clean water. Therefore, using this scarce resource for the purposes of the power grid interconnection (in particular, cooling of renewable generation facilities, construction, mining etc.) may cause even more acute water shortages (Cooper and Sovacool, 2013; van de Graaf and Sovacool, 2014). Although this issue is not directly related to the envisioned transmission systems, but to the generation facilities, it should be considered if the large-scale renewable energy generation facilities such as envisioned by the Gobitec are to become the core of the regional power grid interconnection.

Long-distance transmission lines may often have to pass through sensitive ecological areas such as national parks, woodlands with valuable tree species as well as densely populated areas (Hippel et al., 2011; Koshcheev, 2003).

Accurate estimates of land use for the construction of transmission lines, including the total area used for towers, should be made a part of the feasibility study of any long-distance interconnection project (Koshcheev, 2003).

When cooperating on power grid interconnections in the region, stakeholders should also take into account and carefully assess some further potential risks, such as marine ecosystem damage from tidal power or undersea cables, possible human health and ecosystem effects from transmission lines as well as the environmental effects associated with specific alternative energy sources (nuclear, hydro etc.) (Streets, 2003).

Although the above-mentioned environmental challenges require thorough consideration and sustainable mitigation mechanisms, there is in general widespread agreement that, from the environmental perspective, the benefits of a cross-border interconnection in North-East Asia significantly outweigh the possible damage. In most of the proposed interconnection scenarios, regional power systems have better environmental and economic performance than independent ones (Zhang et al., 2016). When it comes to the environmental feasibility and benefits of singular interconnection initiatives, large-scale interconnection projects, such as the Asian Super Grid, NAPS or GEI have very significant potential for decarbonizing the regional power sector (Otsuki, 2017a; Energy Charter, 2014; Otsuki et al., 2016; Wang et al., 2018; Kim, 2020).

## D. Social aspects

### Overview

Opportunities/benefits	Challenges/threats
Improving social welfare and increasing living standards of the poorest population groups.	Taking local interests into account.
Capacity-building as a key enabler of social welfare.	Community support to ensure a just transition.
Alleviating energy poverty and granting high-quality access to energy and energy services.	Stranded assets and sustainable transition to a power system dominated by low-carbon generation.
Avoiding environmental degradation and loss of habitat.	
Contributing to better human health by alleviating air pollution.	

Generally, past experiences in South- and South-East Asia have shown that regional infrastructure can help to increase the standard of living and reduce poverty by connecting isolated places and people with major economic centres and markets, thus narrowing the development gap among Asian economies. It also promotes environmental sustainability and facilitates regional trade integration and the acceleration of regional cooperation (Bhattacharyay, 2010; Zhang et al., 2019).

#### Improving social welfare and increasing living standards of the poorest population groups

Implementing a region-wide interconnection project can have various positive spillovers for the societies of North-East Asia. For example, construction of large-scale power generation facilities such as Gobitec could create up to an estimated 400,000 new jobs in the solar PV sector and about 480,000 jobs in the wind sector, thus contributing to poverty alleviation and diversification of the economy in Mongolia. At the regional level, the creation of an additional 140,000 jobs in the construction and maintenance of the transmission lines is projected (ECT, 2014; REI, 2017). Aside from creating new jobs, deeper inclusion of Mongolia in the regional wind and solar PV value chains would boost the development of critical infrastructure (e.g., railways and highways) in the country, contributing to higher accessibility to social services.

Improvement of living conditions is also expected in the high-income economies such as Japan and the Republic of Korea. There, regional power interconnection will help to overcome social constraints, such as the transmission line and power plant siting, given the little available land (Hippel, 2001). Furthermore, realizing power export projects in the Russian Far East will contribute to alleviation of social tension by giving the population new employment opportunities and promoting economic growth (Hammons, 2011; Voropai et al., 2019; Sevastianov, 2008). Also, the interconnections between the Russian Federation, the DPRK and the Republic of Korea have a high potential for improving the living conditions of the DPRK's population, particularly if that country is not merely a transit area for Russian power exports to the Republic of Korea, but also profits from the power supplies itself. In particular, re-launching the interconnection between the Korean grid and the Kaseong Industrial Complex near

the demilitarized zone could boost the DPRK's economic development (Yoon et al., 2004).

#### Capacity-building as a key enabler of social welfare

According to the report of the Energy Charter, jobs that would have been created by the implementation of Gobitec and the regional power interconnection initiatives, are mainly in the construction sector (both for solar PV installations and the transmission lines) and only available for the period of the projected construction time. In order to avoid the outsourcing of the jobs in the operation and maintenance of the renewable generation facilities as well in the control and operation of the cross-border interconnections (Churkin et al., 2019), capacity-building initiatives should be developed and implemented at an early stage of the regional cooperation on power grid connectivity.

#### Alleviating energy poverty and granting high-quality access to energy and energy services

Power grid interconnections of a regional and intercontinental scale are often positioned as one of the key instruments for granting access to modern and clean energy by the population groups that are still locked in energy poverty (Kell, 2018; Li and Jiang, 2018; Rafique et al., 2018; Yang et al., 2018). However, it is still unclear how population groups in remote and rural areas, with no access to the central grid (and usually with the highest levels of energy poverty) are going to profit from these large-scale infrastructure projects. Cooperation on regional power connectivity should also include initiatives promoting distributed power generation and decentralized power grid solutions (Zhang and Qiu, 2018).

Improving energy services, both in rural and urban areas, is imperative for improving the quality of energy access and for the populations of the North-East Asian countries to be able to profit from the regional power interconnections. The poorest households in Mongolian urban areas might have access to electricity, but in the absence of better energy services they have to rely almost entirely on coal, wood and trash-burning stoves for heating, damaging their health and air quality – power interconnections with the neighbouring countries alone will not be able to solve this problem (van de Graaf and Sovacool, 2014). Sector coupling and electrification of the buildings and transport sector, particularly in

the low-income countries, can be one of the central instruments for granting high-quality access to energy services and enabling the poorest population groups to profit from the regional power grid connectivity.

### Avoiding environmental degradation and loss of habitat

Improperly planned, sited or deployed renewable energy systems can have significant negative impacts on the local environment and residents. For Mongolia's fragile environment specifically, habitat loss and land degradation are of particular concern. Additional land and water stress may be triggered by activities of the rare earth mining industry that are boosted by the project as well as by the construction of the transmission infrastructure. Cooling of solar generation and some transmission facilities (e.g., DC converters) is conventionally accomplished by water cooling technologies. Given the acute water shortage and the lack of access to clean water for a large share of the population, the use of water-cooling technologies for large-scale power generation and transmission facilities may prove catastrophic. When considering the implementation of the Gobitec project, the stakeholders will need to come up with innovative solutions that enable non-water/dry cooling systems for the power grid infrastructure (Cooper and Sovacool, 2013).

Land degradation, particularly in southern Mongolia, is of significant concern, especially along the edge of the Gobi Desert where unchecked desertification is driven by climate change and over-grazing. A total of 77.8% of Mongolia's overall land area is affected by degradation (UNCCCD, 2019). Wind farm development in southern Mongolia will require construction of access roads and other facilities, which could cause further land degradation. However, wind farm development may also be an effective catalyst for land conservation and anti-desertification initiatives. As the majority of wind development property remains undeveloped, that land can be preserved and protected, unneeded access roads can be reclaimed, and project revenues and taxes can be used for conservation efforts (Borgford-Parnell, 2011).

### Contributing to better human health by alleviating air pollution

Depending on their configuration, cross-border interconnections in North-East Asia may significantly contribute to reducing air pollution on local and regional

levels, thereby improving public health in North-East Asia. The first effect will be felt in the main energy load centres (metropolitan areas such as Beijing, Harbin, Shenyang, Pyongyang and Seoul), powered by closely located, coal-fired thermal power plants. Provided that rural electrification is achieved, also rural communities in northern China, Mongolia, and the DPRK would benefit from reduced particulate levels, in addition to reduced  $\text{SO}_2$ ,  $\text{NO}_x$ , CO and other gases (Streets, 2003; Hoppel, 2011).

Several of the proposed bi- and trilateral cross-border transmission lines are planned on the premise that additional coal-fired generation capacities are constructed in the areas remote from the main load centres (e.g. Interconnections between the Russian Federation, the DPRK and the Republic of Korea). While being more economically feasible due to the lower upfront cost and possibly providing access to cheaper electricity, in the long-term, these projects might have negative spillovers on the air quality in the region. Alternatively exploring the potential cross-border interconnections connecting the load centres with the already existing coal-fired generation facilities might be reasonable in the view of their potential positive effect on the economic development (Wang, 2007, 34). Looking from the perspective of the overall sustainability of the regional power system, however, it is however advisable to focus on integration and deployment of low-carbon energy sources in the long run.

### Challenges

The first challenge concerns taking local interests into account. Long-distance transmission lines, such as those envisioned for the regional power grid interconnection projects, will inevitably go across some populated areas, potentially infringing upon the interests of the local population. The most evident example is that of the nomadic herders who comprise about 30% of Mongolia's population. The construction of transmission lines, large-scale renewable generation capacities and the adjacent infrastructure (e.g., roads) that are planned in order to interconnect the Gobitec facilities with the points of electricity demand in China, can potentially block the traditional routes of the herders, thus disturbing their livelihoods. When it comes to the planned transmission lines, new transmission technologies such as the gas-insulated transmission lines, which are laid underground and have less impact on the landscape, should be considered given their cost-efficiency by the time the

transmission lines are constructed. In the case of large construction sites, policymakers will need to consider how to give the local nomadic families right-of-way across the restricted areas or develop compensation mechanisms in order to accommodate the herders and pre-empt local opposition (Sovacool and Cooper, 2013: 196).

In densely populated countries such as Japan and the Republic of Korea, local opposition to the interconnection projects may arise since the generation and transmission facilities may have some impact on the scenery and the ecosystems. In order to gain public acceptance of these new transmission lines, it is important to engage in a dialogue with the local population and affected stakeholders from an early stage of the project development.

Second, support needs to be given to the communities affected in order to ensure a just transition. Particularly when it comes to the DPRK and Mongolia as well as in north-east China, where a large share of the population do not have access to the central grid,<sup>33</sup> a regional power grid interconnection per se might be of negligible or no benefit to those communities. Together with pursuing the connectivity vision, community support programmes should be developed to ensure that the prosperity

gained from an interconnected, low-carbon power system is shared with the poorest population groups.

**Stranded assets and sustainable transition to a power system dominated by low-carbon generation.**

Growing electricity imports through regional power interconnection may eventually cause profit losses for businesses related to production, transportation and conversion of conventional generation fuels in the importing country; such businesses include mechanical engineering, metallurgy, chemistry and construction (Korneev et al., 2018). So far, no studies have been carried out on the implications of such shifts in social welfare in the importing country. It is, however, important to make sure that the population groups employed in the “conventional” energy sector are provided with new job opportunities should the increase in regional power trade produce such “stranded assets”. Taking the investors onboard in the planning of regional power grid interconnection and the ongoing shift towards low-carbon energy systems is necessary in order to streamline new investments in the energy sector and prevent the creation of further stranded assets.

<sup>33</sup> Here, central grid refers to the main transmission system. In some cases, such as in North-Eastern China, access to electricity is provided through a combination of mini-grid and off-grid solutions.

# Towards regional cooperation on North-East Asian power grid connectivity

## Potential next steps and policy recommendations

**A**side from the immense potential as a facilitator of sustainable development, regional power grid interconnections have significant value as political projects, contributing to cordial relations among the interconnected countries as well as enhancing stability and security. Increasing regional connectivity may prove to be the key instrument in fostering cooperation between North-East Asian countries (Hippel, 2001; Lee, 2013; Podkovalnikov, 2011; van de Graaf and Sovacool, 2014; REI, 2017). There have been historic precedents that prove the potential of cooperation on energy to promote regional integration, with the European Union being the textbook example.<sup>34</sup> Transmission lines, in turn, represent major economic links, create interdependences and contribute to good relations between countries (Hippel, 2011).

<sup>34</sup> European Coal and Steel Community (ECSC), an organization created after World War II to regulate the industrial production of six European countries, initiated the process of regional integration which, almost five decades later, led to the emergence of the European Union

The development of power grid interconnections contributes to the diversification of energy supplies for the import-dependent countries. This, in turn, will strengthen the overall stability of the energy system, which is traditionally threatened by political tensions in the Middle East which is the main supplier of oil and LNG to North-East Asia (Hippel, 2001; Sevastianov, 2008; Liu et al., 2016; Rafique et al., 2018; Li and Kimura, 2016; REI 2017). Diversification of electricity supplies is becoming increasingly relevant, given that electrification of national economies is set high on the political agendas of North-East Asian countries and the fact that electricity is on the way of becoming the dominant type of energy. Also sectors traditionally dominated by fossil fuels, such as transport and heating, are consuming more electricity year-on-year, thus raising the importance of electricity supplies even further.

Cross-border power interconnections may significantly improve the security of power supply. For example, an interconnection between the Republic of Korea and Japan could diminish the risk of power shortages or fallout, as occurred in 2004 when the Mihama nuclear power plant was shut down due to an accident (Kanagawa and Nakata, 2006). Also, in view of the national policies directed towards the deployment of variable renewables, a regional interconnection enhances the grid stability, thus contributing to power supply security.

On the other hand, the potential for North-East Asia regional power interconnection to contribute to peace, stability and security can only be tapped if the political will of the region's countries to cooperate is clearly proclaimed. At the moment, the lack of intergovernmental cooperation on energy issues as well as the generally tense political situation in the region are universally perceived to be the biggest obstacle to regional cooperation on power grid connectivity in North-East Asia (Chung and Kim, 2007; Fan et al., 2019;

Kell, 2018; Otsuki et al., 2016; Yilmaz and Li, 2018; Zhan et al., 2016; Kim, 2020). Although no large military conflicts have occurred in North-East Asia since the Korean War, historical sentiments, territorial disputes and geopolitical rivalries sometimes involving extra-regional actors enfeeble any attempts to commence a high-level regional dialogue on energy issues. The high dependence of Japan, the Republic of Korea and, increasingly, China on energy imports is an additional factor that contributes to political inertia when it comes to cooperation on energy issues. Given their vulnerability to disruptions in energy supplies, these countries traditionally perceive energy as a matter of national security.

The following strategies and policy recommendations can (1) facilitate the development of a transparent and stable institutional and regulatory framework (2) create an environment of mutual trust and understanding and (3) map a way towards an interconnected North-East Asia.

## **A. Policy recommendations for North-East Asia power system connectivity**

A draft Roadmap for Power System Connectivity has been developed by the ESCAP Expert Working Group on Energy Connectivity and aims to eventually create a pan-Asian interconnected grid that offers a more reliable, affordable and sustainable electricity supply. The proposed draft Roadmap is based on a set of nine reference strategies and aligns power system connectivity with the Sustainable Development Goals, especially the meeting of the SDG 7 targets (ESCAP, 2019). In alignment with the nine proposed strategies, a proposed framework for power system connectivity in North-East Asia is presented below.

Strategy 1: Building trust and political consensus on a common vision for power grid connectivity.	<ul style="list-style-type: none"> <li>Start of an inclusive governmental dialogue.</li> <li>Negotiating clear principles for long-term cooperation on power grid connectivity.</li> <li>Discussions on reframing the notion of regional energy security when it comes to power system interconnections.</li> <li>Dialogue on “new” security issues.</li> <li>Public-private dialogue to ensure fair distribution of benefits.</li> </ul>	Baseline Strategy. Ensuring the Coherence of Energy Connectivity Initiatives with the Sustainable Development Goals
Strategy 2: Developing a Master Plan for regional power grid interconnection.	<ul style="list-style-type: none"> <li>Creating a business case to kick-off the implementation of the Master Plan.</li> <li>Working out the minimum requirements for regional power grid interconnection.</li> <li>Including the existing cross-border interconnections and domestic power grids in the picture.</li> </ul>	
Strategy 3: Developing and implementing Intergovernmental Agreements, creating a broader institutional framework.	<ul style="list-style-type: none"> <li>Signing a comprehensive MoU on multilateral cooperation on power grid connectivity.</li> <li>Developing a set of agreements, creating a framework for cooperation.</li> <li>Creating a formal institution in North-East Asia to support interconnection, including enabling technical, policy and political collaboration.</li> </ul>	
Strategy 4: Coordinating, harmonizing and institutionalizing policy and regulatory frameworks.	<ul style="list-style-type: none"> <li>Harmonization of regulatory norms and standards for efficient operation of cross-border interconnections.</li> <li>Cooperation on climate regulations and carbon pricing.</li> <li>Dialogue and harmonization of environmental standards.</li> </ul>	
Strategy 5: Moving towards multilateral power trade and creating competitive cross-border electricity markets.	<ul style="list-style-type: none"> <li>Developing regulations for cross-border power exchange.</li> <li>Developing coordinated price-building mechanisms for power exchange.</li> <li>Decide on the currency (or currencies) for cross-border power trade.</li> <li>In the short term: sets of regulations for separate interconnection projects.</li> <li>In the medium term: from harmonized bilateral trade towards a multilateral power market.</li> <li>In the long term: unbundling and liberalization of energy markets.</li> </ul>	
Strategy 6: Coordinating cross-border transmission planning and system operations.	<ul style="list-style-type: none"> <li>Including cross-border transmission planning into national energy strategies.</li> <li>Coordination of cross-border transmission planning and operation with domestic plans and strategies.</li> <li>Cooperating on joint emergency response mechanisms.</li> <li>Coordination of ancillary services to secure faultless power supply.</li> <li>Mechanism for data sharing to enable faultless operation of the regional power system.</li> </ul>	
Strategy 7: Mobilize investments in cross-border grid and generation infrastructure.	<ul style="list-style-type: none"> <li>A transparent and efficient legal framework for investments in the regional power sector.</li> <li>Support through FTA agreements (bilateral, trilateral and multilateral – in the subregion)</li> <li>A study on policies to support financing of the regional power grid interconnection (governmental loans, guarantees on investment returns, subsidies, tax incentives etc.).</li> </ul>	
Strategy 8: Capacity-building.	<ul style="list-style-type: none"> <li>Publishing data in English for better accessibility and using ESCAP as a platform.</li> <li>Engage in joint capacity-building programmes.</li> <li>Learn from international experience.</li> <li>Raise public awareness and engage in dialogue with the affected communities.</li> </ul>	
Strategy 9: Ensuring that energy connectivity initiatives are compatible with the Sustainable Development Goals.	<ul style="list-style-type: none"> <li>Inclusion of the Paris Agreement and the Sustainable Development Goals in the political and institutional framework on power grid connectivity.</li> <li>Developing guidelines and methodologies for evaluating the sustainability implications of cross-border transmission and generation projects.</li> </ul>	

## Strategy 1. Building trust and political consensus on a common vision for power grid connectivity

All studies on regional power grid interconnection that mention policy issues agree that at the first stage – no matter what the design is of the region-wide interconnection project – the crucial aspect is not economic factors, but rather the political will and the readiness of participating countries to initiate the cooperation process. Also, at the later stages in the medium and long term, political support will be crucial to ensuring unhampered and sustainable development of the interconnection project.

Stakeholders: National Governments and relevant ministries, power sector industry.

Time frame: Short, medium and long term.

### Start of an inclusive governmental dialogue

The necessary first step towards building an environment of trust between the countries of North-East Asia is a multilateral dialogue in which policymakers of the respective countries may find common ground for cooperation on power grid connectivity. Whether in the form of informal meetings or official summits, this dialogue should have continuity and provide all North-East Asian countries with an equal opportunity to present their interests and concerns.

Inclusiveness of this dialogue is of immense importance. One of the issues to be addressed is how to include the DPRK in the regional cooperation process (Bradbrook, 2002; Voropai et al., 2019). The challenge is twofold, since it is related to the political stance of the DPRK Government as well as to the condition of the country's grid, which in its current condition is not suitable to become a link in the regional power interconnection. Although Cha et al. (2008), van de Graaf and Sovacool (2014) and several other studies expressed concerns regarding the inclusion of the DPRK in the regional interconnection initiative, the prevailing opinion is that a regional power interconnection without participation by that country loses a significant part of its value (Lee et al., 2007b; Kawai, 2013; Korneev et al., 2018; Otsuki, 2017b etc.). When it comes to the interconnection for the Russian Federation and the Republic of Korea, the most efficient routes go through the DPRK. The

Korean Peninsula is geographically predestined to play the role of a regional bridge, and an interconnection between the DPRK and the Republic of Korea might lay the foundation for a region-wide interconnection of the North-East Asian national power systems (Lee et al., 2004: 1; Lee et al., 2007a, b, c). An interconnection between the DPRK and other countries in the region is also important from the security perspective, as it “integrates” the isolated country with the rest of the North-East Asia and creates interdependencies that in the long term will help to re-introduce the DPRK to the community of North-East Asian States in a sustainable way.

### Negotiating clear principles for long-term cooperation on power grid connectivity

At the very early stage of intergovernmental discussions, a set of principles for long-term cooperation on power grid connectivity should be developed. These principles will need to be formulated in a very clear and transparent manner, thus creating a working environment of mutual trust, where every participating country has confidence in the conduct of others. For example, agreeing on the principle of consensus and the principle of gradual and orderly progress as the basic norm for cooperation on power grid connectivity would assure all North-East Asian countries that their voices will be heard in the multilateral discussions.

Furthermore, in their cooperation towards regional power grid connectivity, the North-East Asian States are advised to comply with the spirit and principles of the United Nations Charter. The regional power interconnection mechanisms should abide by the following principles – respect for mutual sovereignty, mutual non-interference in internal affairs, respect for the right to equal participation in security matters, and respect for cultural diversity and self-determination.

### Discussions on reframing the notion of regional energy security when it comes to power system interconnections

The North-East Asian States have to offset the “traditional” energy security approach when it comes to cooperation on power grid connectivity as well as come to an understanding that the benefits of enhancing regional power grid connectivity outweigh, by far, the

risks.<sup>35</sup> Enhancing regional power grid connectivity will lead to further stabilization of the power systems, reduction of regional carbon emissions and alleviation of air pollution. It will also foster regional cooperation and economic development. The main security risk, which is perceived in the interdependence created by the power interconnection, is questionable for two reasons – the physical nature of power trade and the scope of cross-border power exchanges compared to national power systems.

As Ahn et al. (2015) has pointed out, the traditional energy-related security concerns in the region revolve around the dependency of Japan, the Republic of Korea and China on energy imports. These concerns and the resulting national policies of self-sufficiency appear to be the central reasons for caution when it comes power interconnection projects (Otsuki et al., 2016; Ivanov and Oguma, 2002). The arguments, which might be valid when it comes to imports of fossil fuels, do not necessarily apply to cross-border and regional power interconnections.

Enhancing regional power grid connectivity creates new interdependencies between the countries. However, contrary to the supplies of fossil fuels, these interdependencies have a very different balance. For example, a country that is dependent on oil imports is in a weak position since, should a conflict arise, but the supplier can always find another buyer.<sup>36</sup> However, trading electricity does not function that way; the fixed nature of power transmission infrastructure means that electricity supplies cannot be effectively rerouted and sold to another buyer. Electricity as a commodity also cannot be stockpiled in large quantities over longer periods of time, and in the case of a conflict both the importing and the exporting party face high costs. This physical trait underlies cross-border power trade and is a major reason why electricity exports cannot effectively be used as a means of political pressure (Kunstyr and Mano, 2013; Lee, 2013; Ivanov and Oguma, 2002; REI 2017).

This argument is even more valid when it comes to region-wide interconnections involving massive

investments in transmission and new generation capacities. Due to the very high upfront cost, the interconnection and the generation capacities will have to be constantly used in order to prove economical and ensure investment returns. Under such circumstances, a situation where the power supply is intentionally cut for political reasons appears highly unlikely. Yet where a country is given full or partial control of the transmission infrastructure and the energy resources, the theoretical risk of energy supplies being used for political gains will remain, however minimal in the case of power trade. This risk can be minimized even further if a transparent institutional framework is set in place and the cooperation between interconnected countries is strengthened by carefully formulated agreements.

Regional power interconnections may indeed pose a significant security risk for one country in North-East Asia, and, surprisingly enough, that country is the one most actively promoting regional interconnection initiatives. For Mongolia, international power trade plays a significant role in the national electricity balance (Korneev et al., 2018) and any disruptions in power supply might have serious economic repercussions. Nevertheless, Mongolia has taken on the role of the regional facilitator of regional power grid connectivity, with the Mongolian Ministry of Energy actively participating in discussions on the Gobitec and Asian Super Grid initiative. Governmental support for the “North East Asia Super Grid” has been also voiced by the President of Mongolia, who called upon the urgent and prompt commencement of the project during the Eastern Economic Forum in 2018 (Battulga, 2019).

Aside from the fact that the interdependencies created by a cross-border power grid interconnections are very unlikely to be exploited as means of political manipulation, the scope of these interdependencies is miniscule compared to the size of the national power markets in countries like Japan, the Republic of Korea or China. According to the estimates of Renewable Energy Institute (2017), the power delivered to Japan after the completion of the Gobitec + Asia Super Grid project, would amount to no more than 2-3 percent of Japan's peak demand. A 2 GW cross-border interconnection between Japan's Kyushu island and the Republic of Korea would cover only 1.1% of peak demand (REI, 2019).

<sup>35</sup> That is, the overall stability and sustainability of the energy system to the.

<sup>36</sup> This, at least, is true for the historically normal state of high demand. The position of the buyer has been strengthened after the dramatic increase in supply due to the United States' tight oil revolution and even further in the present COVID-19 crisis, signified by low demand.

## Potential next steps and policy recommendations

### Dialogue on “new” security issues

More than the traditional security concerns, the policymakers should discuss and jointly address “new” security issues, which arise regardless of whether the national power systems in the region remain isolated from each other or become interconnected. As IRENA (2019) has pointed out, among the “new threats” to energy security are potential geopolitical conflicts caused by the procurement of rare earths and metals as well as the growing vulnerability of the power systems increasingly supported by information technologies to cyberattacks. Cyberattacks including false data injection can affect state estimating process or power market operations by manipulating the nodal price. Similarly, denial of service (DoS) attacks in the cyber layer of smart grids can affect the dynamic performance of physical power system (Han et al., 2019).

### Public-private dialogue to ensure fair distribution of benefits

A dialogue between the representatives of governmental bodies and the relevant stakeholders from the private sector is imperative in order to ensure that all the stakeholders involved in the development of the regional power grid interconnection, or affected by it, may secure their fair share of benefits. Of particular importance is taking the domestic power industry of the net importing countries on board. The effects of the regional power grid interconnection should be discussed in an open and transparent way, and solutions developed in order to ensure that the power companies do not feel threatened by the potential competition and offer their support to the regional efforts on power grid connectivity.

## Strategy 2. Developing a Master Plan for regional power grid interconnection

Stakeholders: National Governments and relevant ministries, research institutions/scientific community, power sector industry

Time frame: Short to medium term.

While agreement on the basic principles for cooperation is a prerequisite for a constructive intergovernmental dialogue, a detailed Master Plan on regional power grid

interconnection should be developed. This Master Plan would include existing and planned projects, and ideally potential projects based on modelling that optimizes around economic and sustainability criteria. It should also include an overview of the stakeholders involved in each area and stage of cooperation, accurate estimates of the costs and required resources as well as a clearly stated time frame. This Master Plan would need to be developed in close cooperation with the transmission system operators, the relevant utility companies as well as with the leading research institutions of the North-East Asian countries, such as EPPEI, KEEI, the Melentiev Institute, IEEJ, MEEI, GEIDCO, the Renewable Energy Institute, and others. Consultation with international institutions with relevant experience (e.g., the World Bank) and organizations involved in the development of similar projects in other regions (e.g., the European Union, the Eurasian Economic Union, MERCOSUR among others) is recommended.

### Creating a business case to kick-off the implementation of the Masterplan

Developing a regional power grid interconnection is a large-scale and multidimensional endeavour. In order to facilitate the necessary first practical step towards the implementation, and to demonstrate the profitability of the project, a business case of a smaller scale (e.g., one section of the regional interconnection) should be developed and implemented within a clear time frame. Among the ongoing initiatives, the China-Republic of Korea interconnection currently under-negotiation has a fair chance of becoming such a business case.

### Working out the minimum requirements for regional power grid interconnection.

Looking beyond a specific business case, the Masterplan for regional power grid interconnection should outline the minimum requirements to be met, in order to enable cross-border power trade on the regional scale. These include political requirements, such as: the necessary intergovernmental agreements; institutional requirements, such as the necessity for new cooperation forums and regulatory institutions; and technical requirements, such as grid codes, agreements on data and information sharing, dispute resolution mechanism etc. (IEA, 2019f). The experience of the existing and currently developing regional interconnection projects shows that the necessary preconditions to kick-off cross-border power trade are, although numerous,

do not require a radical change in countries' national power systems, energy policy, or relevant regulatory apparatus. Therefore, clear definition of these minimum requirements would make it easier for North-East Asia to make the necessary first step and facilitate the implementation of the initial stage of regional power grid connectivity.

### Including the existing cross-border interconnections and domestic power grids in the picture

Although not many cross-border interconnections are already in place between some of North-East Asian countries, estimating their potential and future role in an interconnected North-East Asia is advisable. If estimated as relevant for the regional project, these interconnections could provide a first basic element in terms of transmission capacities and regulatory arrangements.

Inclusion of the domestic power grid integration plans and efforts in the Master Plan on regional power grid connectivity is also recommended. Taking stability and capacity of the domestic power grids into account can provide valuable insights for the optimal development pace and design of regional power grid integration.

## Strategy 3. Developing and implementing Intergovernmental Agreements, creating a broader institutional framework

The institutional framework for regional cooperation in the Asia-Pacific region is composed of many regional and subregional institutions that are partly overlapping, operating at varying speeds and addressing different sets of issues. Most institutional arrangements in the region are informal, with ASEAN (South-East Asia) and SAARC (South Asia) being the only formal frameworks.

Institutionally, China, Japan and the Republic of Korea are involved in the ASEAN+3 forums, both on governmental and track two levels (Aalto, 2014). ASEAN + 3 has proven to be an effective mechanism for energy cooperation among these three major energy consumers of North-East Asia – at least when it comes to fossil fuel resources (e.g., oil stockpiling issue) (Fallon, 2006), but the major share of energy diplomacy in North-East

Asia remains bilateral. Among the existing bilateral arrangements are:

- ERINA's Japan-Russian Energy and Environmental Dialogue, focusing on Sakhalin oil and gas projects, Vladivostok LNG and Magadan II and III;
- China-Japan annual Energy Conservation Forum, accompanied by high-level and Track 2 meetings;
- An agreement, signed in 2007 between China and Japan on the promotion of cooperation in the field of environment and energy, mainly through dissemination of Japanese technology (among others, clean coal technology, gas cogeneration, operation of nuclear plants and high-voltage transmission technology) on a business basis as well as the provision of training for 10,000 people in Japan for three years (Gavin and Lee, 2008);
- China-Russian energy dialogue;
- Energy dialogue between the Russian Federation and the Republic of Korea, focusing on the gas pipeline project through the DPRK as well as on exports of Russian LNG to the Korean market;
- The DPRK-Russian Federation Intergovernmental Commission, working on, among other issues, security-dominated topics of the gas pipeline project through the Democratic People's Republic of Korea;
- The Mongolia-Russian Federation energy cooperation agreement signed in 2019;
- Memorandum of Understanding between the Government of Mongolia and Russia's Gazprom to build a natural gas pipeline from the Russian Federation to China through Mongolia, signed in December 2019.

The annual trilateral summit between China, Japan and the Republic of Korea is one of the few existing non-bilateral mechanisms in the region. The issues addressed during the summit and at the accompanying meetings between governmental and business representatives include but are not limited to energy.

Another cooperation forum worth mentioning is the Greater Tumen Initiative, established in 1995 by China,

the DPRK,<sup>37</sup> Mongolia, the Russian Federation and the Republic of Korea, and originally aimed at promoting regional cooperation on the development of the area around the Tumen river, running through the DPRK, China and the Russian Federation (GTI, 2020). The focus of cooperation has expanded over the past decades and now includes the whole NEA subregion; it covers several issue areas, energy infrastructure being one of them. Several subregional energy infrastructure models have been conceptualized within the GTI, one being the NEA Regional Electrical System Ties (NEAREST). A lack of an institutionalized cooperation framework and governmental support has, however, hindered further (practical) implementation of any of these initiatives (GTI, 2013).

When it comes specifically to cooperation on issues related to power system integration, regional institutional arrangements in North-East Asia are practically absent. To date, ESCAP is probably the only multilateral platform where issues of cross-border power connectivity in NEA have been addressed for almost two decades now. In 2001, ESCAP established the North-East Asian Expert Group Meeting on Intercountry Cooperation in Electric Power Sector Development (ESCAP, 2001; Bradbrook, 2002). In 2003, the first Senior Officials Meeting on Energy Cooperation in North-East Asia was organized by ESCAP, and is set to reconvene periodically with a view to developing a common vision towards regional cooperation (ESCAP, 2003). Finally, beginning in 2016, the annual North-East Asia Power Interconnection and Cooperation (NEARPIC) Forum, has been organized jointly by ESCAP, the China Electricity Council (CEC), Ministry of Energy of Mongolia, ADB and the Ministry of Foreign Affairs of the Republic of Korea. The Forum serves as a multilateral platform for North-East Asian countries to share experiences, knowledge and expertise, and to forge strategic intergovernmental energy partnerships as well as promote regional power interconnection and advancement of the SDGs in the subregion (ESCAP, 2018). Being the only multilateral platform in North-East Asia that focuses specifically on issues of power grid interconnection, NEARPIC has the potential for building the core of the future institutional framework in the region.

Stakeholders: National Governments and relevant ministries, ESCAP.

Time frame: Short, medium and long term.

### **Signing a comprehensive Memorandum of Understanding on multilateral cooperation in power grid connectivity**

Profiting from NEARPIC (and more generally ESCAP) as the multilateral platform for discussions, the member States should jointly develop and sign a Memorandum of Understanding (MoU) on multilateral cooperation in power grid connectivity. The MoU is the necessary first step in order to initiate the development of further arrangements. The readiness to move from a bilateral to multilateral approach towards cooperation in power grid connectivity should be the core message of the MoU, agreed by all involved parties.

The existing MoU between the SoftBank Group, State Grid Corporation of China (SGCC), Korea Electric Power Corporation (KEPCO), and operator of the Russian Federation's energy grid PJSC ROSSETI (ROSSETI) on joint research and planning to promote an interconnected electric power grid in North-East Asia is an important agreement. This because it signifies the general readiness of the region to move towards closer cooperation on power grid connectivity. The MoU needed to kick-off region-wide cooperation can build on this agreement; however, it should have a much wider scope, going beyond a scientific exercise, and be concluded on a high political level, signifying the principal readiness of all North-East Asian countries to cooperate on this regional project. At a minimum, the signatories should include the Governments and transmission systems of the respective countries.

### **Developing a set of agreements, creating a framework for cooperation**

Based on the MoU, the Member States should proceed to drafting a set of agreements in order to create the backbone for regional cooperation on power grid interconnection. These agreements should include arrangements on the form and functions of the institutions steering regional cooperation, the stakeholders involved in the steering process from each side and the time frame within which these institutions are to be established.

<sup>37</sup> DPRK left the GTI in 2009. Re-engagement of the DPRK as well as encouraging participation of Japan remain among the central priorities of the Initiative.

### Creating a formal North-East Asian interconnection body

Although the institutional framework on power grid connectivity will have to include different mechanisms for such issues as cross-border power trade, security issues, harmonization efforts, coordination of operations etc., an overseeing (steering) body could be established in order to guide further process of institution building. It is advised to consider establishing the Interim Secretariat – as proposed by the NAPSI Framework – which would act as a multilateral body that would: (a) draft proposals and updates for the strategic priorities for power grid interconnection development; (b) facilitate and organize international cooperation to mobilize knowledge and expert resources for the promotion of regional power grid interconnection; (c) initiate negotiations to promote investments in cross-border transmission lines and generation facilities, and help to conclude associated agreements for trading with electricity and grid services; (d) coordinate the bilateral interconnection plans, ensuring that the multilateral spirit of power grid interconnection is reflected in these arrangements; and (e) develop recommendations of its own and recommendations supplementary to measures imposed by member countries and international organizations.

This steering body does not necessarily need to have a fixed structure, which might not be necessary or even superfluous at the early stage of interstate cooperation. Rather, it should provide a platform for Working Groups, made up of representatives of the relevant ministries and experts from private sector and academia, to conduct discussions on their respective issues. It is advisable to first set up Working Groups on the technical and regulatory issues. Cooperation on these, traditionally less politicized, issues is easier to initiate in North-East Asia, where political tensions have been the major obstacle to regional institutionalization. In turn, once technical and regulatory dialogue is established, it will pave the way to institutionalization on “higher” levels.

### Ensuring the centrality of the Paris Agreement and the Sustainable Development Agenda for the political and institutional framework on power grid connectivity

In order to ensure that power grid connectivity in North-East Asia is inherently interconnected with the

issue of sustainable development, it is imperative that the regulations of the Paris Agreement as well as the SDGs relevant to the region are included in the core multilateral arrangements.

## Strategy 4. Coordinating, harmonizing and institutionalizing policy and regulatory frameworks

A regional power system can only be as successful as its weakest link. For such a system to function seamlessly, it will need to have a functioning set of rules and regulations. Good governance on infrastructure requires sound financial and legal systems, the systemic protection of rights, and the support of strong regulatory bodies to provide oversight and to monitor and enforce rules (Bhattacharay, 2012; Yun, 2004; Kim, 2020). Given that the regulatory frameworks that underlie the national power systems in North-East Asia are not uniform, major coordination and harmonization efforts are required from the relevant bodies.

Stakeholders: Relevant ministries, power system operation companies, TSOs.

Time frame: Short, middle and long term.

### Harmonization of regulatory norms and standards for efficient operation of cross-border interconnections

On the technical side, harmonizing technology standards, grid codes and other related regulations would greatly facilitate the development of interconnections (IEC, 2016). Cooperation with international standard-setting organizations such as the ISO, IEC and IEEE will help to advance the process of the standardization (Rafique et al., 2018).

A novel management scheme will be necessary to enable the integration of renewable energy sources into cross-border interconnections without causing deterioration of the power quality and compromising stability of the grid (IEC, 2016). Furthermore, in the long term, a multilateral institution should be established that develops common regulations and standards for the operation of North-East Asian transmission links and which takes on the function of a monitoring and coordinating body afterwards (Hippel et al., 2011; Churkin et al., 2019; Lee et al., 2011). Here, the North-

East Asian countries can learn from experience of the ASEAN countries, which established the Heads of ASEAN Power Utilities/Authorities (HAPUA) back in 1981 to perform these functions. As in the case of ASEAN and other regional integration initiatives, the state-owned transmission operation companies will play a central role in advancing the regional harmonization efforts.

As one of the first steps towards a regional regulatory framework and a harmonized environment for cross-border power exchange, it is advisable to take a look at the regulatory norms and standards of the existing cross-border interconnections in North-East Asia. It should be considered whether and how they can be adapted or enhanced to provide the necessary regulatory framework for regional power grid integration.

#### Cooperation on climate regulations and carbon pricing

Coordinated climate policies and emission reductions mechanisms will increase the attractiveness of the regional grid interconnection and provide an additional impetus for investments in the regional renewable sector. Regional cooperation could include coordination on RE targets and support schemes, and on carbon pricing mechanisms. It should also include the possible establishment of the regional carbon market and the conclusion of regional emissions reductions agreements, which is an important area of the regulatory cooperation (Otsuki, 2015; Kanagawa and Nakata, 2006; Wang et al., 2018; Otsuki, 2017a). In order to kick off a regulatory framework for cooperation on carbon policies, the establishment of a working mechanism with the UNFCCC is advisable.

#### Dialogue and harmonization of environmental standards

Environmental standards for the construction and operation of the power transmission infrastructure vary among the North-East Asian countries. These differences can hinder the drafting of a mutually-agreed power interconnection plan and therefore need to be discussed and coordinated.

Given that environmental issues are one of the most advanced areas of cooperation in North-East Asia, it will be very helpful to access the experience of the existing

bilateral and regional dialogues on environmental cooperation, in order to facilitate the coordination process.

### Strategy 5. Moving towards multilateral power trade and creating competitive cross-border electricity markets

Stakeholders: Power trading companies, TSOs, power generation facilities, regulatory bodies.

Time frame: Medium to long term.

As demonstrated in chapter II of this report, national power markets in North-East Asia are in different phases of liberalization on the scale between regulated and fully liberalized markets. Establishment of a fully integrated regional power market is, therefore, a long-term task. In the medium term, regulations and mechanisms will need to be developed that create a level playing field for the market participants from respective national power markets to take part in cross-border power exchange.

#### Developing regulations for cross-border power exchange

Until now, electricity trade in North-East Asia has been conducted via over-the-counter type of arrangements where two parties trade privately according to regulations that have been established on the case-by-case basis. Yet, as the development of regional power grid interconnections takes place, it becomes necessary to enable foreign generation, transmission and distribution companies to have non-discriminatory access to the power markets of North-East Asian countries. Conditions for their participation in the national power exchange platforms will need to be clearly stated, and tariffs on electricity imports clearly defined.

Rules of access to the national power markets as well as the tariffs on the export and import of electricity have to be formulated and coordinated among countries. The diversity of market systems and structures in North-East Asia calls for a multilateral mechanism for regional energy cooperation in the region (Jin et al., 2019; Yamaguchi et al., 2018). In the search for a suitable design, it might be advisable to learn from international experience on designing multilateral power

markets. Creating an integrated power market similar to the European Union might prove challenging, as it requires all participating countries to proceed with the unbundling of their national power markets; this process is currently at very different stages in the North-East Asian countries. It is either possible to establishing a common exchange platform, similar to the NORD POOL, or to enable power trading on the national exchange platforms. The latter option appears to be the most feasible one in the early stage of regulatory cooperation, as it does not require major adjustments of the national markets. Here, the Russian Federation could share its experience in cooperating on a joint power market in the Eurasian Economic Union, which was designed while taking the differences of the national power markets into account.

It is also imperative to clearly set the tariffs on electricity imports and export, on power transit as well as on the charges related to injection of exported power into the grid in the respective countries (Korneev et al., 2018). Specifying the tariffs is particularly important for Japan and the Republic of Korea which, due to a lack of experience in power imports and exports, do not list electricity in their Customs Tariff Acts. Even if the customs tariff is to be zero, it will have to be specified for cross-border power trade to take place (REI, 2017).

#### Developing coordinated price-building mechanisms for power exchange

Existing contracts for cross-border electricity trade in North-East Asia are negotiated every year with a fixed price. Such contracts do not include short- and long-term price formulae to adapt to market conditions and are therefore not suitable for regulating power trade in a regional power system. The inflexibility of the contracts has already led to controversies such as, for example, during the suspension of cross-border power trade between the Russian Federation and China in 2007. It will become even more of a challenge in a flexible power system that accommodates large amounts of variable renewable generation (Hippel et al., 2011).

Therefore, agreements on a transparent and stable system of power pricing are necessary (Xuegong et al., 2013; Korneev et al., 2018). However, given the differences in price-building mechanisms among North-East Asian countries, achieving an agreement on regionally applicable pricing mechanisms will be a long-term task. In the medium-term, the price for electricity

traded through new interconnections might have to be established between the respective power generation and sales companies.

#### Decide on the currency (or currencies) for cross-border power trade

As soon as cross-border power exchange begins to take place on multilateral exchange platforms, the issue of the currency to be used in transactions will arise. The following solutions (or their combinations) may be recommended for regional power trade – payment in hard currency, with the most probable choice being the Japanese Yen, as it is the only freely convertible currency in the region or, alternatively, payment may be issued in national currencies or in a barter form of payment where, in exchange for electricity, goods and services are provided. While the last two solutions may be acceptable to more participating countries than the first solution, they would complicate the procedure of mutual payments.

#### In the short term – sets of regulations for separate interconnection projects, moving towards a harmonized bilateral trading

The development of a comprehensive regulatory base for a regional power system is a long-term endeavour, requiring a certain institutionalization level of the regional cooperation on energy issues. In the short term, countries are advised to develop sets of regulations for the interconnection projects on a case-by-case basis (Hippel et al., 2011). Such regulatory arrangements would require less effort to negotiate and would set precedents that could serve as a basis for the regional regulatory regime.

Using a set of standardized templates for the conclusion of the bilateral trading agreements together with a standardized methodology for calculating the price of transmission (wheeling charge) in each interconnection project, will form a basis for the development of harmonized multilateral trading (IEA 2019f).

#### In the medium term – from harmonized bilateral trade towards a multilateral power market

Building on the bilateral trade ties, in the medium term the North-East Asia region can move towards a regional power market that enables multilateral trade and exists parallel to the national markets. This model is

## Potential next steps and policy recommendations

used by several regions, including South Africa (SAPP), Central America (SIEPAC) and Central Asia (the planned common power market of the Eurasian Economic Union), where countries can trade power with each other, regardless of whether they share a border, in a harmonized environment that does not interfere with the countries' national markets. Aside from a certain level of harmonization, establishing the regional bodies responsible for coordination and operation of the power trade is a key to the development of a multilateral power market.

### In the long term – towards a fully integrated regional power market through further harmonization, unbundling and liberalization of energy markets

In order to tap the full economic potential of a regional power interconnection, in the long term North-East Asian countries should ideally develop competitive and transparent markets with minimum price distortions (Ivanov and Oguma, 2002). This necessitates the unbundling of the generation transmission, distribution segments of the power, abolishing subsidies for fossil generation sources as well as the deregulation of the power price-setting. Although necessary in the long term, this task cannot be achieved in the foreseeable future in view of the specific conditions of North-East Asian economies. While unbundling is well underway in Japan and has been partially completed in the Russian Federation, it is currently out of the question in the DPRK. Liberalization of the power prices will prove to be particularly difficult in the Russian Far East (and practically impossible in the isolated areas). Creating a fully integrated regional power market is nevertheless a worthy goal in the long term and should be

## Strategy 6. Coordinating cross-border transmission planning and system operation

Realizing power exchange on a regional scale is a challenging endeavour that requires comprehensive coordination efforts on the part of national power grid operation and transmission companies. Particularly in an interconnected power system with a growing share of variable renewable power generation, mechanisms enabling flexibility of the power system, its seamless operation and efficient coordination between the respective national bodies should be established.

Stakeholders: National TSOs, power generation companies, relevant ministries.

Time frame: Medium and long term.

### Inclusion of cross-border transmission planning into national energy strategies

At the governmental level, the planning of cross-border power interconnections should become part of national energy strategies. To date, the Republic of Korea is the only North-East Asian country that has included a section on “Overcoming Independent System’s Limitations through Super Grid in North-East Asia” in its Basic Plan for Long-term Electricity Supply and Demand (2017-2031). The inclusion of cross-border interconnection planning in national strategies and policy agendas will facilitate interstate dialogue and enable joint planning.

### Coordination of cross-border transmission planning and operation with domestic plans and strategies

Cross-border transmission lines should be planned in a way that does not interfere with, but supports the functioning of domestic power networks, and does not contravene the national strategies in the power sector. For that, stakeholders involved in planning of the former should consult national Governments and receive relevant updates concerning domestic power network design.

As the scope and capacity of the domestic power grids varies strongly between the North-East Asian countries, the development of a backbone power grid that feeds into, but is managed separately from the domestic power grids appears logical. Cross-border links that interconnect domestic power grids, which are then utilized for transmission and distribution, could be an option for North-East Asian countries with a strong domestic power grid, e.g., China, Japan and the Republic of Korea. Additional analysis of technical and economic feasibility of both (or a mix) of these models is necessary.

### Cooperating on joint emergency response mechanisms

In an interconnected system, regional cooperation on joint emergency response mechanisms would further diminish the risk of supply disruptions and create a

secure environment for the operation of cross-border interconnections. National TSOs, in close collaboration with the relevant power generation facilities and national regulatory authorities, should develop the means to maintain power system(s) stability in the region in case of an emergency. This might include emergency and support mechanisms in case of fall-outs due to natural disasters, cooperation on emergency and strategic fuel storage and diversification of power flows etc. (Bogdanov and Breyer, 2016; REI, 2019). As a result, each service area should be prepared for cross-boundary transmission interruptions to ensure the system's reliability and to mitigate security concerns between the stakeholders. Creating a secure environment for the operation of the cross-border interconnections is of a particular importance for North-East Asia, which is particularly susceptible to natural disasters, among them earthquakes, tsunamis, typhoons, floods and landslides.

Together with the regional cooperation, national efforts are required in order to foster further integration of the national grids and thereby strengthen the national emergency response capability.

#### Coordination of ancillary services to secure faultless power supply

Ancillary services, such as scheduling and dispatch, reactive power and voltage control, loss compensation etc., play a central role in securing faultless power transmission. Generation facilities involved in cross-border interconnections should coordinate their provision of ancillary services across the interconnected region. This will become increasingly important with further deployment of variable renewable generation capacities and the resulting increase in power flow variability.

#### Mechanism for data sharing to enable faultless operation of the regional power system

With the cooperation on power grid connectivity advancing, the need to share operational data of the respective national power systems will become increasingly urgent. Among the recommended types of data exchange are real-time conditions at substations at a regular, periodic rate of minutes to hours, reports on network topology changes and reports on changes in the network model (Giri, 2019). The countries of North-East Asia should cooperate to develop a transparent and secure joint mechanism on data-sharing that

clarifies the types of data to be shared, time intervals when data exchange should take place as well as the ways in which the shared data may be used. Although data needed to be shared for seamless operation of the regional power system are usually not sensitive or considered strategically important, a guarantee to preserve confidentiality and the intellectual property of the data should ideally be included in the mechanism – this is particularly important as the national levels of intellectual property rights protection vary among North-East Asian nations (ibid.; ECT, 2014). In the medium term, establishing a regional institution responsible for data collection and sharing as well as strengthening the protection of particularly sensible data – i.e., through the conclusion of bilateral and multilateral non-disclosure agreements – is advisable.

### Strategy 7. Mobilize investments in cross-border grid and generation infrastructure

One of the key tasks for the Governments of North-East Asia is the creation of a stable climate for energy investments. Investors should have guarantees for the return on investments, which requires establishing legally-binding rules for economic cooperation based on transparency and non-discrimination that cover investment and dispute settlement procedures.

Stakeholders: Relevant ministries, companies from the national power sectors, national and international financial institutions.

Time frame: Short, medium and long term.

#### Transparent and efficient legal framework for investments in the regional power sector

In order to create a legal investment framework in North-East Asia, the stakeholders could consider consulting the existing legal frameworks in the energy sector, the most likely candidate being the Energy Charter Treaty (ECT) of which Japan, Mongolia and the Russian Federation are members.<sup>38</sup> China and the Republic of Korea are observers and have signed the International Treaty Charter of 2015. The opinions differ on whether ECT should be adopted as a legal framework

<sup>38</sup> As of 2019, the Russian Federation signed, but did not ratify, the ECT.

for regional cooperation on energy, or whether a specific regional legal framework should be established. Nevertheless, the ECT provisions, with which all countries in the region can identify themselves, might serve as a common basis to start a regional dialogue on the provisions of the regional legal framework (Yun, 2004; Gavin and Lee, 2008).

Until such a framework is established, long-term contracts with agreed supply volumes and electricity prices for the investment recovery period will remain the central instrument of securing returns on investment and profit for the generation and sales companies involved (Belyaev and Podkovalnikov, 2007).

#### Support through free trade agreements (bilateral, trilateral, multilateral) in the subregion)

The favourable investment climate might be facilitated through free-trade agreements between the countries of North-East Asia. While all six North-East Asian countries are in one way or another involved in the Asian “noodle bowl” of trade agreements, no such arrangement exists at the subregional level, as opposed to, say, South-East Asian countries, which are linked within the ASEAN Free Trade Agreement (AFTA). North-East Asian countries are advised to consider negotiations on a subregional trade deal in the medium to long term.

Meanwhile, it is important to further advance the currently ongoing bi- and trilateral free trade negotiations in the region. For example, if signed, the China-Japan-Republic of Korea free trade agreement could provide a legal framework of cooperation for promoting an energy interconnection between those three countries (Chang et al., 2020).

#### Study on policies to support financing of the regional power grid interconnection (governmental loans, guarantees on investment return, subsidies, tax incentives etc.)

In order to design policy instruments to support financing of the power grid interconnection, national Governments are advised to commission an Expert Group to conduct an applicability assessment for possible financing mechanisms. Existing studies on power grid interconnection in North-East Asia do not focus in detail on the mechanisms for securing investments in the projects and it is necessary to fill this research gap.

## Strategy 8. Capacity-building and sharing of information, data and best practices

Innovative solutions are required in order to interconnect national power systems of North-East Asia in the most efficient and sustainable way. Within the national borders, such solutions have been implemented in abundance (e.g., smart grid technologies on the Republic of Korea’s Jeju Island, solar sharing in China and Japan, energy efficiency policies etc.). In order for this rich experience to work for regional power interconnection, it needs to be shared among the countries of North-East Asia. Such sharing may be facilitated in several ways.

#### Publishing data in English for better accessibility and using ESCAP as a platform

National statistical offices might consider publishing more data in English that are relevant to power grids and innovative solutions in the power sector in English. This way, it may be more quickly accessed by the decision-making and research institutions of other North-East Asian countries, resulting in cross-fertilization of ideas and innovative solutions for regional power grid connectivity. The ESCAP Asia Pacific Energy Portal could provide an optimal platform for such data sharing.

Should the aforementioned bodies not be ready to make such data publicly available, it is advisable to create a data-sharing platform that can only be accessed by the relevant institutions of the five other North-East Asian countries.

#### Engage in joint capacity-building programmes

Operation and maintenance of the interconnected power system(s) with the growing share of variable renewable generation will require sufficient trained staff from all the involved countries. China, Japan and the Republic of Korea, who have considerable experience with operating large-scale variable renewable facilities, should consider organizing training programmes for staff in Mongolia, which will need this kind of expertise should the Gobitec project be implemented.

#### Learn from international experience

Relevant ministries as well as national development organizations should engage in dialogue with

international organizations involved in facilitating innovative power solution and capacity-building initiatives (e.g., the World Bank, ADB, IRENA and IEA) to learn from their experience. In addition, the experience of other regions (e.g., the European Electrical Grid in Europe, CASA1000 and the EAEU's power market in Central Asia, ASEAN Power Grid project in Southeast Asia, BIMSTEC in South Asia, IIRSA and SIEPAC in Central and Latin America, GCCIA in the Gulf and SAPP in South Africa) can be of great value in accumulating the relevant regional expertise.

### Raise public awareness and engage in dialogue with communities

To secure support for cross-border power grid interconnections, transparent communication and acceptance by the affected communities are necessary. Furthermore, public acceptance of these projects will feed into general support for closer relationships with the neighbouring North-East Asian countries.

Building an electricity interconnector is a highly complex task. Therefore, the involvement of public groups (citizens, civil society and other relevant stakeholders) potentially affected by the development of new interconnectors, is necessary at an early stage of interconnector development. Maintaining dialogue with communities and relevant stakeholders will help to address perceived concerns about health issues, or the adverse impact on the landscape and nature ecosystems, and thus reduce the length and impact of procedural delays.

## Strategy 9. Ensuring that energy connectivity initiatives are compatible with the Sustainable Development Goals

It is critically important that cooperation on regional power grid interconnection contributes to the sustainable development of the region. Whatever policy option is considered, and whatever regulatory mechanism is developed, the stakeholders should consider the interests of the local communities, the needs of the poorest population groups as well as sustainable energy guidelines introduced by the

Sustainable Development Agenda and the Paris Agreement on Climate Change.

Stakeholders: All the stakeholders involved in Strategies 1 to 8.

Time frame: short, medium and long term.

When elaborating on the power grid Master Plan, an accurate and detailed sustainability assessment should be conducted for the existing project proposal.

Planning of cross-border power interconnections should include sustainability guidelines for the construction and operation of the transmission lines.

In order to prevent possible habitat damage resulting from large-scale deployment of renewable generation capacities, conservation measures should be considered and/or partly financed by the revenue from power trade. In the case of Gobitec, wind farms in particular might be suitable for preserving vast sections of steppe habitat.

Although the focus of the envisaged power grid connectivity is on the interconnection of the centralized grids, interests and needs of communities without centralized electricity access – especially communities that might be potentially affected by the construction of the new transmission lines and generation facilities – should be considered. The development of a set of policy measures is advisable in order to ensure an inclusive energy transition. Such measures might include payments of a specific percentage of annual transmission-fee earnings, directly (and proportionally) to local communities crossed by a new interconnection, and the establishment of a North-East Asian Investment Fund for the territories affected by construction, in order to facilitate investment in those territories to boost their economic activities or providing more public facilities etc. Therefore, it is advisable to learn from the experience of interconnection initiatives from other regions, particularly the Central Asia-South Asia Electricity Transmission and Trade Project (CASA-1000), which is currently under development and includes social safeguards for the affected population groups as well as the general assessment of possible social benefits from its early stages (World Bank, 2014).

# Conclusion

**T**here is a wealth of scientific evidence that underlines the potential for enhanced power grid connectivity to bring multiple benefits to the economies and societies of North-East Asia. The evidence ranges from increased affordability of electricity and stability of national power systems to increased deployment of low-carbon power sources and improved social welfare from reduced emissions. While numerous variations of the power grid interconnection have been proposed and analysed, those encompassing the whole region, and therefore requiring the cooperation of all six States, promise the most significant output.

Cooperation on power grid connectivity in North-East Asia already enjoys the support of the international community (including ESCAP, ADB, World Bank, IEA, IRENA and others) and some representatives from the power and telecommunications sectors in the region. It is now up to the North-East Asian States to take the necessary steps towards the establishment of a fully-fledged multilateral cooperation mechanism. Unlike other Asia-Pacific subregions, however, at present North-East Asia lacks a jointly-organized institutional framework to support long-term cooperation. Establishing a multinational body that focuses on power grid connectivity is therefore an important

task, not least because it can help build political consensus among decision-makers and initiate the process of working together on technical and political issues. As a starting point, the NEARPIC Forum could provide a platform for high-level exchanges.

Together with the institutional framework, transparency is a key aspect in building trust between stakeholders as well as securing support for cooperation on power grid connectivity, both from the private sector and the civil society stakeholders. The secure and continuous exchange of up-to-date and accurate data between national Governments and utilities is also necessary. This will support planning efforts and help to build trust, while also providing the transparency that international financial institutions and the private sector require if they are to support the much-needed investments.

There is a global trend towards increased cooperation on power grid connectivity and cross-border integration of the power grid infrastructure, with numerous connectivity initiatives underway in almost every region of the world. North-East Asia has its own specific geographical, economic, political and historical context. Nevertheless, the challenges it will face while working towards increased regional power system integration (including, but not limited to, building political

consensus, securing investments, and coping with technical and regulatory differences between national power systems) have also been faced in other regions. Learning from the experiences of other connectivity initiatives will provide the decision-makers in North-East Asia with valuable insights and help to accelerate the process of integration.

Finally, cooperation on power grid connectivity in North-East Asia must take place in a way that supports and strengthens national efforts to develop secure, sustainable power sectors and to meet the Sustainable Development Goals. While a wealth of research results exists that cover the topic of power system integration in North-East Asia, there is still much to do to examine the implications of power grid connectivity for sustainable development. Facilitating research on this topic and integrating this expertise into the cooperation process is crucially important in ensuring consistency with the Sustainable Development Goals. While much work remains to be done, the momentum behind increased integration is building, and the foundation for success is already being established. Regional power system integration is, in the end, a tool – not a goal. Properly guided, increased power system connectivity can support the development of a secure, sustainable and affordable power system across North-East Asia.

# Appendices

## Appendix I. Overview of regional and cross-border interconnection proposals for North-East Asia

Region-wide interconnections							
Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/Transmission capacity	Supporting Institutions	Status Source
<b>Gobitec+ Asian Super Grid</b>	2,500 km 2 of solar stations 3,500 km of HVDC lines	Solar energy (large-scale PV, CSP), wind	min. 1000 kV	294.6 (Energy Charter est., other estimates: 330 (Voropai et al., 2019), 550 (Van de Graaf et Sovacool, 2014)	100 GW (50 GW wind and 50 GW solar)	Hanns-Seidel Foundation, Daesung Energy Company Ltd., Mongolian Ministry of Energy and Mineral Resources, IEA Photovoltaic Power Systems Program, Energy Charter, KEEI, ESI SB RAS, JREF	Design and feasibility stage
<b>North-East Asian Super Grid</b>	Mongolia, China, Japan, Republic of Korea, DPRK	Solar energy ground-mounted and rooftop; wind onshore, CSP hydropower, biomass and waste-to energy power plants.		683 (Total annualized cost), \$69.4/MWh - expected LCOE	Total RE capacity (installed and to-be-installed) 5639 GW, Generated electricity - 11,721 Tw/h. Electricity from storage - 2075 TWh/yr. (or 27%), electricity trade - 1582TWh (or 20%), electricity excess - 721 TWh (or 9%)	Lappeenranta University of Technology	Model

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
<b>North-East Asian Super Grid</b>	Mongolia, China, Japan, Republic of Korea, DPRK, Russian Federation	HVDC transmission lines between 11 city nodes (demand, generation and storage) and 4 supply nodes (generation and storage)	Solar PV, wind, hydro, nuclear, coal-fired, gas-fired, oil-fired, hydrogen turbine, fuel cell; and three types of storage – pumped hydro, battery and compressed hydrogen tank (hydrogen production by means of water electrolysis).	24.4("Limited Integration scenario")		Skoltech, En+ Group, KEPCO (separate studies by KEPCO and Skoltech)	November 2013 - study initiated by Skoltech within the framework of a Memorandum signed between Skoltech, En+ Group and KEPCO during Vladimir Putin's visit to KOR.	Otsuki, 2015
<b>NEAREST (North-East Asian Electrical System Ties)</b>	China, DPRK, Japan, Republic of Korea, Mongolia, Russian Federation	Large-scale renewable generation (primarily hydropower)				Melentiev Energy System Institute, SO RAN; the Republic of Korea Electrotechnology Research Institute (KERI)	Model	Yilmaz and Li, 2018
<b>APPG (Asia-Pacific Power Grid)</b>	North-East, South and South-East Asia	Not specified (main goal – enhancing the grid to balance variable power generation)				Japan Policy Council	Model	Yilmaz and Li, 2018

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Asia Super Grid (ASG)	North-East, South and South-East Asia 7,300 km		800 kV	56.7	100 GW transmission capacity, 200TWh/yr. transmission	Japan Renewable Energy Foundation (JREF, research institution), SoftBank	September 2016 - the four sides signed a NEA Power Network Cooperation Memorandum to pursue regional interconnectivity. Same year the GEIDCO has been established. Liu Zhenya, chairman of CSGC, is the president.	Yilmaz and Li, 2018
Pan-Asian Infrastructure concept	Asia-Pacific	Solar PV (from Australia), wind power (from China)					Model	Taggart et al., 2012,
GEIDCO connectivity routes	Intercontinental ring-shaped grids with a main load centre and a centralized power access in each region (NEA, SEA, CEA) interconnected with each other		1,500kV UHVDC, 1,100kV HWAC			IEC, GEIDCO, IIASA (Austria)	Model	Dai et al., 2018

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
North-East Asia Power Grid Interconnection (NEAG) - NEA part of GEI	Step 1: 1,830 km; 2,300 km; 1,220 km; 1,720 km;	Gas, coal, renewables - wind, solar			Step 1: 8 GW; 8 GW; 10 GW; 10 GW		Model	Jang et al., 2011
Step 1: Yerkovsy -Bazhou, Irkutsk-Tangshan, Xibo Oboo-Tianjin, Booth Oboo-Jinan	Step 2: 450 km; 190 km; 360 km; 350 km; 460 km; 860 km;				Step 2: 3/10 GW; 2/10 GW, 2/10 GW, 2/10 GW, 10 GW			
Step 2: Shenyang-Pyongyang, Pyongyang-Seoul, Weihai-Seoul, Seoul-Busan, Busan-Matsue, Matsue-Osaka-Tokyo	Step 3: 2,360 km				Step 3: 10 GW			
Step 3: Sakhalin – Sapporo – Tokyo								

	Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
North-East Asia Energy Interconnection (NEAEI) – NEA part of GEI, latest model.	China, DPRK, Republic of Korea, Japan, Mongolia, Russian Federation	Step 1 (by 2025): 1,500 km (MNG-CHN), 830 km (CHN-ROK-JPN), 500 km (CHN-DPRK-ROK), 300 km (RUS-JPN)	2 HPPs (54.5 GW), 19 wind (430 GW) and 5 solar (510 GW) energy bases (total technical potential – ca. 990 GW)	Step 1 (By 2025) 500 and 600kV HVDC interconnections	2,700 (by 2050)	Step 1: 4 GW; 2 GW; 3 GW; 0.75 GW; 2 GW.	GEIDCO	Model	GEIDCO, 2018
		Step 2 (by 2035) 1,700 km (MNG-CHN), 2,000 km (CHN-ROK-JPN), 750 km (CHN-DPRK-ROK), 2,700 km (RUS-CHN), 2,300 km (RUS-DPRK-ROK), 2,000 km (RUS-JPN).		Step 2 (by 2035) 800kV HVDC interconnections		Step 2: 8 GW transmission capacity for all new interconnections			
		Step 3 (by 2050) 1,900 km (MNG-CHN), 1,600 (CHN-JPN), 1,600 (CHN-DPRK-ROK), 2,000 (CHN-DPRK-ROK-JPN), 2,700 (RUS-CHN), 2,700 (RUS-JPN)		Step 3 (by 2050) 800kV HVDC interconnections		Step 3: 8 GW transmission capacity for all new interconnections			
"Three-ring, and one-line" power grid model. 5 corridors: MNG-CHN-ROK, CHN-RUS, RUS-JPN, CHN-DPRK-ROK, RUS-DPRK-ROK									

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
NAPSI Phase I Darkhan (MNG) -Buryatia (RUS); Kyzylskaya (RUS) - Ernegov (MNG); Oyutolgoi (MNG) - Hohhot (CHN); Weihai (CHN) - Sinsiheung (ROK); Hadong (ROK) - Hino (JPN) Primorsky (RUS) - Kashiwazaki- Kariwa (JPN) or Vladivostok (RUS) - DPRK - Donghe (ROK)	Phase I: Gobi RES-E base: 500kV substation; 500kV AC transmission system overlaying the existing 220 kV one in Mongolia; eight HVDC and AC cross-border interconnections.	Various (surplus electricity, increasingly electricity from expanded Gobi RE base)	500 kV DC and AC overhead and submarine cables	12.9	0.3 GW in 2020, 5 GW in 2026	ADB, EDF, NovaTerra, LLC;  GRENATEC (see Grenatec, 2010)	Model	Otsuki, 2015, Leinhardt 2018, ADB/EDF 2020
Weihai (CHN)- Sinsiheung (ROK); Gobi RE base (MNG) – Baotou (CHN);	Phase II: Reinforced Gobi RES-E base substation; two HVDC cross-border interconnections		500 kV DC overhead and submarine cables	5.7	10 GW in 2036	ADB, EDF, GRENATEC	Model	ADB/EDF 2020
Gobi RE base (MNG)-Buryatia (RUS); Gobi RE base (MNG)- 9 load centres in CHN; WeiFang (CHN) – Hwasung (ROK); Haodong (ROK) – Hino/ Takahama/ Odo (JPN); Yasan (ROK) – Minamiwaki (JPN); Chitinskaya (RUS) – Keyskaya (RUS)	Phase III: Reinforced Gobi RES-E base substation; Seventeen cross- border HVDC interconnection, one additional interconnector between Russian Siberia and the Russian Far East		800 and 1,100 kV HVDC overhead and submarine cables	129	100 GW in 2036+	ADB, EDF, GRENATEC	Model	ADB/EDF 2020

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/Transmission capacity	Supporting Institutions	Status	Source
Cloud Energy (GRENATEC)	ASEAN, Australia, China, Japan, Republic of Korea, Taiwan Province of China	HV interconnections (power lines), gas pipelines and fibre optic cables to realize "cloud energy"					Model	
Bi-/Trilateral interconnections								
Wei-hai-Incheon	China, Republic of Korea	366 km	500kV	1.4	2.4 GW	SGCC, KEPCO, Soft Bank, GEIDCO	2016 – Joint Feasibility study on China-Republic of Korea-Japan Interconnection 2017 – MoU on joint development signed by SGCC, KEPCO and GEIDCO	Presentations by KEPCO and GEIDCO at NEAPIC, 24 October 2019
Bratsk-Ulaanbaatar-Beijing	China, Russian Federation, Mongolia	2,250 km	600kV	1.8	5-6 GW Transmission capacity, 18 TWh/yr.		Project proposal	Voropai et al., 2019, S.3
Bratsk-Beijing	China, Russian Federation	2,250 km	600kV	1.8-2.1 (depending on transmission capacity), total derived benefit – \$5.9-7.1	5-6 GW transmission capacity	Melentiev Energy System Institute, SO RAN	Project proposal	Belyaev et al., 2006;
Bratsk-Beijing		2,600 km	600kV	4.2 (1.5 – transmission, 2.7 Billion – Boguchansk HPP)	3 GW transmission capacity, 18 TWh/yr.	Melentiev Energy System Institute, SO RAN	Project proposal	Belyaev et al., 2002, 236

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Bureya HPP- Harbin	700 km	Hydro	400kV	2.2 (0.25 - transmission, 1.75 Billion - completing the construction of the Bureya HPP)	1 GW Transmission capacity, 3 TWh/yr.	Melentiev Institute, SO RAN	Project proposal	Voropai et al., 2019, S.3
HPPs in the Amur Oblast and Khabarovsk Krai: Nizhne-Zeyskaya (400 MW), Selendzhinskaya (300 MW), Gilyuyskaya (462 MW) and Nizhne-Nimanskaya (600 MW)						Rushydro (51% ownership), China Three Gorges	2013 - agreement signed btw RusHydro and CTG; 2016 - suspended	Rushydro, 2014 - <a href="http://www.eng.rushydro.ru/press/news/95544.html">http://www.eng.rushydro.ru/press/news/95544.html</a>
Erkovetskaya TPP-Shenyang	1,300	Coal	600kV	8.8	3.6 GW Transmission capacity, 18-20 TWh/yr.	Inter RAO/JSC "Eastern Energy Company", State Grid Corporation of China	Project proposed by InterRAO in 2012	Voropai et al., 2019, S.3; Otsuki, 2015, Smirnov, 2012
Amurskaya-Harbin-Shenyang-Beijing	1,900	Hydro	1150kV	1.2 (0.775 - transmission cost, 0.285 - substations, 0.15 - compensation devices).	transmission capacity 5 GW		Model	Zilberman and Smirnov, 2007
Siberia-North-East China	4,200 km (2775, 2335 and 4200)	Hydro, gas	750kV (3 one-circuit lines)	8.0-8.3 Billion.	10 GW total capacity	Melentiev Institute, SO RAN	Project proposal	Belyaev et al., 2006

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Expansion of existing ties between China and the Russian Federation	1. Line to Heilongjiang + expansion to Liaoning 1400 km 2. Line to Beijing area - 1650 km plus	Coal	1. 500kV+5-kV 2. 600kV	18 (est. 2006),	Line to Heilongjiang - 3.6-4.5 TWh/yr., Line to Liaoning - 22.5 TWh/yr., + 2 new coal TPPs: 3.6 GW Line to Beijing Area - 60 TWh/yr., + TPPs in Eastern Siberia: 7.2 GW	InterRao UES, State Grid Corporation of China	Contract for the delivery of elements for the first stage (Heilongjiang) signed in 2006.	Hippel et al., 2011, S. 6859-6861
Erkovetskaya TPP-Beijing		China, Russian Federation			7-7.5 GW, 38 TWh/yr.	Inter RAO/JSC "Eastern Energy Company"	Project proposed by InterRAO in 2012	Smirnov, 2012 (Presentation at AEC in Irkutsk)
Olon-Shibirskaia TTP-Beijing; Tataurovskaya TTP through Charanorskaya TTP-Beijing		China, Russian Federation			1. 3.6 GW, 2. 1.2 GW, 2.4 GW, totally 38 TWh/yr.	Inter RAO/JSC "Eastern Energy Company"	Project proposed by InterRAO in 2012	Smirnov, 2012 (Presentation at AEC in Irkutsk)
DC Amur/ Khabarovsk EPS- DPRK- Republic of Korea	1. Amur/ Khabarovsk EPS - Primorye EPS - 700 km (AC line) 2. Primorye EPS - DPRK - 900 km (DC) 3. DPRK-ROK - 250 km (DC)	Russian Federation, DPRK, Republic of Korea	1. 500kV 2. 500kV 3. 500kV		1. 3 GW 2. 4 GW 3. 8 GW	Melentiev Institute, SO RAN, KERI	Model	Voropai et al., 2019, S.3, Belyaev et al., 2002, 236
Vladivostok-Chongjin	370 km	Russian Federation, DPRK		0.13	500kV, 0.5 GW transmission capacity, 3 TWh/yr.		Model	Voropai et al., 2019, S.3
AC Interconnection Vladivostok-Chongjin+ DC Interconnection Chongjin-Seoul		DPRK, Republic of Korea, Russian Federation	AC 500kV+ DC 500/600kV	0.2		KERI, Melentiev Institute SO RAN	Discussions largely suspended in 2005 due to political and economic conditions	Hippel et al., 2011, S. 6859-6861

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Vladivostok-Pyongyang-Seoul	1,150 km	Coal, nuclear	500kV	4.8 (2 - interconnection cost, 2.8 - cost for Primorye NPP)	4 GW on the section Russian Far East-DPRK, 8 GW on the section DPRK-KOR, 7 TWh/yr.	Melentiev Institute, SO RAN	Model	Voropai et al., 2019, S.3, Belyaev et al., 2002, 236, Voropai et al., 2019 (2), S.47; Podkovalnikov et al., 2015; Yoon et al., 2007
South of Russian Far East and North-East part of the Democratic People's Republic of Korea							Abolished after the collapse of the Soviet Union, discussions about follow-up projects	Chudinova et al., 2018, s.6
Yanyang (Korea) - DPRK - Yanji	1,080 km (700 km Yangyang-DPRK-Yanji, 2 lines 200 km in North-East China). 20% added for adjustments to topography.	Nuclear, coal	500kV	0.25 - converter station. 0.582 - total transmission line cost	2 GW total capacity	Nautilus Institute	Project proposal (suspended due to Simpo LWR failure and break-off of the cooperation due to the DPRK attempting a nuclear test)	Hippel (2001)
Yanyang (Korea)-DPRK (Sino LWR) - Yanji (Northern China) - Khabarovsk	2,040 (700 km Yangyang-h-Yanji, 2 lines 200 km each in north-east China (to move power to demand centres), 600 km Yanji-Khabarovsk, 20% added for adjustments to topography.	Hydro, nuclear, coal	500kV	0.25 - converter station. 1 - total transmission line cost	2 GW total capacity	Nautilus Institute	Project proposal (suspended due to Simpo LWR failure and break-off of the cooperation due to the DPRK attempting a nuclear test)	Hippel (2001)
South-Yakutian HPPs-Shenyang-Seoul	2,400 km	Hydro	750kV	10.5	5 GW transmission capacity, 20TWh/yr.		Model	Voropai et al., 2019, S. 3

	Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Uchursk HPPs- China-Korea (basically, same as above, same cost, but less capacity and much longer - has the Russian Federation been interconnected there?)	China, Republic of Korea, Russian Federation	3,500 km	Hydro	500kV	4.5- interconnection cost, 6 - HPPs	3.5 GW transmission capacity, 17TWh/yr.	Melentiev Institute, SO RAN	Project proposal	Belyaev et al., 2002, 236; Podkovalnikov 2002, 37
Far East Nuclear PP - China - Korea	China, Republic of Korea, Russian Federation	2,300 km	Nuclear, coal (other RFE PPs)		7 (4.1 - cost for the NPP)	4 GW transmission capacity, 23 TWh/yr.	Melentiev Institute, SO RAN	Project proposal	Belyaev et al., 2002, 236
Sakhalin-Hokkaido-Honshu	Russian Federation, Japan	1,850 km total, of which 1,400 are submarine cables	Coal, gas	600kV	9.6	4-3 GW transmission capacity, 24 TWh/yr.	JSC RAO "EES Rossi", Marubeni Corporation	Project proposal, "actively supported by the authorities of neighbouring regions of RUS and JPN". Feasibility study conducted by Marubeni, Sumitomo Electric Industries and Russia's UES in 2005.	Voropai et al., 2019, S.3; Voropai et al., 2019 (2), S.48; Yamaguchi et al., 2018, 12
Sakhalin (Korshakov)-Hokkaido-Honshu (Kashiwazaki)	Russian Federation, Japan	1,255 km total (Sakhalin-Kashiwazaki route), of which 800 km are submarine cables	Wind, hydro	500kV	4.14 - 5.5	2 GW transmission capacity	Renewable Energy Institute	Project proposal	Ichimura and Omatsu, 2019; Kimura and Ichimura, 2019
Sakhalin-Hokkaido	Russian Federation, Japan	500 km total, of which 50 km are submarine cable	Gas-fired combined cycle PPT	500/400kV	6.7 (2.6 - interconnection cost, 4.1 - gas-fired PPT on Sakhalin)	4 GW transmission capacity, 23-4 TWh/yr.	Melentiev Institute, SO RAN	Project proposal, implementation depends on the conclusion of the peace treaty	Voropai et al., 2019, S.3; Belyaev et al., 2002, 236; Ichimura and Omatsu, 2019.

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Gyeongnam Area-Fukuoka	Republic of Korea, Japan 200 km submarine cable, divided into 150 km and 50 km segments, since the cables pass Tsushima Island.		180kV HVDC			KEPCO, Softbank (Masayoshi Son has shown an interest in the project as the first step towards realizing the Asia super grid concept)	Project proposal	Otsuki, 2015, S. 48
Kyungjin - Shinpo	Republic of Korea, DPRK		765kV HVAC				Model	Lee, 2002
Kyushu (JPN)-Jeju-Haenam-Seoul-Busan (KOR).	Republic of Korea, Japan		345kV or 765 kV HVAC and HVDC				Model	
Loop interconnection routes (as proposed in Lee, 2002)								
Kyushu (JPN)-Jeju (KOR) - Haenam (KOR) - Seoul (KOR) - Pyongyang (DPRK) - Supung (DPRK) - Woonggi (DPRK) - Shinpo (DPRK) - Busan (KOR)	Republic of Korea, DPRK, Japan		345 kV or 765 kV HVAC and HVDC				Model	Lee, 2002
Kyushu (JPN) - Busan-Seoul (KOR) - Pyongyang-Shinpo-Woonggi (DPRK) - Vladivostok (RUS) - Sapporo-Tokyo-Osaka-Kyushu (JPN)	Republic of Korea, DPRK, Japan, Russian Federation		345kV or 765 kV HVAC and HVDC				Model	Lee, 2002

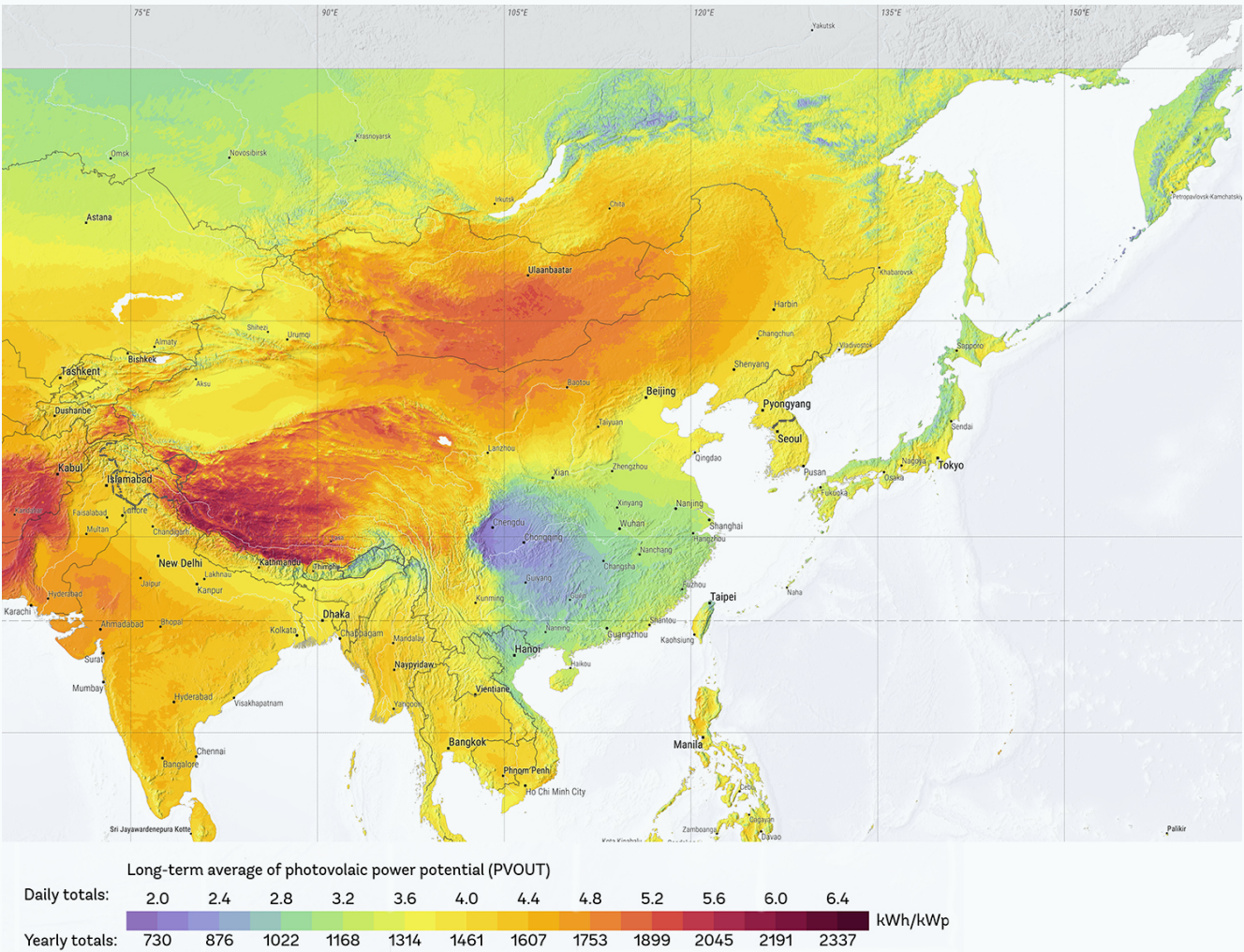
Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Kyushu (JPN) - Jeju-Haenam-Seoul (KOR) - Pyongyang-Supung-Woonggi (DPRK) - Vladivostok (RUS) - Sapporo-Tokyo-Osaka-Kyushu (JPN)			345kV or 765 kV HVAC and HVDC				Model	Lee, 2002
Kyushu (JPN) - Jeju-Haenam-Seoul (KOR) - Pyongyang-Supung-Woonggi (DPRK) - Vladivostok-Khabarovsk-Sakhalin (RUS) - Sapporo-Tokyo-Osaka-Kyushu (JPN)			345kV or 765 kV HVAC and HVDC				Model	Lee, 2002
Kyushu (JPN) - Jeju-Busan-Seoul (KOR) - Shinpo-Woonggi (DPRK) - Vladivostok-Khabarovsk-Sakhalin (RUS) - Sapporo-Tokyo-Osaka-Kyushu (JPN)			345kV or 765 kV HVAC and HVDC				Model	Lee, 2002

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Kyushu (JPN) - Jeju-Haenam-Seoul (KOR) - Pyongyang-Supung (DPRK) Shenyang-Changchun-Harbin (CHN) - Khabarovsk-Sakhalin (RUS) - Sapporo-Tokyo-Osaka-Kyushu (JPN)			345kV or 765 kV HVAC and HVDC				Model	Lee, 2002
Sredne-Uchurskaya HPP-Irkutsk (RUS) -Ulaan-Bator (MNG) - Beijing-Tianjin-Qingdao (CHN) - Seoul (KOR) - Pyongyang-Shinpo-Woonggi (DPRK) - Vladivostok-Khabarovsk (RUS)			HVDC or 765 kV HVAC				Model	Lee, 2002
Sredne-Uchurskaya HPP-Irkutsk (RUS) -Ulaan-Bator (MNG) - Beijing-Tianjin-Jinan-Shanghai (CHN) Jeju (KOR) - Kyushu (JPN) - Seoul (KOR) - Pyongyang-Shinpo-Woonggi (DPRK) - Vladivostok-Khabarovsk (RUS)			HVDC or 345 kV and 765 kV HVAC				Model	Lee, 2002

Countries involved	Length/size	Generation source	Voltage	Est. cost (US\$ billion)	Installed/ Transmission capacity	Supporting Institutions	Status	Source
Sredne-Uchurskaya HPP-Irkutsk (RUS) -Ulaan-Bator (MNG) - Beijing-Tianjin-Jinan-Shanghai (CHN) Jeju (KOR) - Kyushu-Osaka-Tokyo-Sapporo (JPN) - Sakhalin-Khabarovsk (RUS)			HVDC or 765 kV HVAC				Model	Lee, 2002
Sredne-Uchurskaya HPP-Irkutsk (RUS) -Ulaan-Bator (MNG) - Beijing-Tianjin-Jinan-Shanghai (CHN) Jeju (KOR) - Kyushu-Osaka-Tokyo-Sapporo (JPN) - Vladivostok-Khabarovsk (RUS)			HVDC or 765 kV HVAC				Model	Lee, 2002

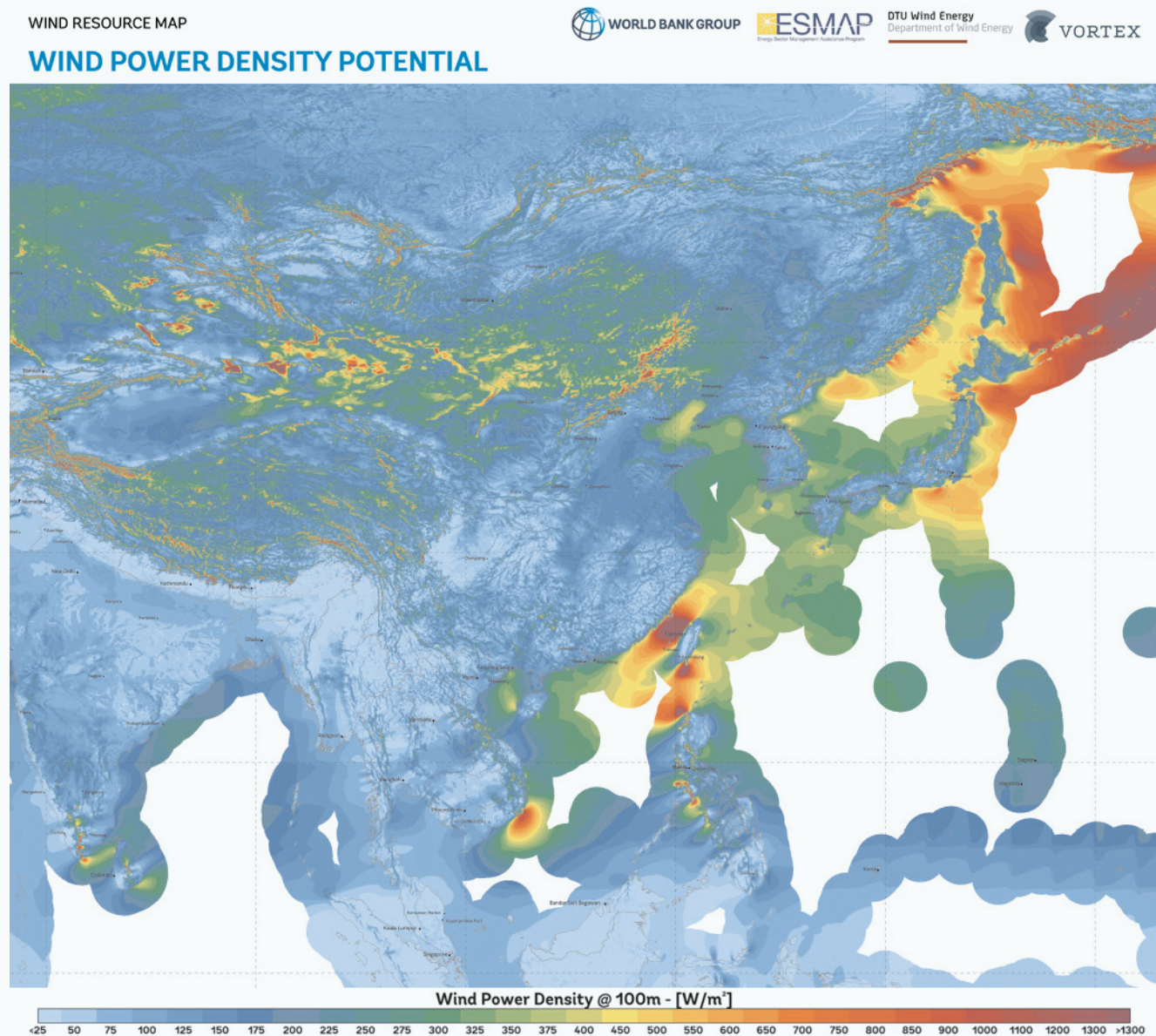
Appendix II: Renewable potential of North-East Asia (maps)

Figure 23 \_ Photovoltaic power potential



Source: World Bank Group (2020). Global Solar Atlas. Map is adapted by ESCAP.  
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

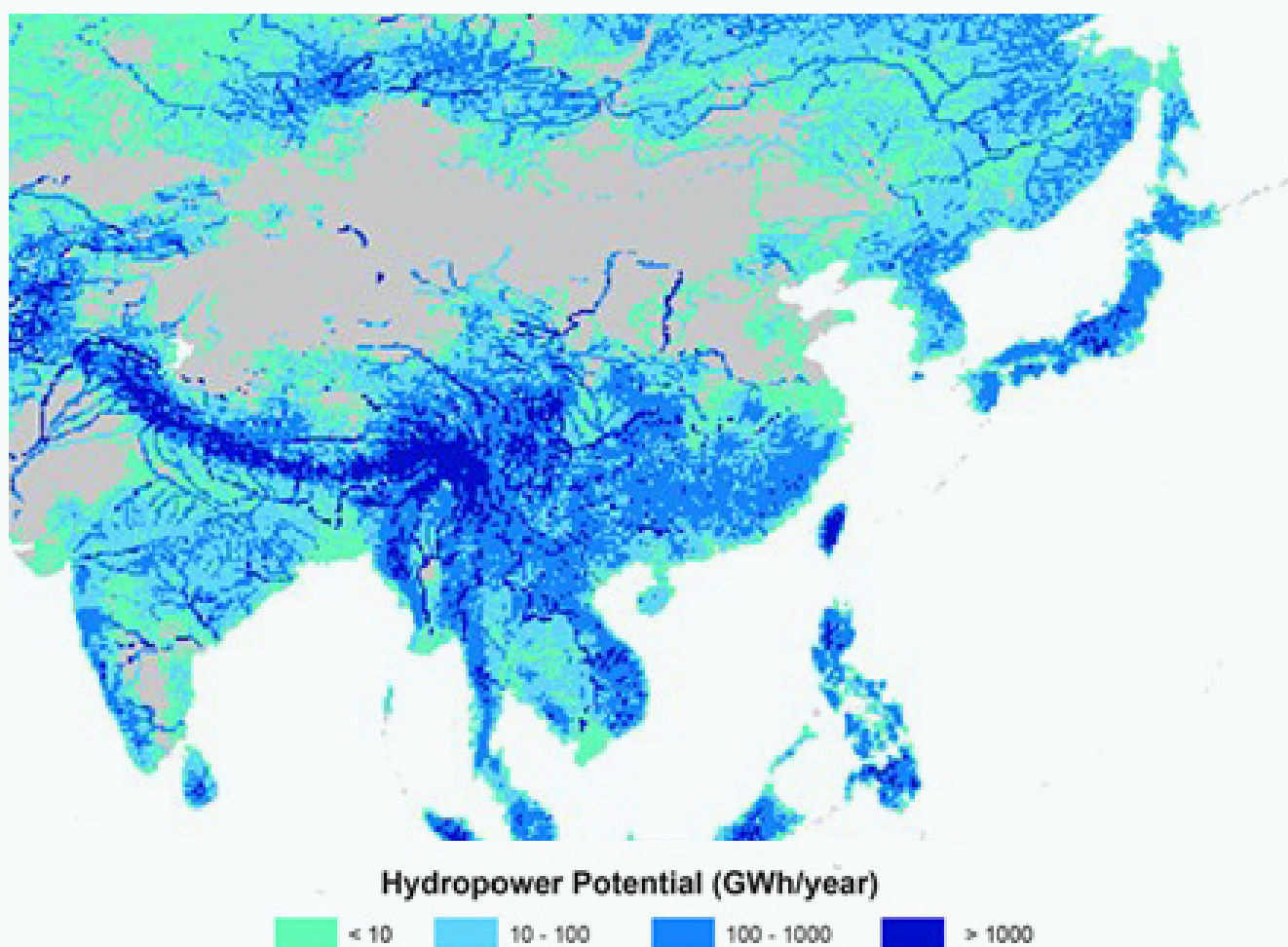
Figure 24 \_ Wind power potential: Wind power density



Source: World Bank Group (2020). Global Wind Atlas.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

**Figure 25** \_ Hydropower potential (GWh/year)



Source: Hoes O. A. C. et al. (2017). Systematic high-resolution assessment of global hydropower potential. PLoS ONE, 12(2): e0171844.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

## Appendix III: Power systems in North-East Asia – country profiles

### People's Republic of China

#### Key data

Grid voltage, 50Hz

Installed capacity (2019), 2010.66 GW

Total gross electricity generation (2019), 7325.3 TWh (CEC, 2019)

Electricity generation mix by type of generation (2018) – coal 67.26%, hydro 16.65%, wind 4.94%, nuclear 3.99%, solar PV 2.39%, natural gas 3.2%, biofuels 1.22%, oil 0.15%, waste 0.18%, solar thermal 0.0041% and tide 0.0001% (IEA, 2020).

Electricity consumption by sector (2018): industry – 61.81%, residential 16.05%, commercial and public services 7.41%, transport 2.34%, agriculture/forestry 2.1% and non-specified 10.27%

Originally designed as a centrally planned system, China's power system is in transition. The power sector reform, first initiated in 2002 ("Document Nr.5"), began the process by unbundling the State Power Grid company and creating separate segments of generation, transmission and distribution. In 2015 a new round of the power market reform was launched, more commonly known as "Document Nr.9", introducing new measures to create a competitive power market with the main goal of lowering electricity prices and increasing the overall flexibility and efficiency of the power sector. As in other industry sectors, the planning and investment cycle is developed within a five-year national plan which sets objectives for generation, transmission and distribution for each province. Provinces are, in their turn, responsible for implementation of these targets.

#### Generation

Since the power sector reform of 2002, five generation companies have been formed out of the former State Power Corporation: Huaneng, Datang, Huadian, Guodian and China Power Investment Corporation. These state-owned enterprises are placed under the administrative supervision of the Ministry of Electric Power Industry. Coal-fired thermal and co-generation power plants account for more than two-thirds of total power generation in the country. Spurred by rapid

economic growth and the increase in electricity demand, China has been actively expanding its generation capacities for the past decade, resulting in ca. 100 GW new generation capacities coming per year. In 2019, the total installed generation capacity was projected to be approximately 2,000 GW, which makes China the world's biggest power market.

The past decade has seen a boost in the construction of coal power plants, which took place after the shift of administrative authority from the central Government to provincial governments in 2013. As a result, there is severe overcapacity in coal power plants that are nevertheless connected to grid at least until the investment returns have been collected. This overcapacity poses a serious challenge for the variable renewable energy sources, such as wind and solar power that are experiencing rapid growth in China, with support of domestic renewable industry clusters and accelerated by considerable reductions of renewable energy technology and equipment. In 2018 alone, China added 44.26 GW of solar and 20.59 GW of wind power that together accounted for 52.9% of last year's capacity additions in China. Whether integration of such significant amounts of variable renewables into the grid will be successful depends on many factors, including the competition from coal power plants. Many of these are still in the debt-servicing period and have to retain their operating hours as well as the flexibility of China's transmission system.

#### Transmission

The State has a monopoly in the transmission segment and is represented by two grid companies, China State Grid Company (CSGC) and the China Southern Power grid, both formed from the State Power Corporation in the unbundling reform of 2002. China has seven power grids, whereas the State Grid Corporation of China (SGCC) owns the north-east, north, central, east, north-west and Tibet power grids, and the China Southern Power Grid Company covers the south China power grid.

There is a demand-supply imbalance in several of China's provinces due to the fact that energy resources are distributed unevenly and far away from the load

**Figure 26** – China's UHV power transmission lines

Source: State Grid Corporation of China. Map is adapted by ESCAP.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

centres.<sup>39</sup> To solve this problem, China has been accelerating the construction of high-voltage grid interconnections among its domestic power grids that will enable transmission of electricity from resource-abundant regions (central/west areas) to 'energy hungry' regions (east coastal area) (Otsuki et al., 2016). Currently, several ultra-high voltage (UHV) transmission lines with the voltage between 800 and 1,000 kV are being actively constructed. Interconnection of China's transmission systems is also seen as means to increase the overall flexibility of the power system and allow for more efficient integration of variable generation capacities. Several UHV direct current lines have already been constructed for bulk power transmission from northern and western provinces, where coal as well as extensive solar and wind generation capacities are installed. In turn, UHV alternating current lines are being constructed in the east coastal area and should help to absorb the massive power output from the UHV DC lines (Fairley, 2019).

<sup>39</sup> For example, 76% of coal resources and 80% of hydropower resources are distributed in the central and western parts of the country, while power demand is concentrated in the eastern coastal region and around the Pearl River Delta in Guangdong Province.

China has interconnections with several neighbouring countries/economies – the DPRK, Kyrgyzstan, Mongolia and South-East Asia.

### Distribution and trading

In China, generated electricity is supplied through SGCC and China Southern Power Grid Company and distributed through dispatch centres that are affiliated to the grid companies and operate on provincial, city and community levels (Otsuki et al., 2016). The provincial level has the central role since provincial dispatch centres are responsible for allocation of power generation quotas to generation facilities in accordance with the "fair dispatch" rule. Under this rule, each generating facility of the same category (e.g., coal-fired) receives the same amount of annual operating hours (IEA, 2019b), and consequently generates an allocated energy volume, rather than one economically reasonable based on the facility's generation cost. While allocating a "fair" number of operating hours to coal-fired generation facilities, this dispatch mechanism has been criticized as a source of inefficiency and a major contributor to curtailment of energy from wind, solar and hydroelectric generators. The power system reform of 2015 foresees

the orderly withdrawal of the administrative allocation system as a crucial next step.

There is currently no spot market, but starting in September 2019 pilot schemes to allow spot trading of electricity in eight provinces and regions have been launched (Reuters, 2017). National implementation of these schemes is planned for 2020. If successful, these markets could promote flexible operation of the overall power system and help reduce curtailment of renewables, adding to their competitiveness against coal-fired generation (Dupuy, 2018).

### Regulatory environment for foreign businesses

Access for foreign companies to China's power system has been considerably eased in recent years. Since October 2016, foreign investment has shifted from the 'approval system' to the 'negative list management system', that is, unless an activity intended by the foreign investor is on a restricted list, it will be granted treatment that is no less favourable than that granted to domestic investors. Although previously on a restricted list, construction and operation of power grid and gas stations was removed from the list in 2018 (Energy Charter, 2018).

### Government policy

China has made optimizing the structure of its power supply a top priority since the early 2000s. Its goals were to reduce the share of coal in power generation and increase the use of renewable energy, natural gas and nuclear power. The 13th Five-Year Plan (2016-2020) sets binding targets to reduce the share of coal-fired power generation to 58% by 2020 and to increase the share of power produced from non-fossil fuels to 15% by the same date (NDRC, 2016).

On 25 April 2017, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) publicly released a strategic paper on "Energy Supply and Consumption Revolution Strategy (2016-2030)", which sets out the main overall targets and strategies of the Chinese energy sector for 2030. The document includes the following targets for 2030: over 50% share of non-fossil generation in the total power generation, over 80% of coal-fired power generation represented by ultra-low polluting coal-fired power plants, and clean energy as the main source of meeting new energy demand.

In December 2017, the Government announced a political launch of the national Emissions Trading System (ETS). The ETS is currently in the simulation phase and primarily covers the power sector in several provinces. Ideally, the ETS will not only reduce power sector emissions, but also reinforce the position of low-carbon generation sources on the power market by adding an emission cost to each emitting generator's operating cost. The success of this system, however, largely depends on the implementation of the 2015 power system reform, including further unbundling of the distribution segment and creation of competitive power markets.

China's policy towards international cooperation on energy is aligned with its intercontinental Belt and Road Initiative (BRI), launched in 2013, and, among others, aims at boosting the interconnectivity of energy infrastructure and strengthening inter-regional cooperation in energy resource exploitation (Energy Charter, 2018). Strengthening the energy infrastructure, i.e., via promotion of cross-border power interconnection projects, and establishment of regional power markets, is one of the seven focus areas for international cooperation within the initiative, as stated in the "Vision and Actions for Energy Cooperation on Silk Road Economic Belt and the 21st Century Maritime Silk Road", published in 2017 by NEA and NDRC (NEA/NDRC 2017). Aligned to the BRI is the Global Energy Interconnection Development and Cooperation Organization (GEIDCO), which in the long term aims to facilitate the construction of an intercontinental power grid, creating the integrated system that would serve as the backbone of a new energy system based on clean energy, smart grids and ultra-high-voltage (UHV) transmission.

## Democratic People's Republic of Korea

### Key data

Installed capacity (2018), **9.5 GW**

Total electricity generation (2017) – **15,163 GWh**

Electricity generation mix (2018) – **coal 30%, hydro 62%, oil 2%. Off-grid: oil products 98%, solar PV 2%**

Electricity consumption by sector (2017). (estimates of Nautilus institute) industry – approx. 45%, transport residential and commercial and public services – approx.

10% each, military – approx. 25 %, agriculture – approx. 5% (Hippel and Hayes, 2018).

The data on the state of the DPRK power system is highly fragmented – there is not much accurate, up-to-date information; however, thanks to research by the Nautilus Institute, Korean Electrotechnical Research Institute (KERI) as well as the reports based on the satellite imagery from 38North and NK Economicwatch, one can see an approximate picture. The DPRK's power system is in a deplorable state and the power shortage is at the core of country's economic crisis. The equipment is outdated, with some facilities dating back to the Japanese colonial period. Most of the equipment is from the Soviet era and some home-grown equipment. Power transmission and distribution systems are fragmented, and the Government encourages the construction of decentralized facilities at the respective counties.

### Generation

Electricity generation is hydroelectric and coal-fired, whereas hydropower plants deliver approximately two-thirds of the total generated power. There is also a small amount of oil-fired electricity generation capacity associated with the oil refinery at Sonbong and in two other plants. Although the total installed generation capacity is estimated to be about 9.3 GW, most studies and reports confirm that the actual amount of generated electricity is significantly lower than the total installed capacity can provide (Yoon, 2011). The reasons for this discrepancy are the fragmented transmission and distribution systems. Furthermore, many of the operating hydroelectric facilities are designed as “run-of-river” type and their output is subject to variations in stream flow (Hippel and Hayes, 2018). The Government places great emphasis on the construction of new hydropower plants, primarily in the northern and north-eastern provinces, where the terrain is more suitable for such projects. Huichon HPP 1 and 2 was one of the recent large-scale hydropower projects, but it never came online due to major setbacks caused by planning challenges and difficult weather conditions. Currently, the focus is on small- to medium-sized power plants, built in tiers (Makowsky, et al., 2019).

With grid power supplies being largely unreliable and insufficient, many citizens, businesses and organizations in the DPRK started to take electricity provision into their own hands. Expanded use of diesel fuel for power generation with diesel and gasoline-fired generators

takes place to substitute for variable grid power supplies, with total installed capacity of up to 1,000 MW (2016 estimate). Furthermore, households are purchasing small solar PV panels imported from China and installing them on their roofs and balconies to generate electricity. With the total output of ca. 20 MW, these panels have little effect on the national energy balance, but they provide thousands of households with electricity for lighting and communication electronics. (Hippel and Hayes, 2018: 29).

### Transmission

The DPRK grid is highly fragmented. Nominally, it operates at a frequency of 60Hz, but in practice the frequency varies between 51.0 and 59.8 Hz (Yoon, 2011), particularly more strongly in the western part of the country. (Podkovalnikov, 2002). Although some expansion of the grid has been taking place sporadically, the country has, de facto, two separate grids, operating at different effective voltages (88-99kV for the nominally 110kV grid and 177-209 kV for the nominally 220kV grid). The Kaesong Industrial Zone, an administrative region close to the demilitarized zone, is connected to the Republic of Korea power grid by a line of ca. 100 MW capacity (Nam, 2012). Upon the temporary closure of the Kaesong Industrial Zone, announced by the Government of the Republic of Korea (Ahn, 2/10/2016), power supplies through this interconnection have been stopped.

### Distribution

The distribution network is outdated, adding to the overall instability of the EPS. In 1990 a supervisory control and data acquisition (SCADA) system was supplied by China and the United Nations Development Programme for better control and management of transmission, distribution and end-use of electricity from the power plants of Supung, Jangjingang, Pyongyang, and Puckchang. However, its efficiency remains unknown due to the issue of its compatibility with the rest of system elements.

The electricity supply in Pyongyang, DPRK's biggest load centre, has reportedly improved after the recent sanctions on DPRK's coal exports to China were introduced. Instead of exporting, the coal is reportedly sent to Pyongyang, the area with the country's highest purchasing power. As a consequence, electricity

Figure 27 \_

Power grid of the Democratic People's Republic of Korea



Source: Global Energy Network Institute

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

supply, indoor heating and warm water supply have all reportedly improved (Moon, 2018).

### Government policy in electricity sector

Government policy is usually defined within the five-year-plans. According to the current five-year plan, announced in May 2016, easing electric power shortages is proclaimed to be a prerequisite for the country to implement its five-year plan for economic growth. To achieve this policy goal, the Government plans to increase renewable power generation capacity up to 5 GW by 2044, largely through exploration of

domestic hydropower and wind resources. In September 2013, a “Renewable Energy Act” was adopted by the Government in order to provide a legal guarantee for the development and use of renewable energy. Furthermore, DPRK is making efforts to develop its own renewable and green technologies, including solar panels and wind turbines, solar-power passenger vehicles and designs for buildings powered by renewable energy. At least one factory (Kwangmyong LED and Solar Cell Factory) and one research institute (Natural Energy Research Centre of the National Academy of Sciences) have been established with the goal of developing home-grown renewable energy technologies.

Finally, in DPRK's quest for renewable energy, China might prove to be the key ally. In late October 2019, the DPRK planned to build a 2.5 GW solar plant near Pyongyang with the help of the Government of China in exchange for access to the DPRK's rare earth mine in the northern part of Pyongyang province (Bellini, 2019). Notwithstanding these developments, integration of additional renewable generation capacity requires a stable grid of sufficient scale, which the country currently does not have. Cooperating with other North-East Asian countries on the development of national and cross-border interconnections may prove to be the most efficient solution to country's electric power shortage.

The DPRK does not have a pronounced policy towards regional power grid interconnection. Nevertheless, it is currently maintaining a dialogue with the Russian Federation on possible cooperation in the power sector. According to the results of a meeting in late 2019, both countries agreed to continue cooperation on the construction of a 500kV power grid and possibly revive the project proposed in the early 2000s to connect Vladivostok in the Russian Far East to Chongjin on the DPRK's north-east coast (Zwirko, 2020).

## Japan

### Key data

Voltage: 50 and 60 Hz

Installed capacity (2017),<sup>40</sup> **299.2 GW** (JEPIC, 2020)

Total gross electricity generation (2018), **999.9TWh**

Electricity generation mix by type of generation (2019) – **natural gas 33.9%, coal 31.64%, hydro 8.8%, solar 7.41%, nuclear 6.38%, oil 4.8%, waste 2.37%, biofuels 1.76%, wind 0.75%, geothermal 0.28% and other 1.9%.**

Peak demand (2018), **159.7 GW**

Electricity consumption by sector (2018) – **industry 36.42%, commercial and public services 33.82%, residential 27.57%, transport 1.85%, agriculture/forestry 0.3% and fishing 0.04%**

As an island country with very limited fossil fuel resources for domestic power generation, whose power supply system is regularly put in danger by natural disasters (most notably, earthquakes and typhoons), Japan places security of supply and reliability of the power system among strategic interests with

top priority. In the wake of severe power shortages caused by the Great East Japan Earthquake and the Fukushima Daiichi Nuclear Disaster, the Government initiated an Electricity System Reform, which was approved by the Cabinet in April 2013 and envisages a three-phase reform process: (1) expansion of cross-regional grid operations, i.e., through the establishment of the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) in 2015; (2) liberalization of the retail market; and (3) legal unbundling of transmission and distribution segments of the power system (JEIPIK, 2019).

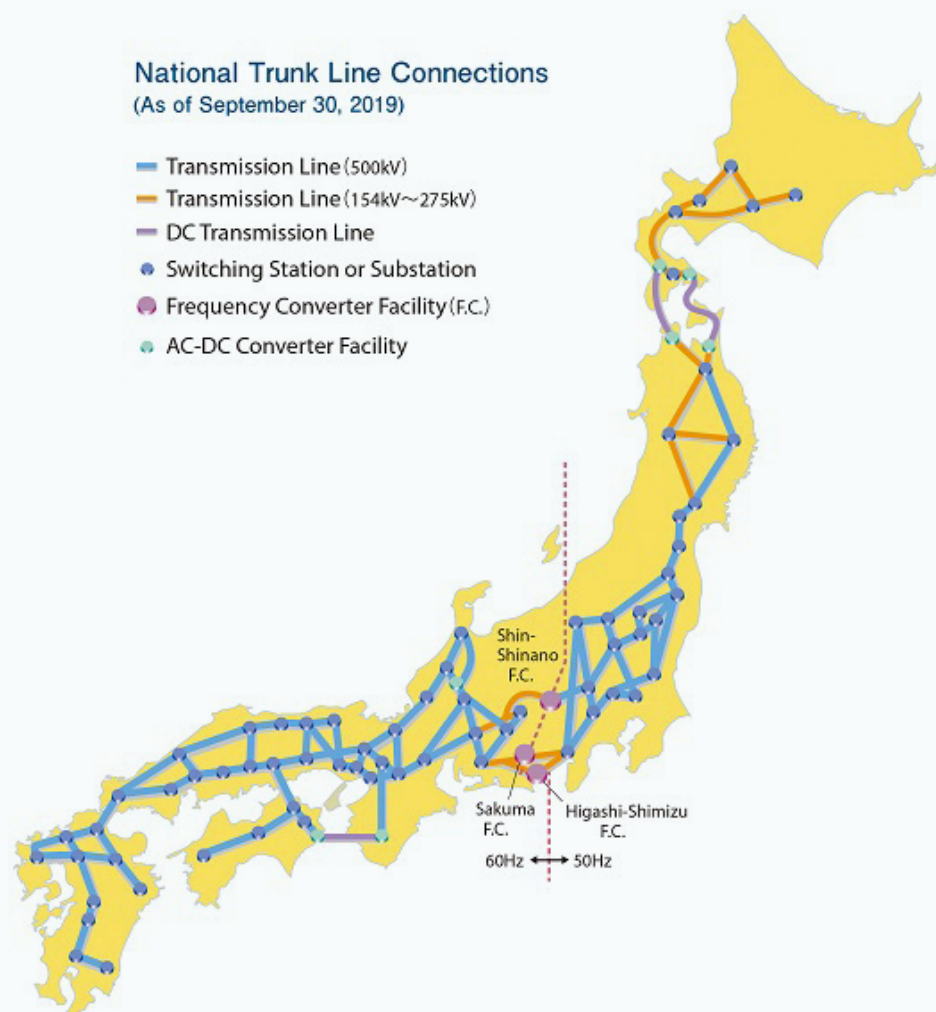
### Generation

Before 2011, nuclear power generation covered about one quarter of Japan's electricity demand (IEA, 2020). As all 57 of Japan's nuclear power plants were shut down shortly after the accident at the Fukushima Nuclear Power Plant, the share of nuclear generation was replaced by an increase in coal and natural gas-fired generation, each accounting for more than 30% of the total power generation in 2018. As increased fossil fuel imports for power generation led not only to considerable increases in electricity prices (METI, 2017), but also caused further growth of the country's CO<sub>2</sub> emissions, the Government attempted to create conditions for a safe restart of the nuclear reactors. In 2013, the nuclear regulation authority (NRA) established new safety standards and regulatory requirements for nuclear reactors and nuclear plants. If the necessary modifications are implemented, plants can apply to restart. As of July 2019, 15 nuclear plants had been found compatible with the new requirements, of which nine went online. Consequently, the share of nuclear power generation in the total generation mix grew from zero in 2014 to a current 6.6%, and under the most recent Strategic Energy Plan an increase to 20%-22% is planned by the fiscal year 2030.

Development of renewable electricity generation<sup>41</sup> has been supported by a renewables portfolio standard (RPS), which has been replaced by a feed-in-tariff (FIT) policy introduced in 2012. Under FIT, the transmission utilities are obliged to purchase renewable energy electricity at a fixed price for a period of between 10 and 20 years, depending on the type and scale of the generating facility (Sato, and Matsudaira, 2018).

<sup>40</sup> <https://www.jepic.or.jp/pub/pdf/epijJepic2020.pdf>.

<sup>41</sup> Wind, solar, geothermal, biomass as well as small and medium-size hydro.

**Figure 28** \_ High-voltage power grid of Japan

Source: The Federation of Electric Power Companies of Japan

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

The generation, transmission and distribution segments are traditionally dominated by 10 privately-owned, vertically integrated general electric power companies (EPCOs). Partial liberalization of the power generation sector began in the 1990s, at a time when generation and transmission were integrated along regional lines of 10 general electric utilities. Liberalization of the retail supply of electricity to all except low-voltage customers was implemented in stages between 2000 and 2005 (JEPIC, 2020). By 2016 the generation sector has been fully liberalized while the legal unbundling of the transmission and distribution sector has been completed in 2020. Currently, the former EPCOs own about 80% of generation capacity. The remaining 20% is represented by other power producers that have participated in the electricity wholesale market since 1995.

### Transmission

The frequency of the transmission lines differs between eastern and western Japan, i.e., 50 Hz and 60 Hz respectively. This difference goes back to the late nineteenth century when entrepreneurs in different parts of the main island began electrifying the country – those in the Tokyo area purchased HVAC generators made in Germany (50Hz) while businesses in Osaka installed 60Hz generators brought from the United States (FEPC, 2018). After the nationwide electrification had been accomplished, the country ended up with two separate grids of different frequencies. Frequency converter facilities with four HVDC interconnections of 1.2GW transmission capacity have been installed to connect the two grids, but this

interconnection has proven insufficient for providing power in case of a power shortage in one of the grids, as happened in the aftermath of the Fukushima accident. It was planned to strengthen the east-west grid connection and expand the transmission capacity to 2.1 GW by fiscal year 2020.

Currently, only the 10 EPCOs are allowed to engage in transmitting electricity to general consumers in their respective service areas. Other companies that operate transmission lines connecting the power plants and the transmission grid as well as the lines for power distribution, are required to obtain approval from METI to supply electricity. In line with the final stage of the current market reform, transmission and distribution segments are fully unbundled from a vertically integrated business (REI, 2017).

### Electricity trade, transmission and distribution

Transmission and distribution of power in Japan is dominated by ten EPCOs. Historically, these EPCOs have been vertically integrated, but legal unbundling was to be introduced in 2020.

The wholesale electricity trade is organized by the Japan Electric Power Exchange (JPEX) platform within four mechanisms – spot market, forward market, intra-day market and the bulletin board trading market, the latter being introduced to enable trading of Kyoto Mechanisms credits (not traded since autumn 2018) as well as “green electricity”, also for non-members of JPEX.

Since March 2016, the retail market has been fully liberalized. All entities registered as electricity retailers are now allowed to provide electricity to the so-called “low-voltage” consumers, that were previously supplied exclusively by EPCOs under a monopolistic arrangement. Full liberalization has attracted many operators, and as of January 2020, 634 retail suppliers had been registered. This newly gained diversity of suppliers has provided consumers with new options, including CO<sub>2</sub>-free electricity supplies, loyalty schemes etc. (JEPIC, 2019). The regulated rates were originally planned to be eliminated in 2020, when the final stage of market reform would be completed. Nonetheless, they remain in place as a transitional measure until the retail market becomes fully competitive.

In order to encourage further competition in the wholesale and retail markets, the Government is planning to create new market mechanisms. The baseload power market and non-fossil fuel trading market have already started functioning, while the capacity market has been introduced with the first auction in July 2020 (Hasegawa, 2020)). The balancing market is currently set to be partially functioning in fiscal year 2021 (OCCTO, 2020).

### Regulatory framework for foreign businesses

The regulations for foreign investments in the electricity sector were tightened in 2019, when the Japanese Diet passed the revision of the Foreign Exchange and Foreign Trade Act. If a foreign company intends to obtain a share of more than 1%<sup>42</sup> of the shares of a company in one of twelve strategic sectors (one of them being electricity) registered with the METI, that company will be eligible to obtain transmission services; however, the investment will need approval by METI and the Ministry of Finance. Should the foreign investment be considered as impairing national security, public safety and order or Japanese economy, the investment may not take place.

In the renewable power generation sector, the Government usually does not become involved with acquisitions of interests, and many foreign companies are active in Japan since the introduction of FIT in 2012, among them being the Korea Electric Power Corporation (KEPCO) and Shanghai Electric, the subsidiary of CSGC.

There are no regulations for import and export of electricity, since Japan has no interconnections with its neighbouring countries.

### Government policy

The fifth and most recent Strategic Energy Plan, adopted in July 2018, re-established the Government’s basic goals of the “3Es” – energy security, economic efficiency and environmental acceptability, together with a fourth goal of safety, thus completing a “3Es+S” approach. Safety of the power system has become a particularly hot topic, given the new safety approach towards nuclear generation, but also in the face of the risks faced by renewable generation facilities from

42 The previous version of the law set a 10% threshold (see Nikkei, 2019).

frequent natural disasters.<sup>43</sup>It further sets forth a policy of reducing Japan's fossil fuel dependence through energy conservation. It also aims to increase the share of renewables in Japan's power generation mix to around 22%-24% by 2030 (JEPIC, 2020).

The FIT resulted in the rapid expansion of renewable, and in particular, solar generation capacities, and contributed to a greater burden for consumers who have to pay a surcharge to cover the difference between conventional power generation and electricity from renewable energy sources (Kimura, 2017). Consequently, in 2020, the Government planned to abolish fixed pricing for large-scale wind and solar generation facilities, and instead to develop a competitive bidding system to keep electricity costs down (Nikkei Asian Review, 2019).

In view of Japan's low energy self-sufficiency ratio as well as the need to reduce the nation's emissions of greenhouse gases, the fifth Strategic Energy Plan identifies nuclear power as an important baseload power source and sets a target for its share of the 2030 energy mix at 20%-22%. Despite security concerns, nuclear power generation is viewed as "an option for decarbonization that is at the practical stage" (METI, 2018a).

Increasing the reliability of the transmission grid is another major priority according to the development strategy up until 2030. Central tasks are strengthening interconnections between two frequency zones as well as enhancing interconnections between the different islands of Japan, in particular between the northern Hokkaido and the Tohoku area on the main island Honshu. Hokkaido has the highest wind resource potential in the country and expansion of transmission capacity would be necessary to supply the electricity from Hokkaido's wind power plants to the Tokyo area, the country's main load centre.

Finally, initiatives to foster the development of hydrogen technologies are given high priority in the Government's energy strategy. Expansion of transmission lines alone is considered an insufficient measure to give the power system the desired flexibility for further integration of

variable renewable energy electricity. Therefore, one of Japan's strategic goals in the medium term is developing new storage technologies, with the primary focus on gas and hydrogen (METI, 2018b).

Expanding Japan's grid reliability by connecting it to neighbouring nations has, until now, not been considered as a strategic option. To-date, Japan has no official policy regarding cross-border interconnections and the possibility of power imports/exports; judging by the statements made by government officials, it has not yet been considered as a high-priority issue.

## Mongolia

### Key data

Installed capacity (2018), **1.1 GW**

Total gross electricity generation (2017), **6,027 GWh**

Electricity generation mix by type of generation (2018):

Domestic generation – **coal (88.8%), oil (4.6%), wind (5.1%), solar (0.5%) and hydro (1%). Imports, 18.8%**

Electricity consumption by sector (2018) – **industry (61.98%), residential (23.96%), agriculture (1%), losses (12%) (IEA, 2020)**

Mongolia is the seventh largest but least densely populated country on Earth, and the combination of a large geographic area, relatively small population and outdated infrastructure has led to the development of an energy system that suffers from significant transmission and generation inefficiencies (Tsevegmid, 2005; ADB, 2010). The total installed generation capacity is 1.1 GW, of which only about 70% can be used due to ageing of the facilities that to a large extent date back to the Soviet era. There is no unified power system, but there are five independent EPSs: Central (CEPS), West (WEPS), South Electric Power System (SEPS), Altai-Uliastai (AUEPS) and East (EEPS). In the reform process since 1990, and in particular after introduction of the new Energy Law in 2011, the power sector has been unbundled into generation, district heating, dispatching, transmission and distribution companies, most of which are state-owned. Among other institutions, the Energy Regulatory Commission (Energy Regulatory Authority until 2011) has been established as an important step towards creating an independent regulatory mechanism (ESCAP, 2005).

<sup>43</sup> For example, as a result of the torrential rainfall that struck western Japan and typhoons in 2018 and 2019, solar panels were blown away, immersed in water or dislodged. The 2019 typhoon Hagibi caused considerable damage to the power grid, resulting in power outages in the Tokyo area.

## Generation

Central EPS, the system that supplies the country's main load centre Ulaanbaatar, covers about 60% of Mongolia's territory and 92.6% of installed generation capacities. In the structure of Mongolia's generating capacities, the co-generation plants account for 92.15%, condensing power plants (Ukhua-Khudag TPP) fired by brown coal make up 1.54%, wind turbines – 4.3%; hydro power plants (HPP) – 1.97%, and solar power plants – 0.04% (Batmunkh et al., 2018).

Coal is the dominant fuel for power generation and, despite the country's enormous renewable potential, is likely to remain so in the mid-term for Mongolia's power system. A number of factors have prevented the large-scale development of Mongolia's renewable energy potential, among them the small scale of energy demand, which is unable to justify creating new infrastructure to support its renewable energy resources, the remote location of solar and wind resources with most potential and lack of funds for the needed grid expansion.

Nevertheless, renewable energy sources play a key role in decentralized power generation. A significant share of decentralized electricity demand, i.e., consumers not covered by the grid, has been satisfied by the "100,000 Solar Ger Electrification Programme", launched in 2000 by the Government of Mongolia with assistance from the World Bank, Global Environment Facility, the International Development Association as well with a grant from the Government of the Netherlands. Under the programme, nomadic herders that account for about 30% of Mongolia's population were encouraged to purchase solar home systems, whereas a cost-sharing mechanism would cover roughly half of the total expense (WB, 2013). The project not only covered about 60-70% of nomadic herders with access to electricity but contributed to capacity-building through training of about 400 people in implementing renewable projects and policies.

The total installed generation capacity would have been sufficient to satisfy the domestic energy demand, but due to its partial inefficiency about 20% of consumed electricity has to be imported from the Russian Federation and China.

The power flows in Mongolia are directed towards three main load centres, the cities of Ulaanbaatar, Erdenet and Darkhan, where 70% of the population is concentrated.

Expansion of transmission lines to increase reliability of power supply in these urban centres and to reduce the risk of power shortages is another policy priority.

## Transmission

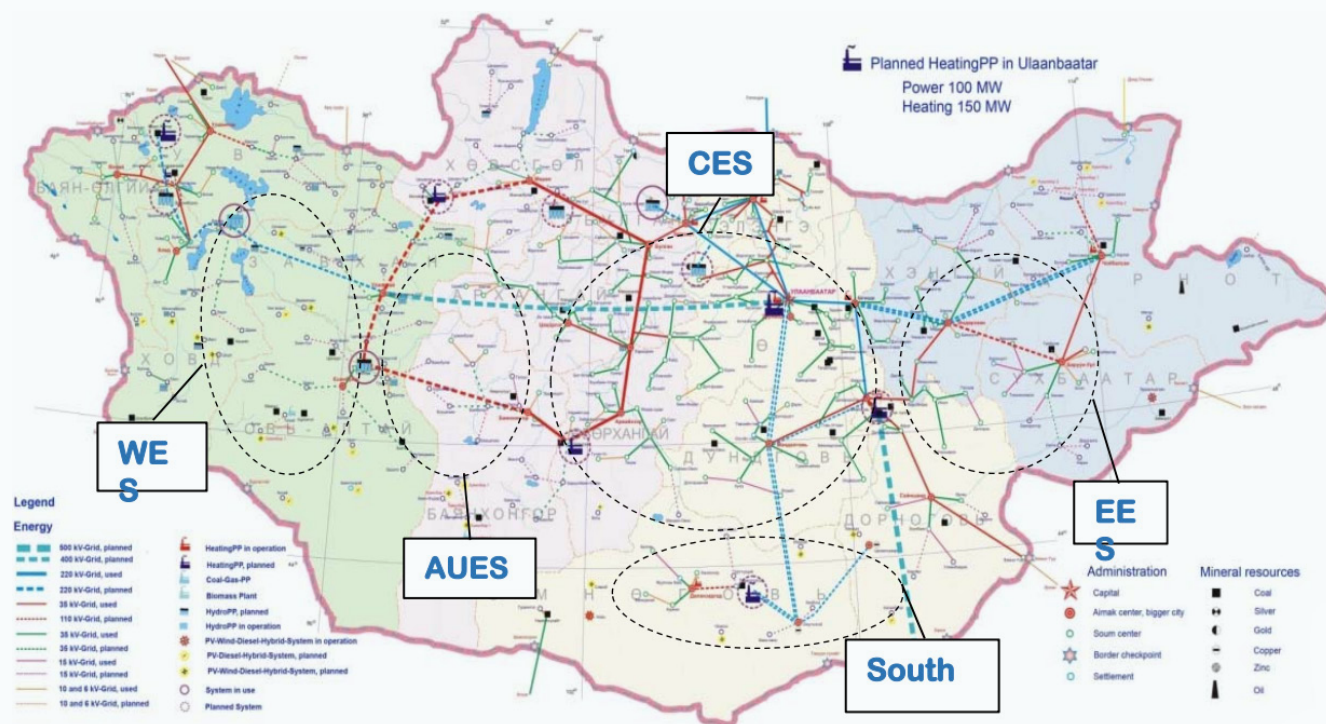
Mongolia's transmission grid is composed of high-voltage (220kV, 110 kV, 35kV) and low-voltage (0.4 kV, 6 kV, 10 kV) overhead transmission lines; however, the operation of the 110 and 35 kV transmission lines is often problematic due to their excessive length. Due to a poorly informed technological policy in the late-1990s, a number of ultra-long lines with voltage up to 110kV have been constructed, some of them covering a distance of up to 1,000 km (Batmunkh et al., 2018). Transmission over such long distances usually requires either much higher voltage or a number of substations to avoid major transmission losses and ensure effective operation of the grid. Both solutions are under discussion and increasing the efficiency of the grid is one of the current policy priorities.

## Distribution and electricity trade

Electricity is supplied through three centralized power grids and two isolated systems, including CES (Central Energy System), EES (the Eastern Energy System), WES (the Western Energy System), Dalanzhadgad system and Zhavhanand Gobi-Altai aimags system.

Electricity trading and distribution is conducted through the so-called Single Buyer Mode that has been in place in the Central EPS since 2002. Under this model, Single Buyer purchases electricity from the five CHP power plants operating in the Central EPS as well as electricity imported from the Russian Federation, and sells it to the 10 electricity distribution companies. In addition, spot and auction markets are in place in the CES.

The Mongolian Renewable Energy Law, in place since 2007, was amended in 2019 and theoretically provides a range of preferential feed-in-tariff rates for electricity generated from renewable energy sources. The exact prices are negotiated between the generation facilities and the Mongolian Energy Regulatory Association and are guaranteed for the following 10 years. However, given heavy subsidization of coal-generated electricity, the FIT-mechanism is, in fact ineffective, since no fuel source can be cost-competitive against coal in this environment (Borgford-Parnell, 2011).

**Figure 29** \_ Power grid of Mongolia

Source: Ministry of Energy, Government of Mongolia

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

### Regulatory framework for foreign businesses

Mongolia signed and ratified the Energy Charter Treaty in 1999. Consequently, foreign investments in the energy sector are protected through such mechanisms as national treatment, most favourable nation and fair equitable treatment, and are protected against expropriation and nationalization. In practice, however, state monopolies restrict access by private companies (both Mongolian and foreign) to the electricity sector (production, transmission and distribution) (UNCTAD, 2013).

When it comes to the deployment of renewables, the environment for foreign participation is quite favourable, given the complete exemption of all equipment (and its parts) used for renewable power generation and research from duties and taxes under the Customs Duty and Value Added Tax Laws of Mongolia.

### Government policy

Mongolia developed its first Master Plan for the energy sector in 1995 with ADB technical assistance. The

Master Plan reflects the main priorities in the energy sector and was updated in 2001 and 2013. Priorities in the electricity sector are stated in the Programme on Integrated Power System of Mongolia, a document first adopted in 2001 by the Parliament (State Great Khural) and updated in 2007 and 2015.

The Government of Mongolia seeks to establish a reliable power system to meet its growing domestic electricity demand. According to the Ministry of Energy, Mongolia's energy goals are to improve base load generation and energy storage, explore opportunities for combined heat and power (CHP), and increase energy efficiency and conservation (Export Solutions, 2017). The central priorities for the Government include financial self-sufficiency, energy efficiency, rural electrification, gradual privatization of generation and distribution companies and establishment of an integrated power system by interconnecting Central EPS and West EPS with an high-voltage electricity transmission line.

Given the high levels of urban air pollution caused by widespread usage of coal for heating in the suburbs

of Ulaanbaatar, one of the primary policy goals is promoting the electricity heating system in residential areas. In addition, as a short-term measure, subsidies are provided for clean stoves for the poorest groups of the population that relies on raw coal firing stoves for cooking and heating.

In the medium term, Mongolia aims to exploit its vast renewable energy resources and to increase the share of renewable generation by supporting construction of new renewable generation facilities. In June 2015, the Parliament adopted the State Policy in the Energy Sector, which sets as a strategic goal increasing renewable energy as a percentage of Mongolia's overall power capacity to 20% by 2020 and to 30% by 2030 (EBRD, 2018). Policy instruments supporting the deployment of renewables and a competitive electricity market are planned to be introduced until 2030 by the State Policy on Energy Sector, among them privatization of the generation and distribution sectors, introducing new pricing mechanisms (State Policy on Energy Sector, 2015) as well as by the latest revision of the Renewable Law (2019).

One of the major policy directions under the State Policy on Energy Sector is cooperation with the neighbouring countries and international organizations on enhancing cross-border electricity trade (State Policy on Energy Sector, 2015). The Government of Mongolia actively supports the idea of constructing Gobitec and connecting the country to its neighbours by the Asia Supergrid, thus enabling renewable electricity exports to consumers in the Russian Federation, the Republic of Korea, Japan, and China (Erdenechuluun, 2014). Another major project, which has been discussed since 2017, is the North-East Asia Power System Interconnection (NAPSI). Work on the NAPSI project involves a multilateral cluster of stakeholders that includes government-linked organizations, academia, research and engineering institutions, think-tanks, private sector companies, international organizations, and power utility and grid companies, and is guided by ESCAP and ADB. In its first stage, the NAPSI project foresees development of 5 GW of renewable energy generation capacity in Mongolia by 2026, accompanied by the construction of several transmission lines interconnecting Mongolia, China and the Russian Federation, Republic of Korea and Japan. Further steps include enhancing the transmission capacity of the interconnectors as well as deploying further renewable

generation capacities ranging from 10 GW to 100 GW by 2036 (Lienhart, 2018).

While the above-mentioned projects are primarily focused on electricity exports and do not require fundamental changes in Mongolia's regulatory framework, large-scale distribution of renewable electricity to the domestic market would additionally require abolishing coal subsidies and would in the short term result in the increase of retail electricity prices.

Finally, the development of energy storage systems is being considered as one strategic option to enable the increase of Mongolia's renewable energy capacity. In April 2020, the Government of Mongolia has secured a \$100 million loan from the ADB to install its first large-scale advanced battery energy storage system. The project, co-financed by the Government of Mongolia (\$11.95 million) and the Government of Japan (\$3 million), is due for completion in 2024 and will support the integration of an additional 859 GWh of renewable electricity into Mongolian power grid (ADB/EDF, 2019).

## Republic of Korea

### Key data

Installed capacity, (2018), **123.096 GW**  
Total gross electricity generation (2018), **593.407 TWh**  
Electricity generation mix (2019 – coal 40.32%, natural gas 26.04%, nuclear 25.1%, oil 2.52%, solar PV 2.24%, biofuels 1.57%, hydro 1.07%, wind: 0.46%, waste: 0.19%, tide: 0.08%, other: 0.41%)  
Peak demand (2018), **92.5 GW**  
Average load (2018), **65 GW**  
Electricity consumption by sector (2018) – industry 52.4%, commercial and public services 31.2%, residential 12.7%, agriculture/forestry 2.5%, fishing 0.6% and transport 0.5%

Since 1999, the Government of the Republic of Korea has implemented policy initiatives to liberalize the country's electric power industry. As part of these initiatives, in the early 2000s, the Government established the Korea Power Exchange (KPX) in order to enable wholesale electricity trading. It also started to unbundle the generation sector by dividing the state-owned Korea Electric Power Corporation (KEPCO) into subsidiary companies. As a result of a political backlash

in the early 2000s, further liberalization initiatives have been suspended and the electric power market consists of both partly liberalized and centralized segments. The government institutions in the Korean electricity sector are the Ministry of Trade, Industry and Energy of Korea (MOTIE) with its Korea Energy Regulatory Commission (KOREC) and Korea Energy Agency (KEA). According to the Electric Utility Act, as the key piece of legislation for the Korean power sector, MOTIE is responsible for overseeing comprehensive policies for demand and supply of energy, including renewable energy policies, and for delivering an Energy Master Plan. This plan is revised and re-implemented every five years over a period of 20 years, with the most recent being the Third Energy Master Plan (2019-2040). The biannually revised Basic Plan for Long-Term Electricity Supply and Demand (the ninth, for 2019-2033) is a central legislation specifically for the power sector and serves as a framework for the national electricity supply and demand strategies for the next 15 years.

### Generation

The Republic of Korea's electricity industry is dominated by the Korea Electric Power Corporation (KEPCO), a state-owned electricity supply company that was created in 1961 as a result of consolidating three state-owned companies – one in charge of generation and transmission and the two others responsible for distribution and sales. In April 2001, the generation sector of KEPCO was split up into six structurally separate generation companies: Korea South-East Power Co. Ltd. (KOSEPCO), Korea Midland Power Co. Ltd. (KOMIPO), Korea Western Power Co. Ltd. (KOWEPO), Korea Southern Power Co. Ltd. (KOSPO), Korea East-West Power Co. Ltd. (KEWESPO) and Korea Hydro & Nuclear Power Co. Ltd. (KNHP). Although privatization of these companies was originally planned, they remained wholly-owned subsidiaries of KEPCO after the liberalization process was suspended in 2003. As of 2019, the power generation industry in the Republic of Korea consisted of six KEPCO generation subsidiaries and 17 independent power producers (excluding renewable energy producers). KEPCO's subsidiaries generate the major portion of electricity in the country and, as of the end of 2018, held approximately 73% of the total installed generation capacity (Export Solutions, 2019). Local independent power producers accounted for 27%.

### Transmission

The Republic of Korea's transmission network has a frequency of 60 Hz and is approximately 31,250 km long, including 835 km of 765 kV lines, 8,653 km of 345 kV lines and 21,530 km of 154 kV and below lines. Most transmission lines in the country have a voltage of 154 kV, but transmission voltages can be 154 kV or 66 kV for local networks; however, many of these smaller lines are now being replaced (IEA, 2012). Transmission lines tend to run from the north-western and south-eastern coastal regions, where much of the generating capacity is located, to major urban and industrial centres in the north-west. Jeju Island is connected to the mainland by submarine HVDC cables.

In order to provide transmission services, a company must receive a transmission business licence from the Ministry of Trade, Industry and Energy. So far, only KEPCO has been granted such a licence and therefore has a monopoly on the national transmission line.

### Distribution

Similar to the transmission licences, a licence allowing engagement in the distribution business can only be granted by the Ministry of Trade, Industry and Energy. Apart from KEPCO, no distribution business has been granted such a licence so far.

The Republic of Korea is divided into 14 electricity supply zones. Community energy suppliers are responsible for the supply of electricity in certain areas. A community energy supplier is a government-licensed power producer who, for purposes of distributed power generation, possesses Combined Cycle Gas Turbine (CCGT) power plants that run on LNG, and distribution facilities in a certain area. Such suppliers generate power and heat, and supply customers within that area (IEA, 2012).

Under the Act on Construction and Facilitation of the Use of Smart Grids, introduced in May 2011, the Government is in charge of developing and implementing a five-year plan for constructing and facilitating the use of smart grids. Research and development funds may be accessible for developers of smart grid technologies, depending on the Government's budget.

The wholesale power trade is being conducted at the KPX, which determines the wholesale electricity prices

**Figure 30** Republic of Korea power grid



Source: KEPCO

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

based on two markers, the system marginal price and the capacity payment, whereas a price cap is being imposed on electricity from base-load generating facilities, such as coal and nuclear power plants (KPX, 2020). The tariffs for retail electricity supply are determined by KEPCO and they vary depending on several factors, including the voltage of the transmission, the season and time of supply. Retail tariffs also vary, depending on the so-called usage category, of which KEPCO has established nine: general; residential; educational; industrial; agricultural; street lighting; midnight power; electric vehicle; and demand management optional.

### Regulatory environment for foreign businesses

Foreign investments in power generation sector, except nuclear generation, are permissible if the total amount of installed capacities acquired by foreign investors from KEPCO or its subsidiaries is not more than 30% of the total installed domestic capacity. Foreign investment in nuclear generation is prohibited. Investment in the transmission and distribution sectors is difficult as they are dominated by a state-owned company that has a ceiling of a maximum number of shares acquired (3%) by any private investor, domestic or foreign.

As the Republic of Korea has no cross-border interconnections and does not conduct cross-border trade in electricity, there are no provisions regulating electricity imports or exports.

### Government policy in the electricity sector

Due to rising public concern over air pollution in the Republic of Korea as well as over safety issues regarding nuclear power generation – the latter resulting from the Fukushima Daichi nuclear disaster – the current Government aims to substitute a large share of coal-fired power plants with LNG and renewable energy sources. In addition, it plans to reduce the country's dependency on nuclear energy. The concrete measures proposed under the Eighth Basic Plan for Long-Term Electricity Supply and Demand, 2017-2031 include closure of 10 coal-fired power plants aged 30 years or more until 2022, conversion of the coal-fired power plants currently under construction into LNG-fired power plants as well as the plan to refuse issuance of a licence for new nuclear power plant projects (Yi and Chin, 2018).

Extensive deployment of renewable energy is the central piece of the current administration's policy that aims to increase the share of renewable energy in electricity generation from around 5% to 20% by 2030, and to 30%-35% by 2040. Several incentives to promote the development of renewable energy generation have been introduced, and several more are planned under the current energy strategy. Expansion of renewable generation facilities has been supported by some tax incentives as well as the Feed-in-Tariff policy introduced in 2001. In 2012, the Feed-in-Tariff mechanism was replaced by the Renewable Portfolio Standard (RPS) policy with the goal of creating a competitive market environment for the renewable generation sector. Under the RPS programme, the 21 largest power companies<sup>44</sup> are required to increase their renewable energy mix in total power generation, either by investing in renewable energy facilities or by purchasing Renewable Energy Certificates. The required minimum for renewable generation was set at 2% in 2012 and will be increased to 10% by 2023.<sup>45</sup> Furthermore, a new type of Feed-in-Tariff has been proposed as a future incentive for small renewable energy projects (Lee/MOTIE 2018).

The Eighth Basic Plan has a particular focus on restructuring the transmission segment to adjust it to the future energy mix. The following strategies should direct the future development of transmission grids:

1. Enhancing system capacity and promoting renewable generation. The measures include reinforcing the national grid interconnections to enable total installed renewable generation capacity to be integrated into the grid, and the introduction of better control systems and new transmission technologies (e.g., flexible AC transmission systems) for more efficient operation of the grid. In the medium term, proactive expansion of transmission and conversion facilities on sites where renewable generation is expected to be particularly intensive, and the introduction of a 70kV voltage standard for small substations for distributed renewable generation.
2. Improving the stability of the power system through timely installations of transmission facilities and compensatory measures in the case of construction

<sup>44</sup> With installed power capacity over 500 MW.

<sup>45</sup> <https://www.iea.org/policiesandmeasures/pams/korea/name-39025-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s&s=dHlwZT1yZSZzdGF0dXM9T2s>.

delays (e.g., alternative installations etc.). In particular, construction of the transmission lines for newly commissioned power plants should be completed in time.

3. Achieving a higher acceptance rate for the new transmission construction projects. To address growing public objections towards newly commissioned overhead transmission lines, which have several times prevented the development of new generation capacities, the Government plans to focus on underground installation of transmission lines in populated areas. In addition, HVDC lines will be used for long-distance transmission, since they require less space and have less impact on the environment. Further measures include governmental support for areas located near transmission lines and facilities, and the inclusion of residents in the site selection process.
4. Overcoming the limitations of the independent power system through the construction of the North-East Asia Super Grid, consisting of interconnections between the Republic of Korea, the Russian Federation, China and Japan. The Republic of Korea is, so far, the only country in the region that has expressed its interest in a regional power grid interconnection in its official Energy Strategy (MOTIE, 2017). Among the newest developments in this direction has been the agreement between Chinese (State Grid of China Corporation and GEIDCO) and Korean (KEPCO) stakeholders on the joint development of China-Republic of Korea power interconnection in late-2017. A Joint Development Agreement on this project was developed in 2019 (signature pending), with construction planned to begin in 2022. The 366 km, 500 kV interconnection of 2 GW transmission capacity is supposed to connect Weihai and Incheon (KEPCO, 2019).

## Russian Federation (focus on Siberia and Far East)

### Key data

**Installed capacity (2019) – 243.2 GW (Russian Federation); 51.8 GW (Siberia), 9.6 GW (Far East) (SO UES, 2020a)**

**Total gross electricity generation (2018) – 1,071 TWh (total); 205.3 TWh, 18.7% (Siberia); 11.2 TWh, 3.4% (Far East)**

**Electricity generation mix by type of generation (2019) – Siberia, TPP – 51.1%, HPP – 48.8%, Solar PV – 0.1%, Far East - TPP – 68.4, hydro- 31.6%.**

**Peak demand (2018), 31.2 GW – Siberia, 5.6 GW – Far East**

**Electricity consumption by sector (Russian Federation, 2018) – industry 44.8%, residential 21.89%, commercial and public services 20.03%, transport 10.8%, agriculture/forestry 2.44% and fishing 0.04%**

The Russian Federation is the world's fourth largest generator and consumer of electricity, with the majority of the load centres and generation facilities located in the European part of the country. The Russian Federation electricity sector consists of generation, divided into wholesale and retail markets, transmission and distribution. The country's power system is divided into seven integrated power systems (IPSs): IPS-Northwest; IPS-Centre; IPS-Middle Volga; IPS-Urals; IPS-South; IPS-Siberia; and IPS-East. Together they comprise 71 regional power systems (SO UES, 2020). All of the power systems are connected by 330-750 kV and 220-500 kV high-voltage transmission lines and synchronized. For the purposes of this report, this section covers the power systems of Siberia and the Russian Far East – regions located in the North-East Asian subregion and adjacent to China, the DPRK, Mongolia and Japan.

### Generation

The generation sector has been largely liberalized, with the exception of nuclear facilities that are owned by the State.<sup>46</sup> After the reorganization of the state-owned monopolist company RAO UES – which controlled 96% of transmission and more than 70% of generation facilities – and the resulting privatization of thermal-generation and regional power-distribution companies, seven wholesale generation companies (former subsidiaries of RAO UES) and 14 territorial generation companies entered the wholesale market in 2008. In IPS-Siberia, hydropower plants account for about 50% of total generation capacity, while the other half is represented by thermal generation.<sup>47</sup> In

<sup>46</sup> Although major hydropower plants are predominantly state-owned, a fair share of HPPs in the Russian Federation are privately-owned.

<sup>47</sup> [https://so-ups.ru/index.php?id=oes\\_siberia](https://so-ups.ru/index.php?id=oes_siberia).

the IPS-East, about 32% of electricity is generated by hydropower while the rest is supplied through thermal (mainly coal-fired) and co-generation (SO UES, 2019). Plans to introduce a nuclear generation capacity of 1 GW in the Primorye region of the EPS-East are also being discussed, with the aim of covering local electricity needs and potentially to send electricity to the DPRK and the Republic of Korea. InterRAO PJSC, another former subsidiary of the RAO UES, has a monopoly on import and export of electricity in Siberia and the Russian Far East.

An electricity consumption decline caused a large excessive capacity in the RFE EPS, reaching nearly 40% of the maximum electric load. Power generating capacities are allocated unevenly in the territory of the RFE's EPS – the volumes of excessive capacity vary in the territory. They are larger in Amur EPS and less in Primorye EPS where electricity consumption is highest. Nevertheless, the power generation potential of both Siberia and RFE is being further developed. Particular prospects in this regard are offered by the region's massive hydropower potential. While the technical hydropower potential of Siberia is used by 12.5%, and of the Far Eastern region by less than 2%, technical conditions for the development of hydropower resources in the east of the Russian Federation, especially in Eastern Siberia, are estimated to be more favourable than in the rest of the country (Voropai et al., 2019).

### Transmission

The Russian Federation's power grid is largely owned and operated by Russian Grids, a state-controlled public joint-stock company. Russian Grids manages 2.3 million kilometres of power lines and 507,000 substations, and operates nationwide through its subsidiaries. Subsidiaries of Rosseti represented in Siberia and the Russian Far East are the Federal Grid Company of Unified Energy System (FGC UES) and Interregional Distribution Grid Company of Siberia. They are responsible for the operation and management of most of the ultra-high-voltage (UHV) and high-voltage (HV) lines. Middle- and lower-voltage lines and distribution grids are owned and operated by interregional distribution grid companies.

Russian Grids PJSC transmits and distributes power to more than 70% of the Russian population and the industrial facilities that account for more than

60% of the Russian Federation GDP. The backbone of the transmission grid of IPS Siberia is formed by transmission lines of between 110 and 500 kV, with total length of 101,288 km. The transmission grid in the IPS East is comprised of 110-500kV transmission lines with a total length of 33,025 km, whereas the 500 kV transmission lines do not form a unified grid. Instead, there are two sections of 500 kV transmissions with a total length of nearly 1,700 km and with no linkages between them; however, there are plans for future interconnection.

The power in the Russian Far East EPS transmission grid flows from west to east and farther south, due to the uneven allocation of electricity consumption and production in the region.

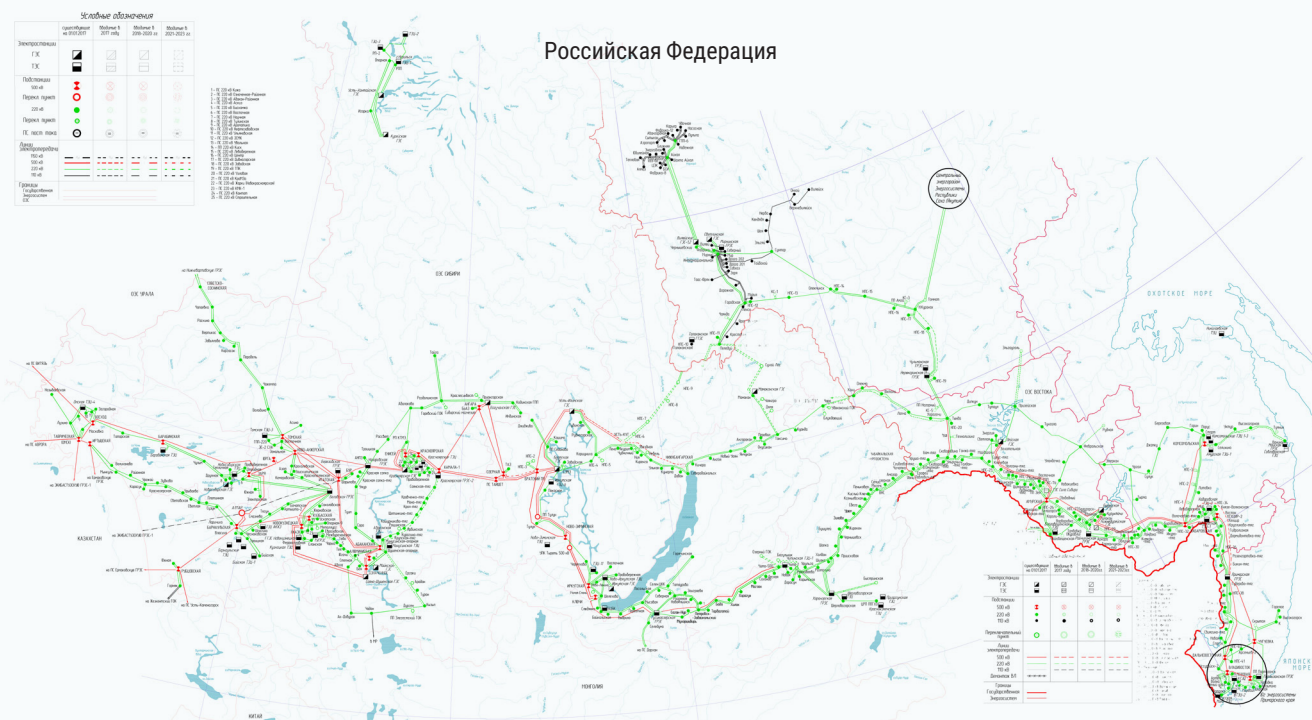
### Distribution and price-building mechanisms

Similar to the transmission sector, distribution is dominated by Russian Grid holding's subsidiary, Far Eastern Distribution Company, although distribution companies from the private sector are increasingly emerging in the market.

On the wholesale market, electricity can be traded through regulated bilateral agreements, free-pricing mechanisms (among them unregulated bilateral agreements and the day-ahead market), and the balancing market. The balancing market is operated by the system operator and is designed to react to any potential change at each of the 8,400 nodes in the Russian Federation's power system (IRENA, 2017a). Wholesale market participants are also obliged to sell power on the retail market for a defined volume of electricity. Furthermore, there is the wholesale market for capacity, where the availability of each generator to provide power when needed is traded.

After the reform, two main price zones were formed, namely the European-Russian price zone and the Siberia price zone. In addition, there are two non-pricing zones where prices are regulated by the Government. One of these zones is the Far East dispatch zone. Three areas with no transmission links with the Far East dispatch zone (Kamchatka, Magadan and Sakhalin) are categorized as isolated. The electricity price in these areas is regulated and subsidized to keep it as low as the nation-wide average. There is no wholesale market in these areas and different power segments are not unbundled. While development of a competitive market

**Figure 31** Russian Federation power grid: Siberia and the Russian Far East



Source: System Operator of the Unified Energy System (SO UPS)

Maps of Siberia (<https://energybase.ru/map/map-substations-powerplants-siberia>) and Far East (<https://energybase.ru/map/map-substations-powerplants-far-east>) are merged.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

in the isolated zone is indeed very difficult and regulated pricing therefore seems a reasonable option, lifting the regulated price from the rest of the Far East dispatch zone has been under discussion in the recent years. The price in this region is being artificially brought below the level of prices in the Central and Ural dispatch zones, through cross-subsidization and at the expense of consumers in the European part of the Russian Federation, the Urals and Siberia. The share of the cross-subsidies is estimated to exceed 2% of the final price in those regions; given that this mechanism will probably remain in place at least until 2028 (Zhikharev et al., 2018), measures to enable a gradual reduction of inter-territorial subsidies and free additional funds for energy development projects in the Far East are being currently discussed by the Government. The EPS Siberia is supplying Central and Western EPS of Mongolia with electricity through two 220kV transmission lines as well as several 10 and 110 transmission lines (388 MWh in 2018), while the EPS East has 110 kV, 220 kV and 500 kV interconnections with China and supplies 3108.9 MWh (SO UES, 2019).

### Regulatory environment for foreign businesses

There are no direct restrictions on foreign ownership of electricity companies in the Russian Federation. However, certain restrictions may apply in cases of investments in companies of strategic importance (the transmission companies or nuclear generation facilities would both fall in this category). In such cases, State approval is required.

Interconnection issues are regulated by bilateral agreements on parallel work of electric energy systems concluded between the market infrastructure bodies of the Russian Federation and the respective country.

Imports and exports of electricity are regulated on a bilateral basis between the market infrastructure bodies of the Russian Federation and the respective country. For example, electricity exports via cross-border interconnections to China are regulated by bilateral agreements. Among these is the agreement between Inter RAO and CSGC, which is concluded annually, the

agreement between System Operator (the Russian Federation) and North-East China Grid Company (2012) as well as a framework of agreements at the intergovernmental level, such as the China-Russian Federation MoU on Cooperation in the Sphere of Power Trade (2018) (China Ministry of Commerce, 6/12/2018).

### Government policy in the electricity sector

Central place in the current Russian Energy Strategy until 2030<sup>48</sup> has been given to the development of the power sector of the Far East region, which is intended to spur regional economic development and contribute to social welfare. The main goals in this region are the development of hydropower generation capacities (1680 MW until 2030), development and implementation of energy efficiency mechanisms as well as expansion of the national grid (500kV transmission line) (Otsuki et al., 2016). Expanding hydropower generation in the Russian Far East has indeed become more feasible due to recent changes in the regulatory landscape. These include changed schemes for attracting investments, revision of plans for the development of industrial production in the regions as well as additional environmental and technological restrictions (Voropai et al., 2019).

Development of “new” renewables (defined in the Strategy as variable sources such as solar and wind power as well as small hydro) is set as another important goal. The national target for renewable electricity generation has been set at 2.5% of the total generation mix by 2020; however, given that the share of renewable generation currently amounts to 1%, it remains questionable whether this target can be achieved on time. The non-binding nature of this target as well as the absence of any sanctions for non-compliance make it a rather weak instrument for promoting the deployment of renewable energy sources beyond the traditionally developed large-scale hydropower.

Besides these targets, the Russian legislative and regulatory frameworks also establish rules for trading electricity generated from renewable energy sources on wholesale and retail markets as well as offer some incentives. In 2007, an attempt to introduce a type of a premium scheme for wholesale electricity prices was made that, if implemented, would have been equivalent to a feed-in tariff. This initiative, however, remained only on paper due to concerns about rising consumer prices as well as legal difficulties in developing a concrete implementation mechanism.

Since 2013, another regulatory mechanism has been in place, which makes all wholesale market consumers purchase electricity from renewable generation facilities over the duration of the contracts (usually 15 years). There are several limitations to this mechanism, including non-applicability of facilities with less than 5 MW installed capacity to participate in this scheme as well as the exclusion of non-price and isolated regions.

Finally, very strict local content rules (a minimum of 79% of domestically-produced equipment) may limit qualification to participate in this scheme. This may make many renewable generation projects uncompetitive on the power markets of Siberia and Far East as well as limit the opportunities for foreign investors (Chukanov et al., 2017). In the Russian Far East region, generation capacity of new and renewable energy is planned to be as high as 400 MW by 2030; however, for the volumes to be achieved, substantial changes in the regulatory landscape will be necessary.

Expansion of electricity exports to neighbouring countries, particularly from the Russian Far East to the countries of North-East Asia, is a further strategic goal of the Russian Federation Government.

<sup>48</sup> The energy strategy until 2035 has been developed for several years now, but it has not yet been adopted.

# References and literature review

## References

- Interfax (12/30/2014). Итоги 2014: переизбыток энергии. Из-за интенсивного строительства новых электростанций обозначился переизбыток мощностей, однако энергетики не собираются останавливаться на достигнутом. Available at <https://www.interfax.ru/business/416001>, retrieved 1/26/2020.
- Reuters (9/8/2017). Shanghai to start opening power market in line with China reforms. Available at <https://www.reuters.com/article/us-china-power-reform/shanghai-to-start-opening-power-market-in-line-with-china-reforms-idUSKCN1BJ0ZM>, retrieved 1/27/2020.
- Nikkei Asian Review (6/12/2019). Japan to overhaul renewable energy system in bid to lower prices. New competitive auction system aimed at reducing burden on consumers. Available at <https://asia.nikkei.com/Spotlight/Environment/Japan-to-overhaul-renewable-energy-system-in-bid-to-lower-prices>, retrieved 1/27/2020.
- Wind Energy and Electric Vehicle Magazine* (REVE) (6/21/2019). Photovoltaic capacity increased to 505 GW. Available at <https://www.evwind.es/2019/06/21/photovoltaic-cumulative-capacity-increased-approximately-25-to-at-least-505-gw/67686>, retrieved 1/27/2020.
- Ahn, J. H. (2016). S. Korea temporarily closes Kaesong Industrial Complex. Seoul will withdraw all staff from the KIC from today - Unification Minister. NK News, Available at <https://www.nknews.org/2016/02/breaking-south-korea-temporarily-closes-the-kic/> (retrieved 27 January 2020).
- Asian Development Bank (ADB) (2020). ADB accelerating renewable energy in Mongolia with advanced battery storage system. Available at <https://www.adb.org/news/adb-accelerating-renewable-energy-mongolia-advanced-battery-storage-system> (retrieved 28 August 2020).
- Battulga, K. (2019). Speech by Khaltmaagiin Battulga, President of Mongolia, at the extended session of the Fourth Eastern Economic Forum, 9 December 2018. Available at <https://president.mn/en/2018/09/12/speech-of-president-at-the-eastern-economic-forum-2018/>, retrieved 9/17/2020.
- Bellini, E. (2019). North Korea plans 2.5 GW solar plant with Chinese help. *PV Magazine*. Available at <https://www.pv-magazine.com/2019/10/25/north-korea-plans-2-5-gw-solar-plant-with-chinese-help/> (retrieved 27 January 2020).
- Belyaev, L., V. Savelyev and L. Chudinova (2018). The role of hydropower in electric power integration of Asian countries. In *E3S Web Conf.* vol. 27, No. 4, p. 1005. DOI: 10.1051/e3sconf/20182701005.
- Bengali, S. (2019). China, Japan and South Korea, while vowing to go green at home, promote coal abroad. *Los Angeles Times*. Available at <https://www.latimes.com/world/asia/la-fg-indonesia-south-korea-coal-energy-finance-20190513-story.html> (retrieved 27 January 2020).
- BP (2019a). BP Energy Outlook. 2019 edition. BP. Available at <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf> (retrieved 26 January 2020).
- \_\_\_\_\_. (2019b). BP Statistical Review of World Energy. 2019 | 68th edition. BP. Available at <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf>.
- China Electricity Council (2019). 2019年全国电力工业统计快报一览表. Available at <https://www.cec.org.cn/upload/1/editor/1579576517375.pdf> (retrieved 28 September 2020).
- China Electric Power Research Institute (CEPRI) (2018). UHV Transmission Technology, Elsevier: China Electric Power Press.
- Climate Action Tracker (2020). Russian Federation. Available at <https://climateactiontracker.org/countries/russian-federation/pledges-and-targets/> (retrieved 26 January 2020).
- Dupuy, M. (2018). The quiet power market transformation behind the new carbon market in China. *Energy Post*, 11 January 2018. Available at <https://energypost.eu/the-silent-power-market-transformation-behind-the-new-carbon-market-in-china/> (retrieved 27 January 2020).
- Electric Power Statistics Information System (EPSIS) (2020). Key Electric Power Index. Available at <http://epsis.kpx.or.kr/epsisnew/selectEkesKepChart.do?menuId=010100&locale=eng> (retrieved 27 January 2020).

Enerdata (2019). Global Energy Statistical Yearbook 2019. Enerdata. Available at <https://yearbook.enerdata.net/> (retrieved 26 January 2020).

Energy Charter (2018). China Energy Efficiency Report. Protocol on Energy Efficiency and Environmental Aspects. Energy Charter Secretariat. Brussels. Available at [https://www.energycharter.org/fileadmin/DocumentsMedia/EERR/EER-China\\_ENG.pdf](https://www.energycharter.org/fileadmin/DocumentsMedia/EERR/EER-China_ENG.pdf) (retrieved 27 January 2020).

Erdenechuluun, Kh. (2014). Mongolian power sector. Background and current policy. UBEDN, August 2014. Available at <https://enen.iej.or.jp/data/5590.pdf> (retrieved 27 January 2020).

Economic Research Institute for ASEAN and East Asia (ERIA) (2018). An International Analysis of Public Acceptance of Nuclear Power, ERIA Research Project Report 2017 No. 3, Economic Research Institute for ASEAN and East Asia 2018, p.14-15. Available at: [https://www.eria.org/uploads/media/ERIA\\_RPR\\_2017\\_03.pdf](https://www.eria.org/uploads/media/ERIA_RPR_2017_03.pdf) (retrieved 4 March 2020).

ESCAP (2001). Khabarovsk Communique: North-East Asia Expert Group Meeting on Inter-Country Cooperation in Electric Power Sector Development, 23-24 October 2001, Khabarovsk, Russian Federation.

\_\_\_\_\_ (2003). Vladivostok Statement of Senior Officials on Energy Cooperation in North-East Asia, 10 April 2003, Vladivostok, Russian Federation.

\_\_\_\_\_ (2005). Electric power in Asia and the Pacific 2001 and 2002. United Nations, New York. Available at <https://digitallibrary.un.org/record/587512?ln=en> (retrieved 27 January 2020).

\_\_\_\_\_ (2018). Northeast Asia Regional Power Interconnection and Cooperation Forum 2018, 31 October-1 November 2018, Ulaanbaatar, Mongolia.

\_\_\_\_\_ (2019). Electricity Connectivity Roadmap for Asia and the Pacific. Strategies towards interconnecting the region's grids. With assistance of ESCAP, Bangkok. Available at [https://www.unescap.org/sites/default/files/Publication\\_Electricity%20Connectivity%20Roadmap%2027%20December%202019.pdf](https://www.unescap.org/sites/default/files/Publication_Electricity%20Connectivity%20Roadmap%2027%20December%202019.pdf).

\_\_\_\_\_ (2020). Subregional Office for East and North-East Asia. Available at <https://www.unescap.org/subregional-office/east-north-east-asia> (retrieved 26 January 2020).

European Bank for Reconstruction and Development (EBRD) (2018) Support for Competitive Procurement of Renewables in Mongolia. Available at <https://www.ebrd.com/documents/procurement/support-for-competitive-procurement-of-renewables-in-mongolia.pdf> (retrieved 3 April 2020).

Eurostat (2019). Glossary: Renewable energy sources. European Commission. Available at [https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Renewable\\_energy\\_sources](https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Renewable_energy_sources) (retrieved 27 January 2020).

Export Solutions (2017). Mongolia - Energy Generation. International Trade Administration. Available at <https://www.export.gov/article?id=Mongolia-Energy-Generation> (retrieved 27 January 2020).

\_\_\_\_\_ (2019). Korea - Energy New and Renewable. Available at <https://www.export.gov/article?id=Korea-Energy-New-and-Renewable> (retrieved 27 January 2020).

Fairley, P. (2019). China's ambitious plan to build the world's biggest Supergrid. IEEE. Available at <https://spectrum.ieee.org/energy/the-smarter-grid/chinas-ambitious-plan-to-build-the-worlds-biggest-supergrid> (retrieved 27 January 2020).

Federal Institute for Geosciences and Natural Resources (BGR) (ed.) (2013). Energy Study 2013. Reserves, resources and availability of energy resources. Hannover. Available at [http://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie\\_2013\\_en.pdf?\\_\\_blob=publicationFile&v=2](http://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2013_en.pdf?__blob=publicationFile&v=2), retrieved 1/27/2020.

Fraunhofer Institute for Solar Energy Systems (2020). Photovoltaics Report 2019. Freiburg. Available at <https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>, retrieved 1/27/2020.

Gerretsen, I. (2020). "South Korea formally commits to cutting emissions to net zero by 2050". Climate Home News, 28 October 2020. Available at <https://www.climatechangenews.com/2020/10/28/south-korea-formally-commits-cutting-emissions-net-zero-2050/> (retrieved 12 November 2020).

Global Wind Atlas (2020). Available at <https://globalwindatlas.info/downloads/maps-country-and-region>, retrieved 1/27/2020.

Global Solar Atlas (2020). Available at <https://globalsolaratlas.info/download/world>, retrieved 1/27/2020.

Government of Mongolia (2015). State Policy on Energy Sector (Annex to 2015 Parliament Resolution #63), Unofficial translation.

Greater Tumen Initiative (2013). Capacity Building Training on Energy: Policies and Prospects for Regional Energy Cooperation, 26.07.2013, Available at <http://www.tumenprogramme.org/?info-608-1.html>, retrieved 10/08/2020.

\_\_\_\_\_ (2020). Overview, available at <http://www.tumenprogramme.org/?list-1524.html>

- Han, C.-H., S.-T. Park and S.-J. Lee (2019). The Enhanced Security Control Model for Critical Infrastructures with the Blocking Prioritization Process to Cyber Threats in Power System. In *International Journal of Critical Infrastructure Protection*, Vol. 26, 100312, September 2019.
- Hasegawa, M. (2020). "Japan mulls 177GW for first power capacity auction". *Argus Media*, 29 May 2020. Available at <https://www.argusmedia.com/en/news/2109642-japan-mulls-177gw-for-first-power-capacity-auction>, retrieved 9/28/2020.
- Hippel, D. v and P. Hayes (2018). Energy Insecurity in the DPRK. Linkages to regional energy security and the nuclear weapons issue. Nautilus Institute (NAPSNET Special Report). Available at [http://nautilus.org/wp-content/uploads/2018/01/IFANS-Energy-DvH-PH-revised\\_Dec28-SR-version.pdf](http://nautilus.org/wp-content/uploads/2018/01/IFANS-Energy-DvH-PH-revised_Dec28-SR-version.pdf), retrieved 1/27/2020.
- Hoes O. A. C., L. J. J. Meijer, R. J. van der Ent and N. C. van de Giesen (2017). Systematic high-resolution assessment of global hydropower potential. *PLoS ONE*, 12(2): e0171844.
- Hook, L. (2020). China pledges to be 'carbon-neutral' by 2060. *Financial Times*, 22 September 2020. Available at <https://www.ft.com/content/730e4f7d-3df0-45e4-91a5-db4b3571f353> (retrieved 12 November 2020).
- Institute of Energy Economics Japan (IEEJ) (2020). IEEJ Outlook 2019. Coping with increasingly challenging energy trilemma (3Es): Energy, Environment and Economy. IEEJ. Available at <https://eneken.iej.or.jp/data/8650.pdf>, retrieved 1/26/2020.
- Institute for Far Eastern Studies (IFES) (2013). North Korea adopts renewable energy law. *NK Econwatch*, 17 September 2013. Available at <http://www.nkeconwatch.com/2013/09/17/north-korea-adopts-renewable-energy-law/>, retrieved 1/27/2020.
- \_\_\_\_\_ (2016). Progress in North Korea's renewable energy production. *NK Econwatch*, 15 February 2016. Available at <https://www.nkeconwatch.com/2016/02/15/progress-in-north-koreas-renewable-energy-production/>, retrieved 1/27/2020.
- INTER RAO UES (2020). Eastern Energy Company. Available at <https://www.interrao.ru/en/activity/trading/vek/about/>, retrieved 1/27/2020.
- Interfax (2014). Итоги 2014: переизбыток энергии. Из-за интенсивного строительства новых электростанций обозначился переизбыток мощностей, однако энергетики не собираются останавливаться на достигнутом. 30 December 2014. Available at <https://www.interfax.ru/business/416001>, retrieved 1/26/2020.
- International Energy Agency (IEA) (2012). Energy policies of IEA countries. Republic of Korea 2012 Review. Paris: OECD/IEA. Available at <https://webstore.iea.org/energy-policies-of-iea-countries-republic-of-korea-2012-review>, retrieved 1/27/2020.
- \_\_\_\_\_ (2017a). Energy Efficiency 2017. Organization for Economic Co-operation and Development (OECD); International Energy Agency (IEA). Available at <https://www.iea.org/reports/energy-efficiency-2017>, retrieved 1/27/2020.
- \_\_\_\_\_ (2017b). World Energy Outlook 2017: China. Report — November 2017. International Energy Agency (IEA). Available at <https://www.iea.org/reports/world-energy-outlook-2017-china>, retrieved 1/27/2020.
- \_\_\_\_\_ (2018). World Energy Investment 2018. Organization for Economic Co-operation and Development (OECD); International Energy Agency (IEA). Available at <https://webstore.iea.org/download/direct/1242?fileName=WEI2018.pdf>, retrieved 1/27/2020.
- \_\_\_\_\_ (2019a). World energy outlook 2019. France, International Energy Agency.
- \_\_\_\_\_ (2019b). China Power System Transformation. Assessing the benefit of optimized operations and advanced flexibility options. International Energy Agency (IEA). Available at [https://webstore.iea.org/download/direct/2440?fileName=China\\_Power\\_System\\_Transformation.pdf](https://webstore.iea.org/download/direct/2440?fileName=China_Power_System_Transformation.pdf), retrieved 1/27/2020.
- \_\_\_\_\_ (2019c). SDG 7: Data and Projections. Flagship Report. International Energy Agency (IEA). Available at <https://www.iea.org/reports/sdg7-data-and-projections>, updated on 1/27/2020, retrieved 1/27/2020.
- \_\_\_\_\_ (2019d). Tracking SDG 7. The Energy Progress Report. With International Renewable Energy Agency, UNSD, World Bank and World Health Organization. Washington DC. Available at <https://trackingsdg7.esmap.org/data/files/download-documents/2019-Tracking%20SDG7-Full%20Report.pdf>, retrieved 1/27/2020.
- \_\_\_\_\_ (2019e). Offshore Wind Outlook 2019. World Energy Outlook Special Report. International Energy Agency (IEA). Available at [https://webstore.iea.org/download/direct/2886?fileName=Offshore\\_Wind\\_Outlook\\_2019.pdf](https://webstore.iea.org/download/direct/2886?fileName=Offshore_Wind_Outlook_2019.pdf), retrieved 4/20/2020
- \_\_\_\_\_ (2019f). Establishing Multilateral Power Trade in ASEAN. International Energy Agency (IEA). Abu Dhabi. Available at [https://webstore.iea.org/download/direct/2826?fileName=Establishing\\_Multilateral\\_Power\\_Trade\\_in\\_ASEAN.pdf](https://webstore.iea.org/download/direct/2826?fileName=Establishing_Multilateral_Power_Trade_in_ASEAN.pdf), retrieved 4/22/2020
- \_\_\_\_\_ (2020a). Data and Statistics. International Energy Agency (IEA). Available at <https://www.iea.org/data-and-statistics>, retrieved 10/8/2020.

\_\_\_\_\_ (2020b). IEA Atlas of Energy. International Energy Agency (IEA). Available at <http://energyatlas.iea.org/#/tellmap/1378539487>, retrieved 10/8/2020.

International Energy Agency, IRENA, UNSD; World Bank, WHO (2020). Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC. © World Bank. License: Creative Commons Attribution—Non-Commercial 3.0 IGO (CC BY-NC 3.0 IGO). Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/May/SDG7Tracking\\_Energy\\_Progress\\_2020.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/May/SDG7Tracking_Energy_Progress_2020.pdf).

International Renewable Energy Agency (2015). From Baseload to Peak: Renewables Provide a Reliable Solution. International Renewable Energy Agency (IRENA). Abu Dhabi. Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA\\_Baseload\\_to\\_Peak\\_2015.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Baseload_to_Peak_2015.pdf), retrieved 4/17/2020.

\_\_\_\_\_ (2016). Mongolia: Renewables Readiness Assessment. . Abu Dhabi. Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA\\_RRA\\_Mongolia\\_2016.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_RRA_Mongolia_2016.pdf), retrieved 1/27/2020.

\_\_\_\_\_ (2017a). REMAP 2030. Renewable Energy Prospects for Russian Federation. International Renewable Energy Agency (IRENA). Abu Dhabi (Working Paper). Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Apr/IRENA\\_REmap\\_Russia\\_paper\\_2017.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Apr/IRENA_REmap_Russia_paper_2017.pdf), retrieved 1/27/2020.

\_\_\_\_\_ (2017b). Geothermal Power. Technology Brief. International Renewable Energy Agency (IRENA). Abu Dhabi. Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA\\_Geothermal\\_Power\\_2017.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf), retrieved 1/26/2020.

\_\_\_\_\_ (2017c). Energy Profile: Mongolia. Abu Dhabi. Available at [https://www.irena.org/IRENADocuments/Statistical\\_Profiles/Asia/Mongolia\\_Asia\\_RE\\_SP.pdf](https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Mongolia_Asia_RE_SP.pdf), retrieved 10/08/2020

\_\_\_\_\_ (2019). Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects. (A Global Energy Transformation: paper). International Renewable Energy Agency (IRENA). Abu Dhabi. Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA\\_Future\\_of\\_Solar\\_PV\\_2019.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Future_of_Solar_PV_2019.pdf), retrieved 1/27/2020.

\_\_\_\_\_ (2020). Renewable Power Generation Costs in 2019. International Renewable Energy Agency (IRENA). Abu Dhabi. Available at <https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019>, , retrieved 8/28/2020.

Japan Electric Power Exchange (2020). Available at <http://www.jepx.org/english/market/index.html>, retrieved 1/27/2020.

Japan Electric Power Information Center (JEPIC)(2019). The Electric Power Industry in Japan 2019. Tokyo. Available at <https://www.jepic.or.jp/pub/pdf/epijJepic2019.pdf>, retrieved 1/27/2020.

\_\_\_\_\_ (2020). The Electric Power Industry in Japan 2020. Tokyo. Available at <https://www.jepic.or.jp/pub/pdf/epijJepic2020.pdf>, retrieved 9/28/2020.

Korean Energy Statistical Information System (KESIS) (2019). Yearbook of Energy Statistics. Available at: [http://www.kesis.net/sub/sub\\_0003\\_eng.jsp](http://www.kesis.net/sub/sub_0003_eng.jsp), retrieved 4/26/2020.

Kim, S. (2018). N Korea Science and Technology Part 4: Advances in Sustainable Farming and Renewable Energy. *Zoom in Korea*, 10 July 2018. Available at <http://www.zoominkorea.org/part-4-advances-in-sustainable-farming-and-renewable-energy/>, retrieved 1/27/2020.

Kimura, K.(2017). Feed-in Tariffs in Japan: Five Years of Achievements and Future Challenges. Renewable Energy Institute, Tokyo. Available at [https://www.renewable-ei.org/en/activities/reports/img/pdf/20170810/REI\\_Report\\_20170908\\_FIT5years\\_Web\\_EN.pdf](https://www.renewable-ei.org/en/activities/reports/img/pdf/20170810/REI_Report_20170908_FIT5years_Web_EN.pdf), retrieved 1/27/2020.

Kodaki, M. (2020). "Japan tightens entry of foreign investors in 12 strategic sectors: Space, rail and utilities among 400-plus companies covered by 1% prescreening rule." *Nikkei Asian Review*, 21 February 2020. Available at <https://asia.nikkei.com/Economy/Japan-tightens-entry-of-foreign-investors-in-12-strategic-sectors>, retrieved 3/5/2020.

Korean Electric Power Corporation (2019). Korea-China Power Grid Interconnection. Presentation at the 2019 NEARPIC Forum. Seoul, 10/24/2019. Available at: <https://www.unescap.org/sites/default/files/Session%201-2.%20KEPCO.pdf>, retrieved 10/8/2020.

Korean Peninsula Energy Development Organization (KEDO) (2020). About Us: Our History. Available at [http://www.kedo.org/au\\_history.asp](http://www.kedo.org/au_history.asp), retrieved 1/27/2020.

Korea Power Exchange (2020). Market Price Determination. Available at: <https://www.kpx.or.kr/eng/contents.do?key=302>, retrieved 10/8/2020.

Krutova M., A. Kies, B. U. Schyska and L. von Bremen (2017). The smoothing effect for renewable resources in an Afro-Eurasian power grid. In *Advances in Science and Research*, 14, 253-260, 2017.

Kwong, E. (2019). Mongolia's Capital Banned Coal to Fix Its Pollution Problem. Will It Work? National Public Radio (NPR), 30 July 2019. Available at <https://www.npr.org/2019/07/30/727688757/mongolias-capital-banned-coal-to-fix-its-pollution-problem-will-it-work?t=1573452340271&t=1580081481885>, retrieved 1/27/2020.

- Lee, K.-H. (2018). Korea's Renewable Energy 2020 Plan. Ministry of Trade, Industry and Energy (MOTIE), October 2018. Available at <http://gggi.org/site/assets/uploads/2018/10/Presentation-by-Mr.-Kyung-ho-Lee-Director-of-the-New-and-Renewable-Energy-Policy-Division-MOTIE.pdf>, retrieved 1/27/2020.
- Lienhardt, P. (2018). Strategy for North-East Asia Power System Interconnection (NAPSI). EDF technical assistance to Mongolia, ADB Project. Medium-term information on the project. NEA Symposium, EDF, Tokyo, 8 March 2018. Available at [https://www.renewable-ei.org/activities/events/img/20180308/Philippe\\_Lienhart\\_Session2.pdf](https://www.renewable-ei.org/activities/events/img/20180308/Philippe_Lienhart_Session2.pdf), retrieved 1/27/2020.
- Makowsky, P., J. Town and S. Pitz (2019). North Korea's Hydroelectric Power – Part II. *38 North*, 29 August 2019. Available at <https://www.38north.org/2019/08/hydropower082919/>, retrieved 1/27/2020.
- Ministry of Commerce, People's Republic of China (6/12/2018). China and Russia Sign the Memorandum of Understanding on E-commerce Cooperation. Available at <http://english.mofcom.gov.cn/article/newsrelease/significantnews/201806/20180602754949.shtml>, retrieved 1/27/2020.
- Ministry of Commerce, People's Republic of China (4/17/2019). The 15th Round of Negotiations of China-Japan-ROK FTA Held in Tokyo. Available at: [http://fta.mofcom.gov.cn/enarticle/chinarihen/chinarihennews/201904/40325\\_1.html](http://fta.mofcom.gov.cn/enarticle/chinarihen/chinarihennews/201904/40325_1.html), retrieved 10/8/2020.
- Ministry of Economy, Trade and Industry (2013). 再生可能エネルギーに関する ゾーニング基礎情報整備報告書. Ministry of Economy, Trade and Industry (METI). Available at <https://www.env.go.jp/earth/report/h25-03/full.pdf>, retrieved 1/27/2020.
- Ministry of Commerce, People's Republic of China (2018). China and Russia Sign the Memorandum of Understanding on E-commerce Cooperation. 12 June 2018. Available at <http://english.mofcom.gov.cn/article/newsrelease/significantnews/201806/20180602754949.shtml>, retrieved 1/27/2020.
- Ministry of Economy, Trade and Industry (METI) (2013). 再生可能エネルギーに関する ゾーニング基礎情報整備報告書. Available at <https://www.env.go.jp/earth/report/h25-03/full.pdf>, retrieved 1/27/2020.
- \_\_\_\_\_ (2015): Japan's Energy Plan. Available at [https://www.enecho.meti.go.jp/en/category/brochures/pdf/energy\\_plan\\_2015.pdf](https://www.enecho.meti.go.jp/en/category/brochures/pdf/energy_plan_2015.pdf), retrieved 1/27/2020.
- \_\_\_\_\_ (2016): F I T 制度見直しの詳細制度設計等 について, 資源エネルギー庁. Available at [https://www.meti.go.jp/shingikai/enecho/kihon\\_seisaku/saisei\\_kano/pdf/009\\_01\\_00.pdf](https://www.meti.go.jp/shingikai/enecho/kihon_seisaku/saisei_kano/pdf/009_01_00.pdf), retrieved 3/5/2020.
- Ministry of Economy, Trade and Industry (METI) (2018a). Strategic Energy Plan. Available at [https://www.enecho.meti.go.jp/en/category/others/basic\\_plan/5th/pdf/strategic\\_energy\\_plan.pdf](https://www.enecho.meti.go.jp/en/category/others/basic_plan/5th/pdf/strategic_energy_plan.pdf), retrieved 1/27/2020.
- Ministry of Economy, Trade and Industry (METI) (2018b). Japan's Energy 2018. 10 Questions for understanding the current energy situation. Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI). Available at [https://www.enecho.meti.go.jp/en/category/brochures/pdf/japan\\_energy\\_2018.pdf](https://www.enecho.meti.go.jp/en/category/brochures/pdf/japan_energy_2018.pdf), retrieved 1/27/2020.
- \_\_\_\_\_ (2019). 発電事業に係る届出義務について. 発電事業者一覧. Ministry of Economy, Trade and Industry (METI). Available at [https://www.enecho.meti.go.jp/category/electricity\\_and\\_gas/electricity\\_measures/004/list/](https://www.enecho.meti.go.jp/category/electricity_and_gas/electricity_measures/004/list/), retrieved 1/27/2020.
- \_\_\_\_\_ (2020). 電気事業制度の概要. 登録小売電気事業者一覧. Ministry of Economy, Trade and Industry (METI). Available at [https://www.enecho.meti.go.jp/category/electricity\\_and\\_gas/electric/summary/retailers\\_list/](https://www.enecho.meti.go.jp/category/electricity_and_gas/electric/summary/retailers_list/), retrieved 1/27/2020.
- Ministry of Trade, Industry and Energy (MOTIE) (2017). The 8 Basic Plan for Long-term Electricity Supply and Demand. 29 December 2017. Available at <https://www.kpx.or.kr/www/downloadBbsFile.do?atchmnfNo=30051>, retrieved 1/27/2020.
- Moon, D.-H. (2018). 평양 주민 “석탄 수출길 막혔는데 전력 사정은 좋아져” *Daily NK*, 5 September 2018. Available at <https://www.dailynk.com/%ED%8F%89%EC%96%91-%EC%A3%BC%EB%AF%BC-%EC%84%9D%ED%83%84-%EC%88%98%EC%B6%9C%EA%B8%B8-%EB%A7%89%ED%98%94%EB%8A%94%EB%8D%B0-%EC%A0%84%EB%A0%A5-%EC%82%AC%EC%A0%95%EC%9D%80-%EC%A2%8B%EC%95%84/>, retrieved 1/27/2020.
- National Development and Reform Commission/National Energy Administration (2017). 推动丝绸之路经济带和21世纪海上丝绸之路. 能源合作愿景与行动. May 2017. Available at: [http://www.nea.gov.cn/2017-05/12/c\\_136277473.htm](http://www.nea.gov.cn/2017-05/12/c_136277473.htm), retrieved 4/24/2020.
- Nikkei Asian Review (2019). Japan to overhaul renewable energy system in bid to lower prices. New competitive auction system aimed at reducing burden on consumers. 12 June 2019. Available at <https://asia.nikkei.com/Spotlight/Environment/Japan-to-overhaul-renewable-energy-system-in-bid-to-lower-prices>, retrieved 1/27/2020.
- Observatory of Economic Complexity (2020). Mongolia. Available at <https://oec.world/en/profile/country/mng/>, retrieved 1/26/2020.

Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) (2020). 本小委員会における議論の方向性と整理, 第 17 回需給調整市場検討小委員会資料 5. 12 July 2020. Available at [https://www.occto.or.jp/iinkai/chouseiryoku/jukyuchousei/2020/files/jukyu\\_shijyo\\_17\\_05.pdf](https://www.occto.or.jp/iinkai/chouseiryoku/jukyuchousei/2020/files/jukyu_shijyo_17_05.pdf), retrieved 9/28/2020

Organization for Economic Co-operation and Development (OECD) (2017). Air quality and health. Exposure to PM<sub>2.5</sub> fine particles - countries and regions. In Organization for Economic Co-operation and Development (OECD) (Ed.). *OECD Environment Statistics: OECD*. Available at [https://www.oecd-ilibrary.org/environment/data/air-quality-and-health/exposure-to-pm2-5-fine-particles-countries-and-regions\\_96171c76-en?parentId=http%3A%2F%2Finstance.metastore.ingenta.com%2Fcontent%2Fthematicgrouping%2Fbf1d73c2-en](https://www.oecd-ilibrary.org/environment/data/air-quality-and-health/exposure-to-pm2-5-fine-particles-countries-and-regions_96171c76-en?parentId=http%3A%2F%2Finstance.metastore.ingenta.com%2Fcontent%2Fthematicgrouping%2Fbf1d73c2-en), retrieved 1/27/2020.

Pastukhova, M. and K. Westphal (2020). "Governing the Global Energy Transition". In *The Geopolitics of the Global Energy Transition*, Lecture Notes in Energy 73, Springer Open, pp. 341-364.

Popel O. S. et al. (2015). *Atlas of renewable energy resources on the territory of Russia: scientific edition*. Moscow, D. I. Mendeleev Russian University of chemical technology.

REN21 (2019). Renewables 2019 Global Status Report. REN21 Secretariat, Paris. Available at [https://www.ren21.net/wp-content/uploads/2019/05/gsr\\_2019\\_full\\_report\\_en.pdf](https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf), retrieved 1/27/2020.

Reuters (2017). Shanghai to start opening power market in line with China reforms. 8 September 2017. Available at <https://www.reuters.com/article/us-china-power-reform/shanghai-to-start-opening-power-market-in-line-with-china-reforms-idUSKCN1BJOZM>, retrieved 1/27/2020.

Rosseti (2019). "Rosseti signed the Memo with Erdenes Mongol, the major state-owned company in Mongolia, on the sidelines of the official visit by Russian President Vladimir V. Putin to Mongolia", *Press Release*, 3 September 2019. Available at [http://www.rosseti.ru/eng/press/news/?ELEMENT\\_ID=35940](http://www.rosseti.ru/eng/press/news/?ELEMENT_ID=35940).

Ru-Stat (2020). Экспорт и импорт России по товарам и странам. Available at <https://ru-stat.com/date-Y2019-2019/RU/export/world>, retrieved 1/26/2020.

Sato, N. and S. Matsudaira (2018). Electricity Regulation in Japan. Nishimura & Asahi. Available at <https://www.lexology.com/library/detail.aspx?g=759793b4-ad15-4c15-a778-c47b06f71d84&g=759793b4-ad15-4c15-a778-c47b06f71d84>, retrieved 1/27/2020.

Savage, T. (2002). Introduction to the Special Issue. In *Asian Perspective* 26 (1), pp. 5-8. Available at <http://nautilus.org/wp-content/uploads/2015/01/Asian-Perspectives-DPRK-fulltext.pdf>, retrieved 1/27/2020.

Sergeev Institute of Environmental Geoscience (IEG RAS) (2015). Geothermal Energy Use in Russia. Country Update for 2010-2015. With assistance of V. Svalova and K. Povarov, World Geothermal Congress, Melbourne, 19-25 April 2015. Available at <https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01061.pdf>, retrieved 1/26/2020

Shell (2019). Energy Transition Report. Available at [https://www.shell.com/energy-and-innovation/the-energy-future/shell-energy-transition-report/\\_jcr\\_content/par/toptasks.stream/1524757699226/3f2ad7f01e2181c302cdc453c5642c77acb48ca3/web-shell-energy-transition-report.pdf](https://www.shell.com/energy-and-innovation/the-energy-future/shell-energy-transition-report/_jcr_content/par/toptasks.stream/1524757699226/3f2ad7f01e2181c302cdc453c5642c77acb48ca3/web-shell-energy-transition-report.pdf), retrieved 1/26/2020.

Soft Bank Group (2016). SoftBank Group Corp. Signs Joint Memorandum of Understanding with State Grid, KEPCO and ROSSETI to Cooperate on Research and Planning for Interconnected Power Grid Spanning North-East Asia. Beijing, 30 March 2016. Available at [https://group.softbank/en/corp/news/press/sb/2016/20160330\\_01/](https://group.softbank/en/corp/news/press/sb/2016/20160330_01/), retrieved 1/26/2020.

System Operator of the Unified Energy System (2019). Отчет о функционировании ЕЭС России в 2018 году. System Operator of the Unified Energy System (SO UES). Available at [https://so-ups.ru/fileadmin/files/company/reports/disclosure/2019/ups\\_rep2018.pdf](https://so-ups.ru/fileadmin/files/company/reports/disclosure/2019/ups_rep2018.pdf), retrieved 1/27/2020.

\_\_\_\_\_ (2020a). Единая энергетическая система России. Available at <https://so-ups.ru/index.php?id=ees>, retrieved 1/27/2020.

\_\_\_\_\_ (2020b). Объединенная энергосистема Сибири. Available at [https://so-ups.ru/index.php?id=oes\\_siberia](https://so-ups.ru/index.php?id=oes_siberia), retrieved 1/27/2020.

The Federation of Power Companies of Japan (2018). Electricity Review Japan. Available at [https://www.fepc.or.jp/library/pamphlet/pdf/04\\_electricity.pdf](https://www.fepc.or.jp/library/pamphlet/pdf/04_electricity.pdf), retrieved 1/27/2020.

Tumenjargal, M. (2018). Current Status and Progress in Mongolia for Power Interconnection. North-East Asian Regional Power Interconnection and Cooperation Forum 2018. Mongolian Energy Economics Institute, Ulaanbaatar, 31 October 2018. Available at <https://www.unescap.org/sites/default/files/Session%202-1.%20Mongolian%20Energy%20Economics%20Institute.pdf>, retrieved 1/27/2020.

United Nations Convention to Combat Desertification (2019). The Global Land Outlook, North-East Asia Thematic Report. Bonn, Germany. Available at <https://www.unccd.int/publications/global-land-outlook-North-East-asia-thematic-report-partnerships-achieve-land>.

UNFCCC (2015a). Submission of Japan's Intended Nationally Determined Contribution (INDC). Available at [https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/20150717\\_Japan%27s%20INDC.pdf](https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/20150717_Japan%27s%20INDC.pdf), retrieved 1/26/2020.

- \_\_\_\_\_ (2015b). Submission by the Republic of Korea: Intended Nationally Determined Contribution. 30 June 2015. Available at <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Republic%20of%20Korea%20First/INDC%20Submission%20by%20the%20Republic%20of%20Korea%20on%20June%2030.pdf>, retrieved 1/26/2020.
- \_\_\_\_\_ (2015c). Intended Nationally Determined Contribution (INDC) Submission by Mongolia to the Ad-Hoc Working Group on the Durban Platform for Enhanced Action (ADP). 24 September. Available at [https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mongolia%20First/150924\\_INDCCs%20of%20Mongolia.pdf](https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mongolia%20First/150924_INDCCs%20of%20Mongolia.pdf), retrieved 1/26/2020.
- United Nations Conference on Trade and Development (2013). Investment Policy Review. Mongolia. United Nations. Available at [https://unctad.org/en/PublicationsLibrary/diaepcb2013d3\\_en.pdf](https://unctad.org/en/PublicationsLibrary/diaepcb2013d3_en.pdf), retrieved 1/27/2020.
- United Nations General Assembly (UNGA) (2017). Resolution adopted by the General Assembly on 6 July 2017. Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development. A/RES/71/313 (A/RES/71/313). Available at [http://ggim.un.org/documents/A\\_RES\\_71\\_313.pdf](http://ggim.un.org/documents/A_RES_71_313.pdf), retrieved 1/27/2020.
- US Energy Information Administration (EIA) (2020). Geothermal explained: Where geothermal energy is found. Available at <https://www.eia.gov/energyexplained/geothermal/where-geothermal-energy-is-found.php>, retrieved 1/26/2020.
- \_\_\_\_\_ (2018). South Korea. Available at <https://www.eia.gov/international/analysis/country/KOR>, retrieved 1/26/2020.
- Wind Energy and Electric Vehicle Magazine (REVE) (2019). Photovoltaic capacity increased to 505 GW. 21 June 2019. Available at <https://www.evwind.es/2019/06/21/photovoltaic-cumulative-capacity-increased-approximately-25-to-at-least-505-gw/67686>, retrieved 1/27/2020.
- World Bank (WB) (2013). Mongolia: Portable Solar Power for Nomadic Herders. Available at <https://www.worldbank.org/en/results/2013/04/08/portable-solar-power-for-nomadic-herders>, retrieved 1/27/2020.
- \_\_\_\_\_ (2014). Project Appraisal Document for a Central Asia South Asia Electricity Transmission and Trade Project (CASA-1000). Document of the World Bank. 7 March 2014. Available at: <http://documents.worldbank.org/curated/en/283351468170975849/pdf/832500PAD0P145010Box382156B00OU090.pdf>, retrieved 4/23/2020.
- World Economic Forum (2017). The Future of Electricity. New Technologies Transforming the Grid Edge. With assistance of Bain & Company. World Economic Forum (WEF), Geneva, Switzerland. Available at [http://www3.weforum.org/docs/WEF\\_Future\\_of\\_Electricity\\_2017.pdf](http://www3.weforum.org/docs/WEF_Future_of_Electricity_2017.pdf), retrieved 1/27/2020.
- World Energy Council (2015). New Report: Hydropower's big surge - set to double by 2050. Available at <https://www.worldenergy.org/news-views/entry/new-report-hydropower-as-big-surge-set-to-double-by-2050>, retrieved 1/26/2020.
- World Health Organization (2019). Air pollution in Mongolia. In *Bulletin of the World Health Organization* 97 (2), pp. 79–80. DOI: 10.2471/BLT.19.020219.
- Yi, J. and C. P. Park (2018). Electricity Regulation in South Korea. Bae, Kim & Lee LLC. Available at <https://www.lexology.com/library/detail.aspx?g=4a7f6594-b6b4-4249-a928-a0e02ed683e5>, retrieved 1/27/2020.
- Yoon, J. (2011). The DPRK Power Sector: Data and Interconnection Options. Nautilus Institute (NAPSNET Special Report). Available at <https://nautilus.org/napsnet/napsnet-special-reports/the-dprk-power-sector-data-and-interconnection-options/>, retrieved 1/27/2020.
- Zhikharev, A., N. Posypanko and A. Kim (2018). Russian Far East: Subsidies or Development. Vygon Consulting. Available at [https://vygon.consulting/upload/iblock/411/vygon\\_consulting\\_dfo\\_energy\\_en\\_executive\\_summary.pdf](https://vygon.consulting/upload/iblock/411/vygon_consulting_dfo_energy_en_executive_summary.pdf), retrieved 1/27/2020.
- Zwirko, C. (2019). "Russia continuing talks on reconstruction and repair of North Korean power grid". *NK NEWS*, 9 December 2020. Available at: <https://www.nknews.org/2019/12/russia-continuing-talks-on-reconstruction-and-repair-of-north-korean-power-grid/>, retrieved 4/24/2020.

## Literature review (sources)

- Aalto, P. (2014). Energy market integration and regional institutions in east Asia. In *Energy Policy* 74, pp. 91-100. DOI: 10.1016/j.enpol.2014.08.021.
- Ahn, J., J.R. Woo, and J. Lee (2015). Optimal allocation of energy sources for sustainable development in South Korea: Focus on the electric power generation industry. In *Energy Policy* 78, pp. 78-90. DOI: 10.1016/j.enpol.2014.12.023.
- Akaha, T. (2002). Non-traditional security issues in northeast Asia and prospects for international cooperation. Prepared for presentation at "Thinking Outside the Security Box: Non-traditional Security in Asia: Governance, Globalization, and the Environment," United Nations University Seminar, United Nations, New York, March 15, 2002. United Nations University. New York, 3/15/2002. Available at <https://pdfs.semanticscholar.org/dfaf/51258d77aedf19907ad3ad83a4834d2acfbba.pdf>.

- Asian Development Bank (ADB)/ Électricité de France (EDF) (2019). Mongolia: Strategy for North-East Asia Power System Interconnection. Final Draft. Technical Assistance Consultant's Report, ADB Project Nr 48030-001.
- Batbayar C. (2015). The Role of Mongolia For Development of North-East Asian Super Grid. Ministry of Energy, Government of Mongolia. Seoul, 17 December 2015. Available at <https://www.unescap.org/sites/default/files/Session%203-4%20Batbayar%20Chadraa.pdf>.
- Bat-Erdene B., S. Batmunkh and A. Erdenebaatar (2018). Development of Mongolia's Electric Power Industry and its Role in Shaping the North-East Asian Super Grid. In *Energy Systems Research*, 1-4, 2018, pp. 15-26.
- Belyaev, L. S., L. Yu. Chudinova, O.V. Marchenko, S. V. Podkovalnikov and V.A. Savelyev (Eds.) (2006). Study on the Economic Effectiveness of ISETs "Siberia-China". International Conference on Energy Cooperation in Asia, Irkutsk. Available at <http://isem.irk.ru/AEC-2008/proc2006/21.pdf>.
- Belyaev, L. S., L. Yu. Chudinova, O. V. Khamisov, G. F. Kovalev, L.M. Lebedeva, S. V. Podkovalnikov and V. A. Savelyev (2002). Studies of interstate electric ties in North-East Asia. In *IJGEI* 17 (3), p. 228. DOI: 10.1504/IJGEI.2002.000942.
- Belyaev, L.S., G. F. Kovalev, L. M. Lebedeva and S.V. Podkovalnikov (1994). "Efficiency Assessment of Interstate Electric Ties in the North-East Asia". In *Proceedings of 4th International Symposium on the World Energy System*, Budapest, October 5 - 8, 1994, pp.131-138.
- Belyaev, L.S., G. F. Kovalev, L. M. Lebedeva and S.V. Podkovalnikov (1995). "Ties in North-East Asia". In *Perspectives in Energy*, 1994 -1995, vol. 3, pp. 321-330.
- Belyaev, L.S. and S.V. Podkovalnikov (2007). Possible Options of Financing Interstate Electric Ties in North-East Asia and Assessment of their Effectiveness in a Competitive Market Environment. In Voropal, N.I. and D. N. Efimov (Eds.). *Asian Energy Cooperation: Mechanisms, Risks, Barriers* (AEC-2006). Proceedings of International Conference (June 27-29, 2006). Irkutsk, pp. 126–134. Available at <http://isem.irk.ru/AEC-2008/proc2006/19.pdf>.
- Biswas N. B. (2010). Estimating Demand for Infrastructure in Energy, Transport, Telecommunications, Water, and Sanitation in Asia and the Pacific. 2010-2020. In *SSRN Journal*. DOI: 10.2139/ssrn.1678417.
- \_\_\_\_\_ (2012). Institutions for Asian Connectivity. In *J. Intl Econ. Comm. Policy*. 01 (02), pp. 309–335. DOI: 10.1142/S1793993310000172.
- Blakers, A., J. Luther and A. Nadolny (2012). Asia Pacific Super Grid – Solar electricity generation, storage and distribution. In *GREEN* 2 (4). DOI: 10.1515/green-2012-0013.
- Bogdanov, D. and C. Breyer (2016). North-East Asian Super Grid for 100% renewable energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options. In *Energy Conversion and Management* 112, pp. 176–190. DOI: 10.1016/j.enconman.2016.01.019.
- Borgford-Parnell, N. (2011). Synergies of scale: A vision of Mongolia and China's common energy future. In *Energy Policy* 39 (5), pp. 2764-2771. Available at <https://www.sciencedirect.com/science/article/pii/S0301421511001364>, retrieved 9/4/2019.
- Bradbrook, A. J. (2002). Electric Power Interconnection in North-East Asia: Towards a North-East Asian Energy Charter? In *Journal of Energy & Natural Resources Law* 20 (2), pp. 135–143. DOI: 10.1080/02646811.2002.11433291.
- Breyer, C., D. Bogdanov, K. Komoto, T. Ehara, Tomoki, J. Song and N. Enebish (2015). North-East Asian Super Grid: Renewable energy mix and economics. In *Jpn. J. Appl. Phys.* 54 (8S1), 08KJ01. DOI: 10.7567/JJAP.54.08KJ01.
- Cha, J., J. Park and J. Choi (2008). Reliability Evaluation for Interconnection Planning in North East Asia. In *2008 3rd International Conference on Innovative Computing Information and Control*, 2008, Dalian, Liaoning, China, 6/18/2008 - 6/20/2008: IEEE, p. 136.
- Chang, Y.-C., T. Zhai and S. Li (2020). China–Japan–Korea free trade agreement and legal issues regarding the construction of the North-East Asia energy interconnection. In *Journal of Renewable Sustainable Energy*, 12, 045901 (2020).
- Chen, Y., G. Gönül and M. Tumenjargal (2016). Mongolia: renewables readiness assessment. IRENA. Available at [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA\\_RRA\\_Mongolia\\_2016.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_RRA_Mongolia_2016.pdf).
- Choi, J. S., T. Tran, J. J. Kwon, D. W. Park, J. Y. Yoon, S. I. Moon et al. (2006). Probabilistic Reliability Based Tie Line Capacity for Interconnecting Power Systems of South Korea, North Korea and Far East Russia. In *2006 International Conference on Probabilistic Methods Applied to Power Systems*, Stockholm, Sweden, 6/11/2006 - 6/15/2006: IEEE, pp. 1–5.
- Choo, J. (2006). Energy cooperation problems in North-East Asia. Unfolding the reality. In *East Asia* 23 (3), pp. 91–106. DOI: 10.1007/s12140-006-0012-3.
- Chudinova, L. Yu., S. V. Podkovalnikov and I. L. Trofimov (2018). Multilateral cooperation for power interconnection in North-East Asia. In *E3S Web Conf.* 27, p. 1001. DOI: 10.1051/e3sconf/20182701001.
- Chung, K.-H., B.-H. Kim (2007). Economic Feasibility on the Interconnected Electric Power Systems in North-East Asia. In *Journal of Electrical Engineering and Technology* 2 (4), pp. 452–460. DOI: 10.5370/JEET.2007.2.4.452.

- Churkin, A., D. Pozo, J. Bialek, N. Korgin and E. Sauma (2019). Can cross-border transmission expansion lead to fair and stable cooperation? North-East Asia case analysis. In *Energy Economics*, p. 104498. DOI: 10.1016/j.eneco.2019.104498.
- Cooper, C. and B. K. Sovacool (2013). Miracle or mirage? The promise and peril of desert energy part 1 and part 2. In *Renewable Energy* 50, pp. 628–636 and 820–825. DOI: 10.1016/j.renene.2012.07.027. and DOI: 10.1016/j.renene.2012.07.039.
- Dai, Q., S. Zhao, Q. Zhou, J. Wu and C. Gao (2018). The Transmission Technology Maturity Assessment and its Effect on the Asia Power Grids Interconnection Development Patterns. In : 2018 International Conference on Power System Technology (POWERCON). 2018 International Conference on Power System Technology (POWERCON). Guangzhou, 11/6/2018 - 11/8/2018: IEEE, pp. 101–108.
- Ding, T., R. Lu, Y. Xu, Q. Yang, Y. Zhou, Y. Zhang and Y. Wen (2020). Joint electricity and carbon market for Northeast Asia energy interconnection. In *Global Energy Interconnection*, Vol. 3 Nr. 2, April 2020, pp. 99–110.
- Energy Charter, Energy Economics Institute of the Republic of Korea, Energy Systems Institute, Siberian Branch of Russian Academy of Sciences, Ministry of Energy, Government of Mongolia, Japan Renewable Energy Foundation (2014). Gobitec and the Asian Supergrid for Renewable Energy Sources in Northeast Asia. Energy Charter (978-905948-144-2). Available at [https://energycharter.org/fileadmin/DocumentsMedia/Thematic/Gobitec\\_and\\_the\\_Asian\\_Supergrid\\_2014\\_en.pdf](https://energycharter.org/fileadmin/DocumentsMedia/Thematic/Gobitec_and_the_Asian_Supergrid_2014_en.pdf).
- Fallon, K. S. (2006). Promoting an Energy Partnership in Northeast Asia. In *Pacific Focus* 21 (1), pp. 175–200. DOI: 10.1111/j.1976-5118.2006.tb00317.x.
- Fan, J., X. Wang, Q. Huang, X. Zhang, Y. Li, P. Zeng (2019). Power grid interconnection with HVDC link in Northeast Asia considering complementarity of renewable energy and time zone difference. In *The Journal of Engineering* 2019 (16), pp. 1625–1629. DOI: 10.1049/joe.2018.8851.
- Frick, M. and M. Thioye (2018). Global Electricity Interconnection. Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300744>, retrieved 9/2/2019.
- Gavin, B. and S. Lee (2008). Energy security through regional collaboration: the case of North East Asia. In *Energy Security Insights* 3 (2), pp. 2–6. Available at [http://bookstore.teri.res.in/docs/newsletters/ESI%203\(2\)%20July%202008.pdf](http://bookstore.teri.res.in/docs/newsletters/ESI%203(2)%20July%202008.pdf).
- GEIDCO (2018). Northeast Asia Energy Interconnection. Global Energy Interconnection Development and Cooperation Organization. October 2018.
- Georg Kell (2018). GEI—An idea whose time has come. In *Global Energy Interconnection* 1 (1), pp. 1–3. Available at <https://www.sciencedirect.com/science/article/pii/S209651171830015X>, retrieved 9/10/2019.
- Giri, J. (2019). Data and modeling requirements for electricity grid interconnections. Nautilus Institute (NAPSNET Special Report). Available at <http://www.nautilus.org/wp-content/uploads/2019/05/Jay-Giri-RES-Regional-Grid-NAPSNet-Special-Report-May9-2019.pdf>.
- Hammons, T. J. (Ed.) (2011). *Electricity Infrastructures in the Global Marketplace*. 1st ed. Rijeka: InTech.
- von Hippel, D. (2001). Estimated costs and benefits of power grid interconnections in Northeast Asia. Based on a presentation prepared for Northeast Asia Grid Interconnection Workshop. Nautilus Institute. Beijing. Available at <http://nautilus.org/wp-content/uploads/2011/12/dvh.pdf>.
- von Hippel, D. and P. Hayes (2008). Growth in energy needs in Northeast Asia: Projections, consequences and opportunities. Nautilus Institute. Available at <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.826.4729&rep=rep1&type=pdf>.
- von Hippel, D., T. Suzuki, J. H. Williams, T. Savage and P. Hayes (2011). Energy security and sustainability in Northeast Asia | Elsevier Enhanced Reader. In *Energy Policy* 39, pp. 6719–6730. Available at <https://reader.elsevier.com/reader/sd/pii/S0301421509005138?token=0C9C295A88ABB1D530311AB77489FBBF8FD212A8CE9A58613BFE65DEFFBA044A28040279C758EA2B840EDC635BE1A604>, retrieved 9/2/2019.
- von Hippel, D., R. Gulidov, V. Kalashnikov and P. Hayes, Peter (2011). Northeast Asia regional energy infrastructure proposals. In *Energy Policy* 39 (11), pp. 6855–6866. DOI: 10.1016/j.enpol.2009.08.011.
- Hou, Y., Z. Bie, Z., T. Ding and S. Liu (2018). Long-Term Cross-border Electricity Trading Considering the Uncertainty of Wind Power. In *2018 International Conference on Power System Technology (POWERCON)*. 2018 International Conference on Power System Technology (POWERCON). Guangzhou, 11/6/2018 - 11/8/2018: IEEE, pp. 788–793.
- Ichimura, S. and R. Omatsu (2019). Route designs and cost estimation for Japan-Russia and Japan-South Korea interconnection. In *Global Energy Interconnection*, Vol. 2 Nr. 2, April 2019, pp. 133–42.
- International Electrotechnical Commission (2016). Global energy interconnection. White paper. Geneva, Switzerland: International Electrotechnical Commission.

Jin, X., Y. Zhang, W. Dong and L. Munuera (2018). Analysis of the contribution of large-scale interconnection to greenhouse gas emission reduction in Northeast Asia. In *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*. 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2). Beijing, 10/20/2018 - 10/22/2018: IEEE, pp. 1-5.

Ivanov, V. I. and E. Oguma (2002). Energy Security and Sustainable Development in Northeast Asia: Prospects for Cooperative Policies. International Workshop held in Khabarovsk, September 17-19, 2002. The Economic Research Institute for Northeast Asia (ERINA). Niigata. Available at <https://www.erina.or.jp/en/wp-content/uploads/2014/11/Report2002-1.pdf>.

Kalashnikov, V. D. (1997). Electric Power Industry of the Russian Far East: Status and Prerequisites for Cooperation in North-East Asia. Far Eastern Branch of Russian Academy of Sciences. Hawaii. Available at <http://www.nautilus.org/wp-content/uploads/2015/06/KalashnikovPARES.pdf>.

Kanagawa, M. and T. Nakata (2006). Analysis of the impact of electricity grid interconnection between Korea and Japan—Feasibility study for energy network in Northeast Asia. In *Energy Policy* 34 (9), pp. 1015-1025. DOI: 10.1016/j.enpol.2004.10.003.

Kawai, M. (2013). Financing Development Cooperation in Northeast Asia. In *SSRN Journal*. DOI: 10.2139/ssrn.2220071.

Kazutomo, I. (2019). APEC Energy Demand and Supply Outlook. Asia Pacific Research Center (APERC). Tokyo, 6/19/2019. Available at [https://www.rieti.go.jp/jp/events/bbl/19061901\\_irie.pdf](https://www.rieti.go.jp/jp/events/bbl/19061901_irie.pdf).

Khamisov, O. V. and S. V. Podkovalnikov (2018). Shadow Price Analysis of Potential Northeast Asia Power System Interconnection. In : *2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*. 2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC). Kota Kinabalu, 10/7/2018 - 10/10/2018: IEEE, pp. 606-610.

Kim, J.-H. (2020). *Governance Building and Implications of Northeast Asia Power System Integration*. August 2020, Sejong University.

Kim, Y. H., S. T. Cha, T. K. Kim and J. B. Choo (2004). Fundamental Study of Power System Interconnections in Northeast Asia. In N. I. Voropai (Ed.), *AEC - 2004. Asian energy cooperation interstate infrastructure and energy markets proceedings of the 4-th International Conference*, Irkutsk, Russia, September 13-17, 2004. Irkutsk: Energy Systems Institute, pp. 74-83, retrieved <http://isem.irk.ru/AEC-2008/proc2004/9.pdf>.

Kimura, S. and S. Ichimura (2019). Cost-profit analysis for Japan-Russia and Japan-South Korea interconnectors. In *Global Energy Interconnection*, Vol. 2 Nr. 2, April 2019, pp. 114-21.

Komoto, K., N. Enebish and J. Song (2013). Very large-scale PV systems for North-East Asia: Preliminary project proposals for VLS-PV in the mongolian gobi desert. In *2013 IEEE 39th Photovoltaic Specialists Conference (PVSC)*. 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC). Tampa, FL, USA, 6/16/2013 - 6/21/2013: IEEE, pp. 2376-2379.

Korneev, K. and A. Korneev (2019). Institutions of international energy cooperation in North-East Asia region. In *E3S Web Conf.* 77, p. 1004. DOI: 10.1051/e3sconf/20197701004.

Korneev, K., D. Maksakova and S. Popov (2018). Institutional Issues of International Power Grid Development in Northeast Asia. In *E3S Web Conf.* 27, p. 1002. DOI: 10.1051/e3sconf/20182701002.

Koshcheev, L. A. (2002). Basic Principles of Interstate Electrical Power Links Organization in Northeast Asia. Nautilus Institute. Available at [https://www.researchgate.net/publication/266472350\\_BASIC\\_PRINCIPLES\\_OF\\_INTERSTATE\\_ELECTRICAL\\_POWER\\_LINKS\\_ORGANIZATION\\_IN\\_NORTHEAST\\_ASIA\\_REGION](https://www.researchgate.net/publication/266472350_BASIC_PRINCIPLES_OF_INTERSTATE_ELECTRICAL_POWER_LINKS_ORGANIZATION_IN_NORTHEAST_ASIA_REGION).

\_\_\_\_\_ (2003). Environmental characteristics of HVDC overhead transmission lines. High Voltage Direct Current Power Transmission Research Institute. Third Workshop on Power Grid Interconnection in North-East Asia,. Available at [http://www.nautilus.org/wp-content/uploads/2012/01/Koshcheev\\_paper\\_final1.pdf](http://www.nautilus.org/wp-content/uploads/2012/01/Koshcheev_paper_final1.pdf).

Kunstyr, J. and S. Mano (2013). Energy Security and Cross-Border Electricity Trade: Can the Asian Super Grid project pose security risks for Japan? Renewable Energy Institute. Tokyo. Available at [https://www.renewable-ei.org/en/activities/reports\\_20140130.php](https://www.renewable-ei.org/en/activities/reports_20140130.php).

Lee, J.-S. (2013). Towards green energy cooperation in Northeast Asia: implications from European experiences. In *AEJ* 11 (3), pp. 231-245. DOI: 10.1007/s10308-013-0359-1.

Lee, J.-S. and J. Yu (2012). North-East Asian Perspectives on the Challenges to Energy Security and the Sustainable Use of Energy. North-East Asia Sub-regional Consultation Meeting for the Asia-Pacific Energy Forum. UNESCAP. Incheon, 11/12/2012. Available at [https://www.unescap.org/sites/default/files/Session2\\_Jae-Seung\\_Lee.pdf](https://www.unescap.org/sites/default/files/Session2_Jae-Seung_Lee.pdf).

Lee, S. S., J. K. Park and S. I. Moon (2003). Power system interconnection scenario and analysis between Korean peninsula and Japan. In *2003 IEEE Power Engineering Society General Meeting (IEEE Cat. No.03CH37491)*. 2003 IEEE Power Engineering Society General Meeting. Toronto, Ont., Canada, 13-17 July 2003: IEEE, pp. 1455-1460.

- Lee, S. S., Y.-S. Jang, S.-H. Ahn, G.-P. Park, J.-K. Park and Y. T. Yoon (2012). Northeast Asia Interconnection-based integration of DG, DR, HVDC, and nuclear load-following under Smart Grid in the South Korean power system. In *2012 IEEE Power and Energy Society General Meeting. 2012 IEEE Power & Energy Society General Meeting*. New Energy Horizons - Opportunities and Challenges. San Diego, CA, 7/22/2012 - 7/26/2012: IEEE, pp. 1-7.
- Lee, S. S., Y.-S. Jang, G.-P. Park, J.-H. Park, Y.-C. Kim and J.-K. Park (2011). Northeast Asia interconnection and virtual power system simulator design. In *2011 IEEE Power and Energy Society General Meeting. 2011 IEEE Power & Energy Society General Meeting*. San Diego, CA, 7/24/2011 - 7/29/2011: IEEE, pp. 1-6.
- Lee, S. S., Y.-C. Kim, J.-K. Han, J.-K. Park, S.-H. Lee, M. Osawa, S.-I. Moon and Y.-T. Yoon (2007a). Northeast Asia Power Interconnection and Transmission Route Strategy in South Korea. In *2007 IEEE Power Engineering Society General Meeting. 2007 IEEE Power Engineering Society General Meeting*. Tampa, FL, USA, 6/24/2007 - 6/28/2007: IEEE, pp. 1-6.
- \_\_\_\_\_ (2007b). Northeast Asia Power Interconnection Studies; Trends and Prospects in South Korea. In *2007 IEEE Power Engineering Society General Meeting. 2007 IEEE Power Engineering Society General Meeting*. Tampa, FL, USA, 6/24/2007 - 6/28/2007: IEEE, pp. 1-6.
- \_\_\_\_\_ (2007c). Northeast Asia Power Interconnection Routs and Representative Studies in South Korea. In : *2007 IEEE Lausanne Power Tech. 2007 IEEE Power Tech. Lausanne, Switzerland, 7/1/2007 - 7/5/2007: IEEE, pp. 1893-1898.*
- \_\_\_\_\_ (2008). Power flow study and regional market on the way to Northeast Asia power interconnection. In *2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*. Energy Society General Meeting. Pittsburgh, PA, USA, 20.07.2008 - 24.07.2008: IEEE, pp. 1-6.
- Lee, S. S., J.-K. Park, S.-I. Moon, J.-F. Moon, J.-C. Kim, S.-K. Kim and H.-Y. Kim (2004). North-East Asia interconnection scenario map, and power reserve strategy in South Korea. In *IEEE Power Engineering Society General Meeting, 2004. 2004 IEEE Power Engineering Society General Meeting*. Denver, CO, USA, 6-10 June 2004: IEEE, pp. 1333-1338.
- Lee, S. S., J.-K. Park, S.-I. Moon and Y.-T. Yoon (2005). Northeast Asia interconnection, and power flow considering seasonal load patterns. In *IEEE Power Engineering Society General Meeting, 2005. IEEE Power Engineering Society General Meeting, 2005*. San Francisco, CA, USA, June 12-16, 2005: IEEE, pp. 694-699.
- \_\_\_\_\_ (2006). Northeast Asia interconnection, and technical & market considerations. In *2006 IEEE Power Engineering Society General Meeting. 2006 IEEE Power Engineering Society General Meeting*. Montreal, Que., Canada, 6/18/2006 - 6/22/2006: IEEE, 6 pp.
- Lee, S. S., M.-U. Yang, K.-J. Kim, Y.-T. Yoon, S.-I. Moon, J.-K. Park (2013). Northeast Asia power system interconnection and smart grid operation strategies in South Korea. In *2013 IEEE Power & Energy Society General Meeting. 2013 IEEE Power & Energy Society General Meeting*. Vancouver, BC, 7/21/2013 - 7/25/2013: IEEE, pp. 1-5.
- Li, J. and S. Jiang (2018). Global Energy Interconnection: an effective solution to climate challenges. In *Global Energy Interconnection 1* (4), pp. 406-408. Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300756>, retrieved 9/2/2019.
- Li, P., Y. Huang, W. Wang, L. Zhang, S. Li and L. Balzari (2017). Optimization of continental power exchange under the framework of global energy interconnection. In *2017 IEEE Conference on Energy Internet and Energy System Integration (EI2). 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2)*. Beijing, 11/26/2017 - 11/28/2017: IEEE, pp. 1-6.
- Li, Y and S. Kimura (2016). Study on Power Grid Interconnection and Electricity Trading in Northeast Asia. ERIA. Available at [http://www.eria.org/RPR\\_FY2015\\_09.pdf](http://www.eria.org/RPR_FY2015_09.pdf).
- Liu, Z.(2015). Global energy interconnection. Amsterdam: Elsevier/AP.
- Liu, Z., G. Chen, X. Guan, Q. Wang and W. He (2016). A concept discussion on Northeast Asia power grid interconnection. In *CSEE JPES 2* (4), pp. 87-93. DOI: 10.17775/CSEEJPES.2016.00053.
- Neuhoff, K. (2012). Economic consideration for international electricity interconnection in North-East Asia. University of Cambridge. Available at <http://www.nautilus.org/wp-content/uploads/2012/01/neuhoff.pdf>.
- Ongsakul, W., K. Teng, S. Marichez and H. Jiang (2018). An innovation idea for energy transition towards sustainable and resilient societies: Global energy interconnection. In *Global energy interconnection, 1* (3), pp. 312-318. Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300422>, retrieved 9/2/2019.
- Otsuki, T. (2015). Electric power grid interconnections in northeast Asia. A quantitative analysis of economic and environmental benefits. With assistance of R. D. Samuelson, Aishah Binti Mohd Isa, D. Sokolov, B.T. Liddle. APERC/IEEJ. Tokyo.
- \_\_\_\_\_ (2017a). Analysis on cost-optimal Deployment of Variable Renewables and Grid Interconnection in Northeast Asia. In *Tokyo Journal of Japan Society of Energy and Resources* Vol.38, No.5, (2017, in Japanese, [https://doi.org/10.24778/jjser.38.5\\_9](https://doi.org/10.24778/jjser.38.5_9)) Translated version available at: [https://aperc.ieej.or.jp/publications/papers/journal\\_articles/7664.pdf](https://aperc.ieej.or.jp/publications/papers/journal_articles/7664.pdf), retrieved 3/5/2020.

- \_\_\_\_\_ (2017b). Costs and benefits of large-scale deployment of wind turbines and solar PV in Mongolia for international power exports. In *Renewable Energy* 108, pp. 321-335. Available at <https://www.sciencedirect.com/science/article/pii/S0960148117300964>, retrieved 9/4/2019.
- Otsuki, T., A. B. M. Isa; R. D. Samuelson (2016). Electric power grid interconnections in Northeast Asia\_ A quantitative analysis of opportunities and challenges | Elsevier Enhanced Reader. In *Energy Policy* 89, pp. 311-329. Available at <https://reader.elsevier.com/reader/sd/pii/S0301421515301993?token=F5F69565586A5CB98D2FF15D5BD92D44BF572FB1ADA8A654E86643E0912E9B65823DE8E450056C3EF3296DF6DD2D72DE>, retrieved 9/2/2019.
- Park, D. W., H. Y. Kim, J. Y. Yoon, N. I. Voropai, L. S. Belyaev and S. V. Podkovalnikov (2004). Analysis of Scenarios for Potential Power System Interconnections in Northeast Asia. In N. I. Voropai (Ed.), *AEC - 2004. Asian energy cooperation interstate infrastructure and energy markets proceedings of the 4-th International Conference*, Irkutsk, Russia, 13-17 September 2004. Irkutsk: Energy Systems Institute.
- Park, J., T. Oh, K. Cho, J. Choi, S.-S. Lee, J. Watada and A. A. El-Keib (2012). Reliability evaluation of interconnected power systems including wind turbine generators. In *International Journal of Innovative Computing, Information and Control* 8 (8), pp. 5797-5808. Available at <http://www.ijicic.org/isme10-17.pdf>.
- Podkovalnikov, S. V. (2002). Study for Russia, Democratic People's Republic of Korea, Republic of Korea and China Power Interconnection: Analysis of Current Status. Energy Systems Institute, Siberian Branch of Russian Academy of Sciences. Irkutsk. Available at [http://www.nautilus.org/wp-content/uploads/2011/12/Podkovalnikov\\_0206171.pdf](http://www.nautilus.org/wp-content/uploads/2011/12/Podkovalnikov_0206171.pdf).
- \_\_\_\_\_ (2011). Power Grid Interconnection in Northeast Asia: Perspectives from East Russia. Energy Systems Institute, Siberian Branch of Russian Academy of Sciences.
- Podkovalnikov, S. V. V.A. Savelev and L.Yu. Chudinova (2015). Prospects of electric-energy cooperation between Russia and northeast Asian countries. In *Stud. Russ. Econ. Dev.* 26 (4), pp. 403-412. DOI: 10.1134/S1075700715040085.
- Podkovalnikov, S. V. V.A. Savelev, O.V. Khamisov and L.Yu. Chudinova (2018). Justification of Effectiveness of International Power Interconnections with Separation of Effects between Participants. In *Autom Remote Control* 79 (10), pp. 1756-1766. DOI: 10.1134/S0005117918100028.
- Podkovalnikov, S.V and L. Yu. Chudinova (2020). Renewables expansion in Northeast Asian power grid. In *Conference Proceedings, ENERGY-21: Sustainable Development & Smart Management. International conference*. September 7-11, 2020, Irkutsk, Russia. Melentiev Energy Systems Institute SB RAS.
- Rafique, S. F., P. Shen, Z. Wang, R. Rafique, T. Iqbal, S. Ijaz and U. Javaid (2018). Global power grid interconnection for sustainable growth: concept, project and research direction. In *IET Generation, Transmission & Distribution* 12 (13), pp. 3114-3123. DOI: 10.1049/iet-gtd.2017.1536.
- Renewable Energy Institute (2017). Asia International Grid Connection Study Group Interim Report. Renewable Energy Institute.
- \_\_\_\_\_ (2018). Asia International Grid Connection Study Group Second Report. Renewable Energy Institute. Available at [https://www.renewable-ei.org/pdfdownload/activities/REI\\_ASG\\_SecondReport\\_EN.pdf](https://www.renewable-ei.org/pdfdownload/activities/REI_ASG_SecondReport_EN.pdf).
- \_\_\_\_\_ (2019). Asia International Grid Connection Study Group Third Report. Renewable Energy Institute. Available at <https://www.renewable-ei.org/en/activities/reports/20191023.php>.
- Sevastyanov, S. (2008). The More Assertive and Pragmatic New Energy Policy in Putin's Russia. Security Implications for Northeast Asia. In *East Asia* 25 (1), pp. 35-55. DOI: 10.1007/s12140-008-9040-5.
- Sikow-Magny, C. and N. Vasilakos (2018). Enhancing the public acceptance of cross border electricity interconnection projects. Crucial step in the EU energy transition process. Florence: EUI (Robert Schuman Centre for Advanced Studies Policy Briefs, Issue 2018/06, May 2018).
- Song, J. (2014). Super Grid in North-East Asia through Renewable Energy. In *Tech Monitor* Jan-Mar. Available at [http://www.techmonitor.net/tm/images/2/2d/14jan\\_mar\\_sf3.pdf](http://www.techmonitor.net/tm/images/2/2d/14jan_mar_sf3.pdf).
- Sovacool, B. and C. J. Cooper (2013). *The Governance of Energy Megaprojects: Politics, Hubris and Energy Security*. Edward Elgar Publishing, 2013.
- Streets, D. G. (2001). Environmental Aspects of Electricity Grid Interconnection in Northeast Asia. *Workshop on Power Grid Interconnection in Northeast Asia*. Beijing, 5/14/2001. Available at <http://oldsite.nautilus.org/archives/energy/grid/materials/streets.pdf>. Streets, David. G. (2003). Environmental benefits of electricity grid interconnections in Northeast Asia. In *Energy* 28 (8), pp. 789-807. DOI: 10.1016/S0360-5442(03)00030-6.
- Streets, D. G., G. R. Carmichael, M. Amann, R. L. Arndt (1999). Energy Consumption and Acid Deposition in Northeast Asia. In *Ambio* 28 (2), pp. 135-143.
- Taggart, S., G. James, Z.-Y. Dong and C. Russell (2012). The Future of Renewables Linked by a Transnational Asian Grid. In *Proc. IEEE* 100 (2), pp. 348-359. DOI: 10.1109/JPROC.2011.2159089.

- Trofimov, I. L. (2020). Optimization of capacities of wind and solar powerplants in the interstate power grid in North-East Asia, considering the intermittence of their power output. In *Energy Systems Research*, 3-2. Melentiev Energy Systems Institute SB RAS.
- van de Graaf, T. and B. K. Sovacool (2014). Thinking big: Politics, progress, and security in the management of Asian and European energy megaprojects. In *Energy Policy* 74, pp. 16-27. DOI: 10.1016/j.enpol.2014.06.027.
- Voropai, N. I. (2007). Energy Cooperation in Northeast Asia: Mechanisms, Risks, Barriers. In N. I. Voropai, D. N. Efimov (Eds.). *Asian Energy Cooperation: Mechanisms, Risks, Barriers (AEC-2006)*. Proceedings of International Conference (June 27-29, 2006). Irkutsk, pp. 9-17.
- Voropai, N. I., S. V. Podkovalnikov, L. Yu. Chudinova and K. Letova (2019). Development of electric power cooperation in Northeast Asia. In *Global Energy Interconnection* 2 (1), pp. 1-6. DOI: 10.1016/j.gloei.2019.06.001.
- Voropai, N. I., S. V. Podkovalnikov, V. Savelyev and S. Palamarchuk (2019). Hydropower Development in Eastern Russia in the Context of Interstate Cooperation: Current State and Prospects. In *Energy Systems Research*, 2-1(5), 2019, pp. 43-51.
- Wang, F. (2007). The Outlook and Problems for Electric Power Cooperation between China and Russia in Far East. In N. I. Voropai, D. N. Efimov (Eds.). *Asian Energy Cooperation: Mechanisms, Risks, Barriers (AEC-2006)*. Proceedings of International Conference (June 27-29, 2006). Irkutsk, pp. 34-38. Available at <http://isem.irk.ru/AEC-2008/proc2006/5.pdf>.
- Wang, M., W. Kang, Z. Chen, Y. Zhang, C. Liu and F. Yang (2018). Global Energy Interconnection: an innovative solution for implementing the Paris Agreement—the significance and pathway of integrating GEI into global climate governance. In *Global Energy Interconnection*, 1 (4), pp. 467-476. Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300677>, retrieved 9/2/2019.
- Wang Q., T.-T. Xu and X.-L. Guo (2012). Analysis on the Risk of Northeast Asia Regional Energy Security Cooperation. In *Energy Procedia* 16, pp. 341-345. DOI: 10.1016/j.egypro.2012.01.056.
- Woodford, D. A. (2003). Increasing the dispatchability of wind energy through interconnections in Asia and Australia. In *2003 IEEE Power Engineering Society General Meeting (IEEE Cat. No.03CH37491)*. 2003 IEEE Power Engineering Society General Meeting. Toronto, Ont., Canada, 13-17 July 2003: IEEE, pp. 2191-2194.
- Xuegong, S., G. Liyan and Z. Zheng (2013). Market entry barriers for foreign direct investment and private investors: Lessons from China's electricity market. In *Energy Strategy Reviews* 2 (2), pp. 169-175. DOI: 10.1016/j.esr.2013.02.002.
- Xuming, L. (2018). Application and research of global grid database design based on geographic information. In *Global Energy Interconnection* 1 (1). Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300112>, retrieved 9/10/2019.
- Yamaguchi, S., T. Iitsuka, M. Osada and R. Yokoyama (2018). Asian international grid connection and potentiality of DC superconducting power transmission. In *Global Energy Interconnection* 1 (1), pp. 11-19.
- Yang, Q. T. Ding, W. Ma, H. Zhang, Z. Jia, W. Tian and Y. Cao (2018). Decentralized Joint Power-Gas-Heat Economic Dispatch for Global Energy Internet in Northeast Asia. In *2018 IEEE Power & Energy Society General Meeting (PESGM)*. 2018 IEEE Power and Energy Society General Meeting (PESGM). Portland, OR, 8/5/2018 - 8/10/2018: IEEE, pp. 1-5.
- Yilmaz, S., X. Li (2018). Energy socialization. The Northeast Asia energy grid and the emergence of regional energy cooperation framework. In *Energy Strategy Reviews* 22, pp. 279-289. DOI: 10.1016/j.esr.2018.10.001.
- Yoon, J., D. Park and H. Kim (2004). Environmental impacts and benefits of regional power system interconnections for the Republic of Korea. In *IEEE Power Engineering Society General Meeting, 2004*. 2004 IEEE Power Engineering Society General Meeting. Denver, CO, USA, 6-10 June 2004: IEEE, pp. 427-433.
- Yoon, J., D. Park, H. Kim and J. Choi (2007). Possible interconnection scenarios and impacts on composite system reliability between "ROK-DPRK-RF". In *2007 IEEE Power Engineering Society General Meeting*. 2007 IEEE Power Engineering Society General Meeting. Tampa, FL, USA, 6/24/2007 - 6/28/2007: IEEE, pp. 1-4.
- Yun, W.-C. (2004). A Strategic Approach for Electric Power Interconnection in North-East Asia. APEC Study Centre Conference, May 2004.
- Yun, W.-C. and Z. X. Zhang (2006). Electric power grid interconnection in Northeast Asia. In *Energy Policy* 34 (15), pp. 2298-2309. Available at <https://www.sciencedirect.com/science/article/pii/S0301421505000935>, retrieved 9/2/2019.
- Zhang, D., P. You, F. Liu, Y. Zhang, Y. Zhang and C. Feng (2018). Regulating cost for renewable energy integration in power grids 1 (5). Available at <https://www.sciencedirect.com/science/article/pii/S2096511719300039>, retrieved 9/2/2019.
- Zhang, D. and R. C. Qiu (2018). Research on big data applications in Global Energy Interconnection. In *Global Energy Interconnection* 1 (3), pp. 352-357. Available at <https://www.sciencedirect.com/science/article/pii/S209651171830046X>, retrieved 9/2/2019.

Zhang, D. and R. Xie (2018). Study on the Electricity Replacement Potential in Japan and South Korea Under the Northeast Asia Grid Interconnection Scenario. In *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*. 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2). Beijing, 10/20/2018 - 10/22/2018: IEEE, pp. 1-5.

Zhang, N., F. Luan, Y. Zhao, R. Li and Z. Sun (2018). A Novel Inter-Country Integrated Power Generation-Transmission Expansion Planning Model: Case Study on North-East Asia. In *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*. 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2). Beijing, 10/20/2018 - 10/22/2018: IEEE, pp. 1-6.

Zhang, Y., X. Wang, L. Yao, W. Zhang, Z. Wu and Y. Fang (2016). Multilateral power grid interconnection for complementary utilization of energy in Northeast Asia. In *2016 China International Conference on Electricity Distribution (CICED)*. 2016 China International Conference on Electricity Distribution (CICED). Xi'an, China, 8/10/2016 - 8/13/2016: IEEE, pp. 1-6.

Zhou, Y., X. Chen, X. Tan, C. Liu, S. Zhang, F. Yang et al. (2018). Mechanism of CO<sub>2</sub> Emission Reduction by Global Energy Interconnection. In *Global Energy Interconnection* 1 (4), pp. 409-419. Available at <https://www.sciencedirect.com/science/article/pii/S2096511718300616>, retrieved 9/4/2019.

Zilberman, S. and S. Smirnov (2007). Technical and Economic Analysis of Transmission System from Eastern Russia to China. In N. I. Voropai, D. N. Efimov (Eds.), *Asian Energy Cooperation: Mechanisms, Risks, Barriers (AEC-2006)*. Proceedings of International Conference (June 27-29, 2006). Irkutsk.

Zissler, R. and J. S. Cross (2020). Impacts of a Japan–South Korea power system interconnection on the competitiveness of electric power companies according to power exchange prices. In *Global Energy Interconnection*, vol. 3, No. 3, June 2020, pp. 292-302.



