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에너지경제연구원
Korea Energy Economics Institute

IRENA
International Renewable Energy Agency

RENEWABLE ENERGY AND ELECTRICITY INTERCONNECTIONS FOR A SUSTAINABLE **NORTHEAST ASIA**

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Abbreviations

ACER	Agency for the Co-operation of Energy Regulators
ADB	Asian Development Bank
ADFD	Abu Dhabi Fund for Development
APEC	Asia Pacific Economic Co-operation
APERC	Asia Pacific Energy Research Centre
ASEAN	Association of Southeast Asian Nations
ASG	Asian Super Grid
BRI	Belt and Road Initiative
CAPEX	Capital expenditure
CDMER	Board of Directors of the Regional Electricity Market (Consejo Director del Mercado Eléctrico Regional)
CEAC	Central American Electrification Council
CEC	Clean Energy Corridor
CECCA	Clean Energy Corridor of Central America
CEO	Chief executive officer
CHP	Combined heat and power
CLSG	Côte d'Ivoire-Liberia-Sierra Leone-Guinea
CO_2	Carbon dioxide
CP	Capacity payment
CRIE	Comision Regional de Interconexion Eléctrica
CRIPG	Central Region Integrated Power Grid
CSP	Concentrated solar power
DC	Direct current
EB	Executive Board (of WAPP)
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EDF	French Electricity (Électricité de France)
EEA	European Economic Area
EMS	Energy management system
ENSTO-E	European Network of Transmission System Operators for Electricity
EOR	Regional Operating Entity (Ente Operador Regional)
EPC	Engineering, procurement and construction
EPCO	Electric power company
EPEX	European Power Exchange
EPR	Empresa Propietaria de la Red
ERERA	ECOWAS Regional Electricity Regulatory Authority
ESCAP	Economic and Social Commission for Asia and the Pacific (of the United Nations)
ETS	Emission trading system
EU	European Union
FOB	Free-on-board
GA	General Assembly (of WAPP)
GDP	Gross domestic product
GEI	Global electricity interconnection
GEIDCO	Global Electricity Interconnection Development and Co-operation Organisation
GHG	Greenhouse gas
GIS	Geographic information system
GOM	Government of Mongolia
GS	General Secretariat (of WAPP)
GW	Gigawatt
GWh	Gigawatt-hour
HFO	Heavy fuel oil
HVAC	High voltage alternating current
HVDC	High voltage direct current
Hz	Hertz
ICC	Information and Co-ordination Centre (of WAPP)
IDB	Inter-American Development Bank
IEA	International Energy Agency
IEX	Indian Energy Exchange
IMAR	Inner Mongolia Autonomous Region
IPEX	Italian Power Exchange
IRENA	International Renewable Energy Agency
JPEX	Japan Electric Power Exchange
JVETS	Japan Voluntary Emissions Trading Scheme
KEEI	Korea Energy Economics Institute
KEPCO	Korea Electric Power Corporation
KERI	Korea Electrotechnology Research Institute
K-ETS	Korea Emissions Trading Scheme
kJ	Kilojoules
KPX	Korea Power Exchange

kV	Kilovolt
kWh	Kilowatt hour
LNG	Liquefied natural gas
MT	Million tonnes
MW	Megawatt
MWh	Megawatt-hour
MDB	Multinational development bank
MOTIE	Ministry of Trade, Industry and Energy (of the Republic of Korea)
MOU	Memorandum of understanding
MPE	Ministry of Petroleum and Energy (Norway)
NAPSI	Northeast Asia power system integration
NATO	North Atlantic Treaty Organisation
NDC	Nationally Determined Contribution
NEA	Northeast Asia
NEAEI	Northeast Asia Electricity Interconnection
NEAREST	Northeast Asia Region Electrical System Ties
NEARPIC	Northeast Asia Regional Power Interconnection and Co-operation
NEMO	Nominated electricity market operator
NGDP	Nordic Grid Development Plan
NVE	Norwegian Water Resources and Energy Directorate (Norges vassdrags- og energidirektorat)
OPEX	Operational expenditure
OCCTO	Organisation for Cross regional Co ordination of Transmission Operators (of Japan)
ODECA	Organisation of Central American States
OMEL	Iberian Energy Market Operator, Polo Español S.A. (Operador del Mercado Ibérico de la Energía, Polo español S.A.)
OMVG	Gambia River Basin Development Organisation
OMVS	Senegal River Basin Development Organisation (Organisation pour la Mise en Valeur du fleuve Sénégal)
ORIRES	Optimisation of Power Systems Expansion and Operating Modes
PIPES	Planning, Investment, Programming and Environmental Safeguards (of WAPP)
PM	Mesoamerican Project
PPA	Power purchase agreement
PPP	Purchasing power parity
PPP	Puebla Panama Plan
PSSE	Power system simulator for engineering
PV	Photovoltaic
R&D	Research and development
REI	Renewable Energy Institute (Japan)
REM	Regional Electricity Market
ROK	Republic of Korea
SCADA	Supervision, control and data acquisition
SCO	Shanghai Co-operation Organisation
SDAC	Single day-ahead coupling
SDG	Sustainable Development Goal
SGCC	State Grid Corporation of China
SICA	Central American Integration System (Sistema de la Integración Centroamericana)
SIDC	Single intra-day coupling
SIEPAC	Electricity Interconnection System of the Countries of Central America (Sistema de Interconexión Eléctrica de los Países de América Central)
SMO	System and market operator
SMP	System marginal price
SPC	Special purpose company
SPV	Special purpose vehicle
SvK	Swedish Power Grid (Svenska kraftnät)
TES	Transforming energy scenario
TFEU	Treaty on the Functioning of the European Union
TSA	Transmission service agreement
TSO	Transmission system operator
TWh	Terawatt-hour
UHV	Ultra-high voltage
UPS	Unified Power System (Russian Federation)
UN	United Nations
VRE	Variable renewable energy
WACEC	West Africa Clean Energy Corridor
WAGP	West African Gas Pipeline
WAPP	West African Power Pool

Key messages

This report was developed jointly by the International Renewable Energy Agency (IRENA) and Korea Energy Economics Institute (KEEI). It aims to promote the creation of a regional renewable energy market through cross-border interconnections and associated investments in renewable energy generation capacity, across Northeast Asia (NEA). This objective aligns with the principles of IRENA's Clean Energy Corridor (CEC) initiatives.

To support informed decision making at the national and regional levels, the report provides stakeholders with an updated view of NEA interconnection by drawing insights from two principal *loci* of information. Firstly, it reviews the outcomes of selected past interconnection plans for integrating power systems in NEA. Secondly, in order to search for lessons relevant to building interconnection in NEA, it analyses the evolution and enabling environments of three different regional interconnectivity initiatives: the Electricity Interconnection System of the Countries of Central America (SIEPAC – Sistema de Interconexión Eléctrica de los Países de América Central), in Central America; the West African Power Pool (WAPP), in West Africa; and Nord Pool in Northern Europe.

The report concludes that despite an extensive body of studies and plans on NEA interconnection, further research that targets gaps and flaws in the existing literature is still required.

The report recommends the region's countries enter the next stage of the interconnection process with investment studies that can help bring individual interconnections between pairs of countries closer to investment readiness.

Moving gradually forward from the previous work of outlining holistic grand schemes, the interconnection plans of today need to be realigned to support clean energy deployment in the region. They also need to consider rapid cost declines in solar photovoltaic (PV) and onshore wind as well as take a realistic view of the electricity market environment within which the future cross-border electricity trading will take place.

Finally, the report regards the institutionalisation of regional interconnection development as a necessary step forward. The level of regional economic and political integration, however, does not yet endorse a deep integration of systems and markets. Therefore, the proposed multilateral co-operative bodies start with a more limited scope than those of the equivalent institutions of SIEPAC, WAPP and Nord Pool.

Making renewable electricity development the centrepiece of the political agenda for NEA interconnectivity development.

In light of recent declarations by the presidents of China and the Republic of Korea and the prime minister of Japan that their countries will achieve net carbon neutrality by or near the middle of this century, the countries in the NEA region can confidently place renewable energy development at the centre of plans for regional interconnection.

The desire for trading in renewable energy is a clear motivator behind the political support for interconnection throughout the region. China, Japan, and the Republic of Korea share an interest in importing renewable energy as a means of achieving their climate targets, while Mongolia and the Russian Federation are endowed with large renewable energy resources. This common interest can be used to help reduce the political barriers to interconnection arising from concerns over energy security and the geopolitical aspects of electricity interconnection.

Some of the existing studies of interconnection in NEA do not reflect the full potential of renewable energy, or are based on now-outdated cost estimates. Indeed, it would have been difficult to predict, when these studies were conducted, how rapidly the costs of renewable energy would decline. In some areas cost projections originally made for 2030 have already been achieved. In centring renewable energy in the NEA interconnection debate, therefore, there is a need for updated modelling work that can take into account both the recent changes in costs and NEA countries' policy commitments to renewable energy.

While coal has long been an important energy source throughout the NEA region, there is a clear indication of an active desire to reduce coal-fired capacity and move in the direction of a coal phase-out. Previous models and studies have considered the possibility of coal being used to replace natural gas, or other expansion and support of coal-fired capacity, as part of interconnection. In this new context, planners throughout the region may anticipate constraints on the use and deployment of coal. As countries have pledged ambitious plans for net-zero carbon emissions by or near the middle of this century, it is not unreasonable to exclude the development, life-extension and increased use of coal-fired power generation among the options for future cross-border trading.

A vital issue for future studies is also the need to establish balancing power, associated with the variable renewable energy (VRE) generation. Therefore, it is important to identify and analyse resources in the region that can bring flexibility in the context of planned renewables production, researching their location and the associated grid configuration. A study concerning the use of hydropower capacity in Yenisei-Angara and other Siberian and Far Eastern river systems to balance the variability of wind and solar production in northern China and Mongolia would, for example, be highly valuable.

Future steps require an agreement on a unified view of the future grid configuration.

Many studies propose a variety of possible grid formations and interconnection paths. To date, however, these studies have often been written from a particular national perspective, rather than seeking an objective position on the ideal grid development for the region as a whole.

These national perspectives have provided useful information, but they make it difficult to directly compare grid and interconnection plans. It is therefore necessary for the research community to seek converging views on the optimal grid configuration, as a means of developing a shared foundation for next steps and future action.

A unified view of grid development would also be more effective in promoting the idea of NEA interconnection among decision makers and the financing community. Studies and proposals that seek optimal routes can be more easily compared by investment partner organisations if they share a core set of unifying base assumptions. Routes that can be expected to require exceptionally complex development, such as the proposed routes through the Democratic People's Republic of Korea, could be left as long-term development options rather than included as part of the core discussion.

Once such a unified base plan is identified, it becomes easier to study the details of each individual connector considering specified renewable energy investments. Such studies would look at existing sources of hydro, wind, and solar; transmission and wheeling charges; and the real-life trading of markets on both sides of the border.

Political support among participating countries, along with international organisations, may help build trust during the process and facilitate future investments in the NEA region.

New national markets for electricity and emissions may provide valuable opportunities.

In Central America, SIEPAC infrastructure was developed to support the regional electricity market (REM).

REM operates as a superstructure, which is linked to national electricity markets through physical transmission interconnections. It also acts in addition to national markets, independently and exclusively at the regional level. Trading is based largely on the excesses and shortages of the national markets. Another case study in this report, the WAPP, also intends to develop a similar regional electricity market, but currently operates primarily through bilateral, power purchase agreements (PPA) and transmission services agreements (TSA).

The SIEPAC market model is theoretically an option for NEA, especially as this model does not require profound changes in the regulation of national markets. It also allows a gradual process for deepening electricity integration, if it is seen as beneficial by the participating countries. Yet, it also requires as preconditions that the physical interconnections between the participating countries exist and that there are a multitude of market participants in all countries, in order to ensure the market is liquid. Developing the infrastructure needed for the level of interconnectivity of SIEPAC in NEA would require huge investment and a long period of time, given the massive distances involved in NEA interconnection. Therefore, the SIEPAC market model remains a long-term option. NEA markets can be more effectively developed in the short-term through PPAs and TSAs, or by the selling and buying parties linking to the various competitive marketplaces already operating in the region.

In exploring future paths for the development of markets in the NEA region it is important that regional actors fully explore the possibilities and opportunities presented by recently established national electricity markets.

The Republic of Korea and Japan have existing power exchanges and the Russian Federation has an established competitive market in Siberia (Figure 1). China has begun an experiment with competitive markets in many provinces, including the Inner Mongolia Autonomous Region and Shandong. These provinces are possible landing sites for an interconnector from Mongolia and the submarine interconnector from the Republic of Korea, respectively. Mongolia currently has a single buyer system with regulated prices, and also the Russian Far East region operates with a regulated wholesale market.

Any plan for future market development must work to understand the national and provincial systems that will act as its foundation and be tailored to address the specific needs of the region.

The current market structures within NEA are based on the particular contexts of its countries and strongly influenced by the sheer size of the region. The total electricity supply of the area in question is 170 times the terawatt hours of SIEPAC, or 24 times the electricity supply in the interconnected system of the Nordic countries. At a national level, many NEA countries are already divided into multiple markets, further complicating any ambitions to impose a vision of a unified regional market. In seeking to promote regional interconnection, therefore, it is essential that plans are formed that identify opportunities within the existing markets and focus on realistic solutions that align with the markets of the participating countries.

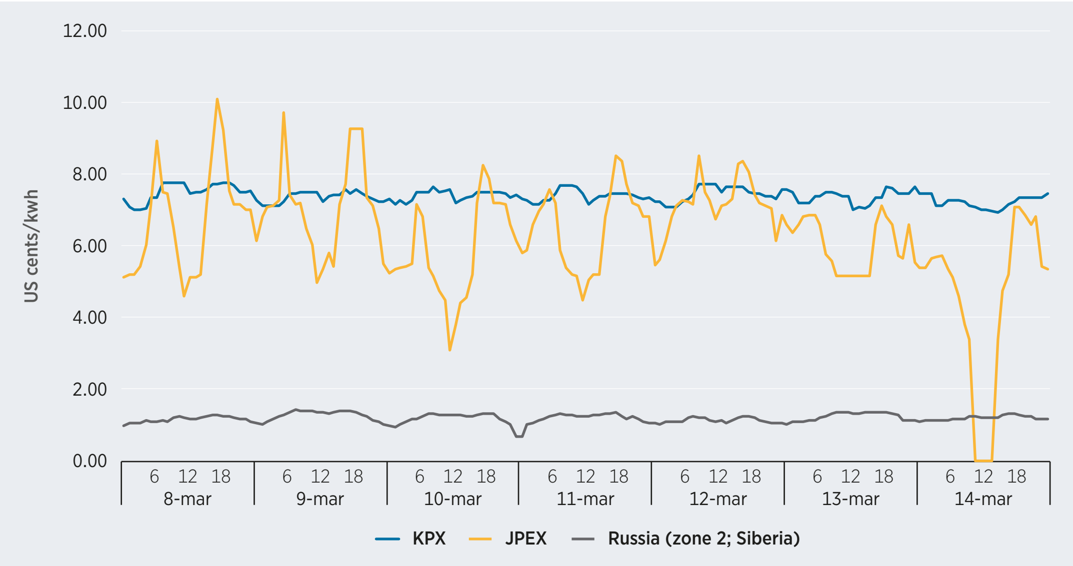
Pursuing the ideal of a deeply unified NEA market, which has been the basis of several previous studies, may not be viable at this stage. Focus could be better placed instead on identifying opportunities and business cases from the existing, increasingly competitive and dynamic national and provincial markets.

Therefore, as an alternative to PPAs and TSAs, cross-border co-operation can be started organically, if the importers and exporters of electricity are allowed to act as market participants in each other's power exchanges.

As shown by the Renewable Energy Institute (REI) studies discussed below, there are also several possible methods for the Transmission System Operators (TSO) in participating countries to recover the costs of developing cross-border interconnectors. It will be valuable if future studies can identify the most feasible methods for cost recovery and mechanisms for efficient trading.

In addition to electricity markets, a variety of emissions trading schemes exist within NEA. The Republic of Korea has one of the longest running emissions trading schemes, after the European Union (EU) emissions trading system (ETS). Japan has a voluntary trading scheme, while China has begun experimenting with a cap-and-trade system. The way in which emissions trading will be organised in each market affects the competitiveness of different forms of production, including renewable energy, fossil fuels-based generation and imported electricity. These effects need to be identified and taken into account when planning the cross-border electricity trade. The possibility of applying Article 6 of the Paris Agreement and generating emissions reductions from other countries could also be an element in the design of the business cases supporting interconnectivity.

Figure 1 Electricity market prices over a period from 8-14 March 2021 in the electricity markets of Japan, the Republic of Korea and the Russian Federation's Siberia Zone



Source: ATS (n.d), JPEX (n.d.), KPX (n.d).

Note 1: The Siberian time series has been adjusted by two hours to make it simultaneous with Japan and the Republic of Korea.

Note 2: Exchange rates as given by the Bank of Japan (BOJ), Bank of Korea (BOK), and Bank of Russia (BOR).

Note 3: Day-ahead energy-only prices are exclusive of any capacity payments.

New institutions for NEA must be designed to match the needs of the region

Both SIEPAC and WAPP initiatives have been developed considering a future regional market mechanism, which is based on free, third-party access and a competitive marketplace combining both demand and supply-side bidding. With such an objective, the composition of regional institutions designed for SIEPAC and WAPP reflects what is also ideal for national level markets and sector institutions when the market has the above-mentioned properties. The consequent institutions include: (i) a regional regulator; (ii) nominated TSOs; (iii) a market operator; and (iv) political oversight.

In contrast to SIEPAC and WAPP, the Nord Pool electricity market was established in an environment where the cross-border interconnection infrastructure between the participating Nordic countries was already in place, due to a long tradition of collaboration in ensuring a stable energy supply, system reserves and optimal utilisation of the different countries' energy resources.

The development of the Nord Pool marketplace was a logical continuation of the almost simultaneous restructuring of the power industries in the participating countries. These all introduced full, third-party access, generation and retail competition in their electricity industries. While the first stages of power system integration were mostly self-governed by the national TSOs, at later stages, the Nordic area became integrated with the rest of Europe and governed by EU-level institutions and regulations.

The specific examples of institutions established in these case studies, however, are not directly applicable to the case of NEA. Firstly, even though the NEA countries have expressed an interest in developing an electricity trade between each other, there is no expressed aspiration for a unified regional market with multilateral regulation. Secondly, unlike the three regional systems analysed in this study, which have the Central American Integration System (Sistema de la Integración Centroamericana – SICA), the Economic Community of West African States (ECOWAS), and the EU respectively bolstering regional economic co-operation, NEA lacks a regional economic co-operation mechanism or organisation that could host and foster regional interconnectivity development. Indeed, while it is essential for any institutions proposed at this stage to align with the NEA vision for interconnectivity development, this vision has not yet been clearly established.

Both governments and TSOs are needed as active proponents and enablers for regional interconnection.

NEA might, however, benefit from the development of an institution that would take the lead in creating such a vision. It could also foster the co-ordination of plans and studies, the identification of priority investments, the development of business cases and engineering concepts for key investments, while maintaining dialogue, seeking to form a more unified view on the desired future regional grid and underlying investments in renewable energy generation.

Experience drawn from the case studies indicates that both governments and TSOs are needed as active proponents and enablers for regional interconnection. Political will, demonstrated by the presence of governmental support for interconnection development, is a necessary prerequisite for cross-border interconnections. On the other hand, in all the case studies analysed, the TSOs or equivalent national utilities had already proactively developed regional interconnectivity, prior to its institutionalisation.

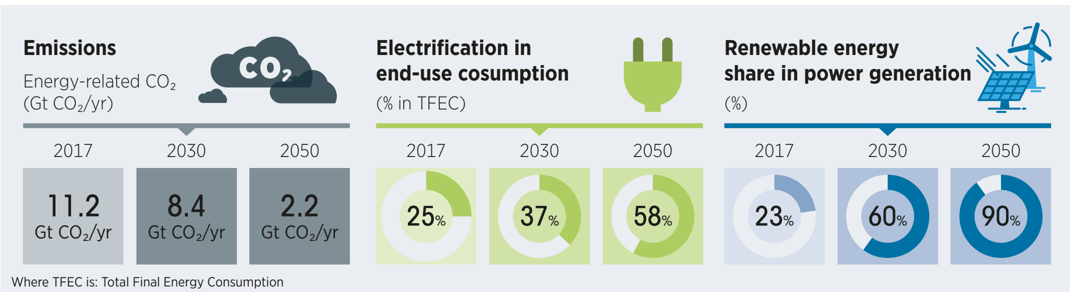
The institution suggested by this report is therefore envisioned as having two bodies in order to gather together both TSOs and governments. One body would be a permanent co-ordination unit – a small secretariat – which would carry out the planning, co-ordination and promotion activities outlined above. The key officials for the secretariat could be nominated by the TSOs or equivalent organisations that are integrally involved in electricity cross-border operations in the five NEA countries. It is suggested that all member countries pledge to support the operations of the unit with funds, co-operation, and access to information. The second body would be a steering committee in the spirit of SIEPAC's Board of Directors of the Regional Electricity Market (Consejo Director del Mercado Eléctrico Regional – CDMER). This would be composed of representatives of the countries' ministries of energy or equivalent, having authority to co-ordinate their own national policies and measures associated with NEA interconnection, to oversee and guide the operation of the co-ordination unit and to maintain the momentum of NEA interconnectivity development in their respective countries.

Introduction

In 2020, the world witnessed three significant announcements from the leaders of the largest economies of East Asia. The presidents of China and the Republic of Korea and the prime minister of Japan pledged that their countries would achieve net carbon neutrality by or near the middle of this century. These announcements imply a major transformation in the way energy is produced, traded and consumed, not only in those three countries, but throughout the region and even globally.

The planned transformation entails three structural changes of great magnitude. The first is to shift the individual countries' primary energy base of electricity generation from fossil fuels to renewables. IRENA's analysis (IRENA, 2020b) shows that energy-related CO_2 emissions in the NEA region can fall by more than 80%[1] in the next 30 years by increasing the share of renewable energy in total power generation from 23% to 90%. This will require a more than 8-fold increase in renewable electricity generation capacity, from 870 gigawatts (GW) today to 7 600 GW by 2050, of which three quarters will be solar and wind energy. Secondly, electricity and electricity-based fuels, such as hydrogen, will occupy a greater share in energy consumption. This shift will be driven partially by policies, but increased electrification of end-uses will be enabled by renewables becoming the lowest-cost option for electricity generation. Finally, industrial processes and difficult-to-decarbonise sectors must seek energy efficiencies and increasingly turn to using renewable fuels, such as advanced biofuels and green hydrogen.

Figure 2 Transforming energy scenario (TES) pathway for NEA



Source: IRENA, 2020b

[1] *According to the IRENA analysis (2020b), CO_2 emissions need to fall more than 70% below today's level, globally, to reach the goals of the Paris Agreement.*

Achieving these three structural changes will also lead to a significant change in the energy landscape throughout NEA. The five countries of the region – China, Japan, the Republic of Korea, Mongolia, and the Russian Federation – have traditional energy trading links for oil, natural gas and coal. In many bilateral and multilateral fora, the leaders of these countries have clearly voiced their interest in deepening regional energy co-operation and expanding it to include electricity. By pairing cross-border electricity interconnectivity with renewable energy development, countries can take advantage of hydropower, solar, and wind resources in remote locations beyond their national boundaries. They will thus be able to accelerate the deployment of renewable energy, as necessitated by their economic and environmental transformation.

In principle, regional interconnection offers attractive opportunities for all the participants within the region. Apart from enabling a higher share of low-cost, renewable energy generation in the system operation, electricity interconnectivity also creates other economic benefits by providing improved energy security, system stability, loss reductions, and decreased emissions.

Japan and the Republic of Korea also have substantial theoretical renewable energy potential. Yet, their high population density, cost of land and difficult terrain make the large-scale exploitation of solar PV and wind power potential that is required for their energy transformation more costly and difficult than it is, for example, in Mongolia. Furthermore, the Russian Federation has substantial hydropower resources in addition to its other energy endowments and has often offered the possibility of exporting electricity to China, Japan and the Republic of Korea. Interconnectivity would therefore also offer an opportunity for Japan and the Republic of Korea to substantially increase their share of renewable energy more easily than by developing their own resources.

NEA interconnectivity has been under discussion for some years. Several academic studies and stakeholder initiatives have already explored the alternative of forming a regional grid through the development of cross-border transmission lines and the optimisation of the energy generation mix regionally, through NEA. These studies have consistently confirmed the multiple benefits of connecting national transmission networks among the countries of the region, but the actual progress of developing interconnectivity has been slow.

The value of renewable energy in meeting the climate goals of NEA, however, may be just the spur needed to encourage interconnectivity progress. Yet, despite some recent developments – such as the agreement to pursue a submarine interconnection between China and the Republic of Korea – many NEA countries still harbour concerns about developing regional interconnection.

These concerns may be related to the security of supply, investment requirements for renewable energy generation and grid infrastructure development, and the required technical and market adjustments. Nevertheless, demonstration of the viability and clear benefits of grid interconnections in promoting further development of renewable energy markets and trade – while based on international good practices and a further strengthening of dialogue and co-ordination among key stakeholders – can help mitigate these obstacles.

In this context, IRENA launched a study to undertake a specific assessment related to the development of power system interconnections in NEA, with the goal of creating a larger renewable energy market and promoting renewable energy trade within the region. This study aligned with IRENA's regional approach in support to its membership, as reflected in its CEC initiatives.

The study included use of two independent sources of information and experience to advise the reader.

First, the study reviewed the outcomes of selected past studies into developing regional power system interconnection in NEA. In doing so, it asked whether these studies had responded to the ever-updating energy policy needs of the region's countries and what other matters required analysis in order to bring the NEA interconnectivity agenda forward.

Second, the study reviewed three regional initiatives – SIEPAC in Central America, WAPP in West Africa, and Nord Pool in North Europe – and examined their evolution and enabling environments in the search for relevant lessons in building interconnectivity in NEA. The three cases exemplify the so called shallow (WAPP and SIEPAC) and deep (Nord Pool) power system integration models described below. The study therefore aimed to provide necessary information to relevant stakeholders and to support informed decision-making at national and regional levels, in order to facilitate the development of an NEA power interconnection system.

This report provides the results of that IRENA study and is divided into five main sections.

The first section provides background concerning the energy landscape of the NEA countries. It is followed by a review of the literature focusing on studies, research papers and initiatives from the five countries that have taken a comprehensive approach to the issue of interconnectivity development. The interest of this document is in examining region-wide interconnection; therefore, studies focusing on country-to-country interconnectors, for example, are not discussed. The discussion ends with conclusions drawn from the review and recommendations for more detailed analysis.

The third section describes the status of interconnectivity in NEA and, as a prelude to the case studies, introduces power system integration stage models that are customarily applied when regional electricity interconnection schemes are characterised and categorised.

The fourth section gives a summarised account of each of the case studies focusing on their political and economic contexts, regional infrastructures developed, institutions established, and the operational modes of the electricity markets created. The fifth section summarises some of the features of the cases and places them in the context of the NEA countries. The fifth section then concludes with a few key take-aways from the analysis.

Background

The energy landscapes of NEA countries

In the NEA region, energy co-operation is mainly characterised by relatively modest bilateral trade, with electricity predominantly involving China, Mongolia and the Russian Federation, while the Russian Federation exports conventional fossil fuels to all the other regional countries. Indeed, Japan, China, and the Republic of Korea are major energy importers – these three countries import 57% of global, liquefied natural gas (LNG) trade, for example – with most of their energy imports coming from countries outside the region, except for those from the Russian Federation.

Despite what appears to be a favourable opportunity, then, energy co-operation between NEA's major importers and exporters remains relatively limited. This is partly a consequence of: geography; the political situation; and the absence of transmission infrastructure between continental countries and the peninsular/island countries of the Democratic People's Republic of Korea, the Republic of Korea and Japan.

The intense importance of energy imports and exports to the Russian Federation's economy has made it one of the most active countries in the region in terms of energy co-operation. While Europe has been a main destination for its oil and gas for decades, in its 2035 Energy Strategy,[2] the Russian Federation has also set a target of increasing East Asia's share in the country's total exports of coal and natural gas from 27% in 2018 to 50% by 2035. A new pipeline called the 'Power of Siberia', was commissioned in 2019 to export 38 billion m^3 of gas per year from the Russian Far East to China.

Although the focus of recent trade developments in the region has been on conventional energy, they also show the importance of NEA in the global energy market and point to an increasing trend of energy connectivity in the region.

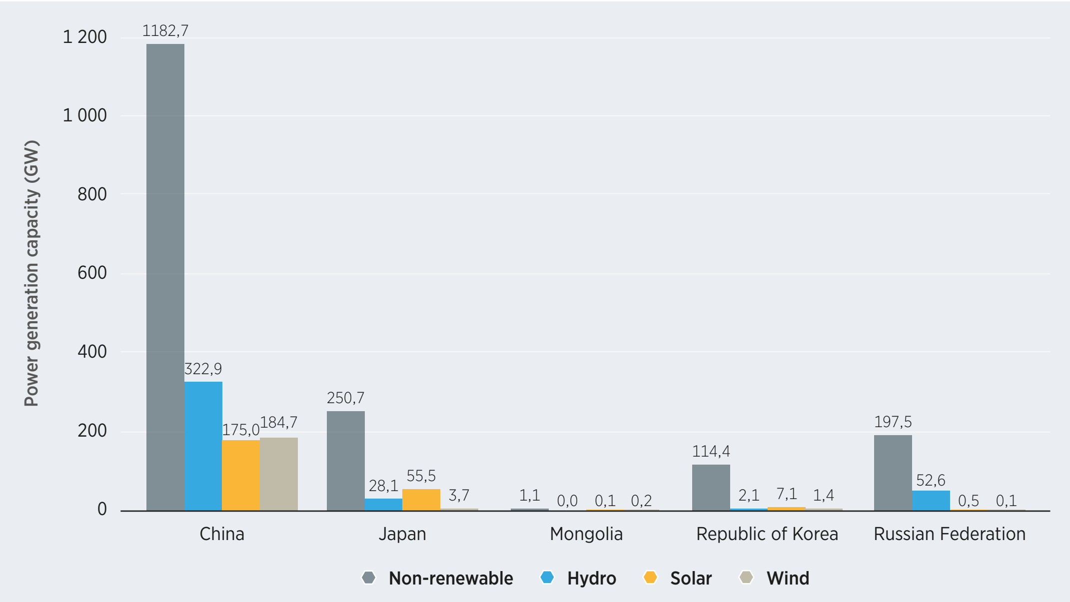
Recent energy trade developments point to an increasing trend of energy connectivity in the region. The shift towards renewable energy production can already be seen in the NEA region and the demand for clean energy resources will increase considerably over the coming years.

[2] *Энергетическая стратегия российской федерации на период до 2035 года (2035 Energy Strategy)*

Conventional fossil fuels also play a major role in the electricity generation sector of most NEA countries. Electricity trade in the region is carried out on a bilateral basis and volume of trade is quite limited compared to the large power generation capacity in each country. China holds the dominant position in power generation capacity within the region – which is unsurprising given that China is the largest electricity producer in the world – but the Russian Federation, Japan, and the Republic of Korea are ranked as the 4th, 5th, and 9th largest electricity producers respectively, globally. The high dependence of these generating capacities on fossil fuels, however, suggests that the region may be exposed to the risk of stranded assets in the future, as NEA countries seek to decrease the dominance of fossil fuels, especially coal, in their energy mix. This would be in accordance with their energy transformation goals, as referred to in this report's introduction.

The shift towards renewable energy production can already be seen in some NEA countries, too, with China, the Russian Federation and Japan, respectively, placed as the 1st, 7th and 8th largest producers of renewable energy power generation in 2018 (IRENA, 2020a). Although coal still has a strong significance in the NEA economy, the demand for clean energy resources is also expected to increase considerably, over the coming years.

Figure 3 Installed power generation capacity by country (2018)



Source: IRENA statistics (country profiles)

China

For the last two decades, China has been considered the economic powerhouse of the world, fuelled by its high economic growth. The country's rapidly growing energy demand has been met through growth in fuel imports, which has worked to increase China's energy trade both globally and within the NEA region.

China is simultaneously the world's largest coal producer – producing 46.6%, or 3 693 million tonnes per year (Mt/yr), of global coal – and the world's largest coal importer, at 298 Mt/yr, although these imports account for only 8% of China's total coal consumption (IEA, 2020). A significant portion of these coal imports come from within the NEA region, with Mongolia and the Russian Federation acting as, respectively, the 2nd and 4th largest coal exporters to China, in 2019.

In 2018, China also became the world's largest oil importer. A major part of this oil comes from the Russian Federation, which is the second largest oil exporter to China, providing 15.3% of total imports – a close second to Saudi Arabia (16.8%). Russian oil imports come mainly from the production of Siberian oil fields (ITC, n.d.). As of 2019, China had also begun to import natural gas from the Russian Federation's eastern Siberia field through the Power of Siberia pipeline.

These energy imports contribute to making China the largest producer of electricity in the world. Non-renewable generation dominates domestic electricity generation – which stood at 63% of total capacity (1 878.5 GW) and 74% of total generation (5 186 terawatt hours [TWh]) in 2018. While the government has taken steps to introduce electricity market competition, thus far, each generator is assigned to produce an allocated amount of electricity, rather than following a competitive economic dispatch approach.

The Great Wall, China.

Overall, China experiences a surplus of electricity production and this means that capacity factors, especially in coal power plants, have been relatively low. Restrictive measures have been placed on the construction of new coal power plants, but this has not yet reduced the dominance of non-renewable generation in the electricity mix.

Yet, although electricity production is dominated by non-renewables, China also has abundant renewable resources for traditional hydropower, as well as wind and solar PV production. Indeed, it is the world's largest producer of renewable energy, as well as the largest manufacturer of associated equipment. Renewable power capacity almost doubled between 2013 and 2018, especially solar PV and wind capacity, which demonstrated impressive 885% and 141% growth rates, respectively. Total renewable electricity capacity stood at 759 GW in 2019.

While renewable energy deployment currently relies on government support, the cost-competitiveness of renewables is increasingly changing the policy landscape. In 2019, China held the world's largest solar auction – 22 GW of new capacity – and the lowest auction price was only USD 0.04/kilowatt hour (kWh), while the average price was USD 0.048/kWh. Due to the lack of transmission capacity and drastically falling costs in recent years, the Chinese government has decided to gradually phase out wind and solar feed-in-tariffs, beginning in 2018.

The rapid increase of solar and wind generation has caused solar/wind power curtailment and transmission constraint issues in some regions, especially those areas with the highest quality renewable resources. In an effort to address these issues, China has developed a high voltage transmission network to increase transfer capacity between the electricity producing areas in the north and west and the load centre in the east. By 2019, renewable energy curtailment had been reduced to under 5%, nationwide. Some northern and western Chinese regions, however, are still experiencing high curtailment, such as Xinjiang (14%), Gansu (7.6%), and inner Mongolia (7.1%).

Currently, China's electricity demand remains robust and the country is committed to renewables development, despite the hindrance of curtailments, which the government is determined to overcome through a variety of measures to increase system flexibility.

In September 2020, President Xi Jinping announced China would achieve carbon neutrality by 2060. China's technological experience of high voltage direct current (HVDC) technology and a large market share in manufacturing and installing wind turbines and solar PV could underpin its intended role in NEA regional energy co-operation.

Japan

Japan has one of the most developed economies in the world, with its economic activities sustained primarily by fossil fuels and nuclear energy.

To achieve its energy mix, Japan relies heavily on the import of fossil fuels, leading to an energy self-sufficiency ratio of 12%, in 2018. This shows a gradual increase in self-sufficiency from 6% in 2014, thanks to the introduction of renewable energy and the restarting of a particular nuclear power plant (METI, 2020).

While the country imports most of its primary energy from the Middle East region, imports of coal, natural gas and oil from the Russian Federation now also make up a substantial part of Japan's fuel mix.[3] Japan also has a highly energy intensive industry structure. Whilst the manufacturing industry accounts for 21% of GDP, the industry consumed 47% of total final energy consumption (TFEC) in 2018.

Although the dominance of non-renewable energy sources currently carries over into the electricity sector, the role of renewables is growing.

In 2018, non-renewables represented the largest share of total electricity production, at 77%, with 38.3% natural gas generation and 31.6% coal-fired generation. Nuclear power produced 6.2%. Among renewables, hydropower and solar accounted for 8% and 6% respectively (METI, 2020).

The Government of Japan has stated, in its Basic Energy Policy, that the ideal energy mix will have renewables constituting 22% to 24% of total generation by 2030. Installed renewable capacity doubled between 2013 and 2018, while solar generation capacity saw an addition of 42 GW during the period. This new capacity brought total installed solar PV capacity to 55.5 GW in 2018, the second largest to China in the world. The role of renewables can be expected to continue to increase, as Prime Minister Yoshihide Suga announced in 2020 that Japan would reach a carbon neutral society by 2050.

As an island country, however, Japan has limited land availability and well protected nature areas that place some constraints on the deployment of renewables. The country therefore foresees the development of offshore wind and innovative energy storage systems, such as improved batteries and hydrogen fuel cells, as promising technological options.

Until recently, Japan has maintained a fragmented power grid system, with 10 vertically integrated power utilities. Japan is also divided into two, wide-area synchronised grids, one operating at 50 Hertz (Hz) and the other at 60 Hz.

[3] The Russian Federation is the 3rd (for coal), and 5th (for natural gas and oil) largest export (ITC, n.d.)

The strengthening of internal interconnectivity progresses steadily and the establishment of the Japan Electric Power Exchange (JEPX) in the early 2000s has gradually increased electricity trading among utilities.

The Fukushima nuclear power plant accident exposed the vulnerability of the regional monopoly system, in that it could not handle power shortages effectively is some areas using electricity trade. The government is currently implementing a major energy market reform to ensure energy markets operate more efficiently and has plans to reinforce interconnection lines between regions. As a result, the Organisation for Cross-regional Co-ordination of Transmission Operators (OCCTO) was established in 2015. The legal separation of the power transmission and distribution sector from power generation is scheduled to be implemented in 2020, which will make third-party access to the transmission lines easier.

These regulatory changes, and Japan's now relatively liberalised power market, will make it possible for Japan to consider interconnection with other countries. The infrastructure development of grid interconnection will remain challenging, however, due to the geographical constraints built in to Japan's nature an island nation.

Mount Fuji and Arakurayama Sengen Park, Japan.

Mongolia

Mongolia's vast territory is both its greatest asset and also a significant constraint on its energy and infrastructure development.

The economy of Mongolia is heavily dependent on the mining industry, with coal products standing as the country's most important export item and representing 43.7% of total exports, in 2018.[4] Over 90% of Mongolia's coal exports head to China. Coal also represents an important fuel source for domestic energy supply, with coal-fired thermal power generation in combined heat and power (CHP) plants accounting for 81% (1.1 GW) of installed capacity in 2018. During the same period, onshore wind accounted for 11.85% (0.16 GW) and solar for 4.4% (0.06 GW).

Despite the importance of coal, the Mongolian government's State Policy on Energy 2015-2030 demonstrates a strong commitment to developing renewable energy, setting an ambitious target of increasing renewable electricity generation to 30% of installed capacity by 2030.

Due to its low population density and the great distances between load centres, Mongolia's access to electricity is currently 86%, while its total generation capacity is only 1.37 GW. While four independent power systems cover large areas of the country, over 90% of generation capacity is concentrated in the central power system. Other regional power systems have significantly less generation capacity and low population density.

The Gobi desert has vast potential for both solar PV and wind plants. This combines around 300 sunny days per year with low temperature and high wind resources.

These problems of population density and distances suggest that, even though grid-connected generating capacity is expanding, off-grid and mini-grid solutions are still viable options in the country. The central power system, with the capital, Ulaanbaatar, as its largest load centre, is located in the northern part of the grid. It is fed with electricity not only from CHP plants from the capital and largest towns, but also through an interconnecting transmission line from the Russian Federation.

The central grid extends from north to south, although the Oyu Tolgoi mine and town in the southern area relies on electricity imported from China. In 2017, Mongolia imported 20% of its electricity consumption from China and the Russian Federation.

[4] https://wits.worldbank.org/countrysnapshot/en/MNG

The same vast territory that creates challenges for grid distribution provides Mongolia with vast renewable energy potential. One area in particular identified as having potential for both solar PV and wind plants is the Gobi Desert. This combines high levels of sunshine – around 300 days per year, on average – with low temperature and moisture levels and high wind resources. The Gobi Desert is, however, distant from Mongolia's main load centres, so it would be challenging to build a new grid that could tap these potential renewable resources for domestic purposes.

The Government of Mongolia (GOM) has therefore expressed deep interest in exporting electricity generated in the Gobi Desert to NEA countries. Mongolia's geographical location is a strength here, giving it the ability to connect the Russian Federation and China.

In 2019, Russia's Gazprom and the GOM signed a memorandum of understanding (MOU) to produce a feasibility study for the Russian Federation's new gas pipeline, Power of Siberia 2, with a route to China via Mongolia. This pipeline would significantly increase energy connectivity in the region. If it proves to be feasible, Mongolia can reduce its dependence on coal for power and heat, with gas fired electricity generation potentially providing system flexibility, enabling an increased share for renewable electricity.

A traditional Ger, Mongolia.

The Republic of Korea

The dominance of manufacturing in its economy and the need to import the vast majority of its energy resources have significantly shaped the development of energy policies and technologies in the Republic of Korea.

The manufacturing industry represented 27.5% of the Republic's gross national product (GDP) in 2019. From 2000 to 2017, energy consumption in the country's industrial sector increased at an average of 3.2% per year, while the share of energy consumption in that sector accounted for more than 60% of final energy consumption.

The majority of the primary energy resources meeting these needs are imported from overseas. They come mostly from the Middle East region, but the Russian Federation is also an important partner, providing 19.7% of total coal imports and substantial quantities of oil and gas, in 2018.

The Republic of Korea also exports a considerable amount of energy products, globally. In 2017, the country imported 112% of its total primary energy supply, which was equal to 13 252 kilojoules (KJ). In the same year, the country exported 137% of total primary energy production, which amounted to 2 799 KJ (IRENA, 2020a). These exports consisted mostly of refined oil and gas. This demonstrates the importance of the energy industry itself in the economy, in addition to its service to other energy intensive industries (steel, cement, chemicals, etc.).

At present, the electricity generation mix of the Republic of Korea is very heavily weighted towards non-renewables and the needs of industry. While there are plans for a gradual phase-out of coal-fired and nuclear power generation, 88% of electricity generation capacity is currently based on non-renewables. The greatest part of that capacity comes from gas (32%) and coal (31%). This emphasis on non-renewables in the country's energy production has led to a strong dependence on imported fossil fuels and consequent concerns relating to energy security.

As the country seeks to pull away from reliance on energy imports, renewable energy is also taking central stage in the government's plans to fight climate change. The Renewable Energy 2030 Plan (2017) set a renewable energy generation target of 20% (125.8 TWh) of electricity generation by 2030, which will be a substantial increase from the starting point of 6% (34.4 TWh) in 2017.[5] In 2019, the Ministry of Trade, Industry and Energy (MOTIE) presented the 3rd Energy Master Plan (2020 to 2040), which also set ambitious renewable power generation targets, ranging between 30% and 35%, by 2040.

[5] *The Republic of Korea uses different categories of renewable energy than IRENA. This figure is from the country's Renewable Energy 2030 Plan.*

The deployment of renewable generation in the Republic of Korea faces significant challenges, however, such as the limited availability and high price of suitable land. This has caused the government to focus its attention on the potential of offshore wind and floating solar PV generation. Most recently, in October 2020, President Moon Jae-In announced the ambitious target of achieving carbon neutrality by 2050.

The integration of renewables into the energy mix has been assisted by the unbundling of the generation and distribution market undertaken in the early 2000s. The Korea Power Exchange (KPX) was established back then for wholesale power trading. Renewable energy generators can sell electricity on the exchange, or apply for a long-term fixed price contract of up to 20 years.

As the Republic of Korea imports 97% of its energy – mainly from outside the NEA region (MOTIE, 2019) – securing cost-competitive energy resources has been a policy priority.

To overcome these challenges, the government has underscored renewable energy and innovation in its energy policy, including the development of hydrogen and energy storage system (ESS) technologies. The Republic of Korea is the global leader in fuel cell technology for utility-scale power generation and has set a target of installing 15 GW of capacity in utility-scale hydrogen fuel cell power generation by 2040. The Republic of Korea is also the only NEA country to formalise and institutionalise the NEA interconnection goal.

MOTIE explored the concept of an NEA super grid in the 3rd Energy Master Plan 2020-2040 (2019) as a means of securing a stable energy supply. Related to this, MOTIE has stated that it will introduce a legal basis for overseas electricity trade in the electricity business act, as well as seeking to establish a special purpose vehicle (SPV) for interconnection between the Republic of Korea and China.

Bukchon Hanok Village in Seoul, Republic of Korea.

The Russian Federation

Energy exports are a central pillar of the Russian Federation's economy and have long contributed to the country's important position, both globally and regionally.

In 2018, some 17% of global gas production and 12% of global oil production came from the Russian Federation, making it the second largest gas and third largest oil producer, worldwide (BP, 2019). Export of energy resources accounted for 54.5% of the country's total exports in 2018. The main export products are crude oil (36.8%), natural gas (27.1%), oil products (18.4%), and coal (17.5%). The main imports are coal (64.1%) and natural gas (26.9%). Although the Russian Federation takes part in bilateral trade of energy resources, its energy imports have been declining, while its energy exports show the opposite pattern, rising continuously during the last 20 years.

As a major energy exporter, excess capacity in the existing power fleet and a good potential for hydropower development underpin plans to export electricity to other NEA countries.

While the Russian Federation's electricity production centres on non-renewables, the role of renewables has been gradually increasing.

Electricity production in 2018 consisted of natural gas (46.2%), nuclear (18.5%), hydropower (17.2%), and coal (17.2%). Large hydropower production represents the main source of renewable energy in the Russian Federation's energy mix, with bioenergy a distant second. In 2019, total installed renewable power capacity reached 52.7 GW, with 95.1% of that accounted for hydropower, followed by bioenergy (2.5%). Solar and wind power generation capacity was recorded at 0.5 GW and 0.1 GW respectively in 2018 (Figure 3). Despite the growing presence of renewables in electricity generation, their share in total primary energy supply (TPES) remains relatively low, at 2.5% on average for the period 2000 to 2017.

Given its status as a major energy exporter globally, the Russian Federation is interested in the concept of electricity interconnectivity in NEA. This also corresponds to the country's 'Turn to the East' policy: a strategy aimed at strengthening economic and political relations with NEA countries. The development of Russian East Region resources, including oil, natural gas, coal and hydropower, is identified as one of the key objectives of the country's Energy Strategy to 2035 (ES-2035), which aims to diversify energy exports towards Asian markets. In order to expand the capacity of the Power of Siberia gas transmission system, additional electricity generation and new grids are also required to power compressor stations.

The relatively slow growth of per capita electricity consumption in the Russian Federation is also a reason for the country's interest in NEA power interconnection. Domestic electricity consumption has fallen short of the targets set out in the Russian Federation's energy policies. Another aspect is the decreasing energy intensity, which now stands at 78% of the 2005 level of domestic energy consumption per unit of GDP (Ministry of Energy, 2018). Despite this reduction, the Russian Federation's economy remains the most energy intensive in the NEA region.

The energy-economic outlook of the Russian Federation's eastern region is mixed. On the one hand, the economy has developed slowly and the demographic situation has been stagnant or unfavourable. Excess capacity in the existing power fleet and a good potential for hydropower development underpin plans to export electricity to the NEA countries. On the other hand, gas fields in Sakha and Irkutsk and deposits in the Krasnoyarsk region and Sakhalin shelf, along with planned LNG developments and gas pipeline projects, increase economic activity and demand from compressor stations, so domestic needs for electricity will also grow.

Meanwhile, activities in the Russian Federation's energy sector are divided up amongst multiple large utilities and transmission companies. It is worth noting that public energy company Inter RAO is in charge of the majority of projects involving international power interconnections and electricity exports. RusHydro operates the majority of the power generation capacity in the Far Eastern region, while Rosseti holds the monopoly on national power grid operation.

Golden Horn Bay in Vladivostok, Russian Federation.

NEA electricity interconnection plans

Overview

Regional energy co-operation has become an important topic in the 'high politics' of NEA countries. It is therefore hardly surprising that scientists and research institutions across the region have been mobilised to study the effectiveness of the development of transboundary interconnections and an integrated regional grid.

In consequence, an enormous amount of research on this topic has been done. A recent report by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) identified 130 studies on power grid connectivity initiatives in NEA, of which some 70 were feasibility studies and models (ESCAP, 2020).

As ESCAP has provided a comprehensive review of the literature, this report will not duplicate work by giving a general overview of the past-to-present literature on NEA interconnection plans. Instead, this study will provide a review of a selected sample of studies, which propose, model, and analyse a comprehensive interconnection scheme covering three or more NEA countries. By doing so, this study will highlight some of the specific gaps in the existing debates and suggest directions for future enquiry.

The selected studies in this report primarily take economic and technical perspectives on the topic and have used optimisation models developed in their respective institutions. Following this approach, they focus on questions of how the generation system should expand, where, when and by which technology and fuels; the capacities and types of power lines that need to be built to connect regional supply and demand; and what the costs and benefits would be. Only a few of the studies address the regulatory, institutional, environmental, and social impacts associated with the studied schemes, even though some of them may have a brief qualitative discussion on those topics.

By reviewing the outcomes of selected past interconnection plans for integrating power systems in NEA, this report provides stakeholders with an updated view of NEA interconnection.

Review of selected studies

► NEA energy co-operation based on resources in the Russian Federation

The concept of interconnecting NEA countries with transmission lines enabling cross-border trade of electricity – or an expanded idea to interconnect many, if not all, NEA countries into an integrated power grid – was already expressed and explored in the 1990s. That era saw strong economic growth driven by vigorous export-oriented industrial production in China, Japan, and the Republic of Korea.

The traditional backbone of these interconnection proposals has therefore been in using the abundance of natural resources in the eastern regions of the Russian Federation to meet the high growth of electricity demand in China, Japan, and the Republic of Korea. The growth of fossil fuels-based electricity production has indeed deepened the dependence of China, Japan, and the Republic of Korea on international energy markets, while also deepening their exposure to the associated risks of long-distance seaborn transportation. Yet, there are alternative energy sources available in the eastern regions of the neighbouring Russian Federation. Coal, natural gas, and hydropower can be brought to neighbouring countries through land-based pipe or cable connections.

For the Russian Federation, energy exports to neighbouring countries represent an opportunity to develop the region's economic base. The Russian Far East suffers from unfavourable population development because of migration outflows, an aging workforce, poverty, and insufficient infrastructure.

In this context, the president of the Russian Federation has placed energy co-operation on the main agenda of the country's foreign relations in NEA. Already, by the 2000s, energy co-operation was therefore spearheading the development of Russian-Chinese relationships.

In 2006 a presidential meeting in Beijing saw a raft of agreements concerning, among other things, oil and gas pipeline development, co-operation on peaceful nuclear energy, and the supply of electricity (Lo, 2006). Ten years later, in 2016, President Putin expressed his support for the concept of creating an electricity super grid at the Eastern Economic Forum in Vladivostok (Belikova, Badaeva, and Akhamova, 2019).

President Vladimir Putin's bilateral meetings with the leaders of the neighbouring NEA countries, including Japan and the Republic of Korea, have highlighted the opportunities that would be provided by intensified energy co-operation, including on natural gas, oil, and electricity.

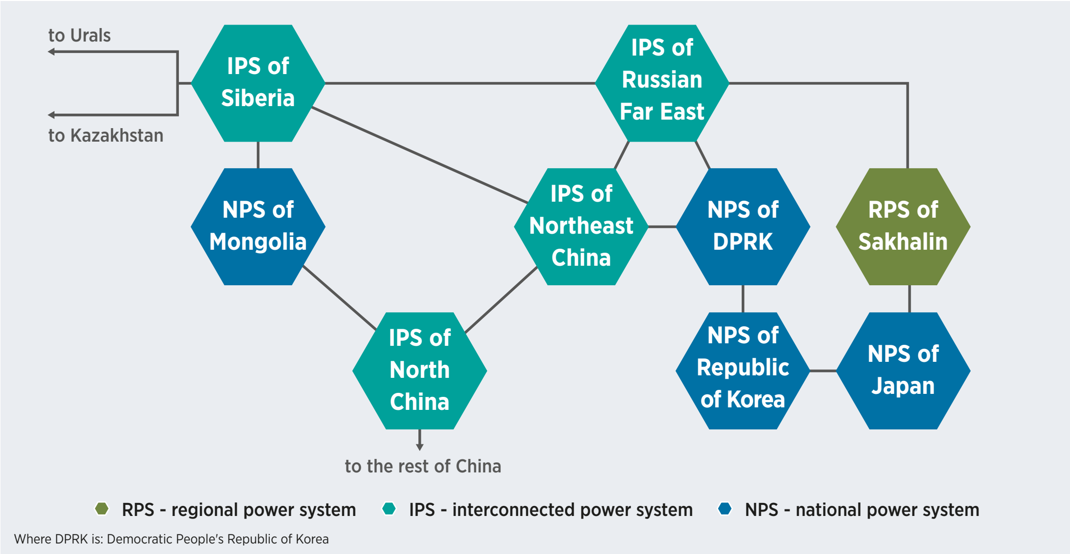
Discussions over the development of the Japanese-Russian Power Bridge started in the early 2000s, based on the idea of electricity production by a gas combined cycle power plant in Sakhalin. Electricity was planned to be conveyed to the Niigata region in Japan from Sakhalin, and the project was supported by Japanese industrial giants Marubeni and Sumitomo Electric Power. This idea was revitalised after the Fukushima nuclear accident, leading to a pre-feasibility study by the Russian Federation company Rossetti and Japan's SoftBank, which was published in 2017 (Lee and Jeong, 2017). President Putin then told members of the press, at the conclusion of the 2017 Japan-Russia summit, that the Japan-Russia Power Bridge had been one of the main topics discussed during that meeting.

The linkage of the Republic of Korea-Russian power system has also been on the agenda since 2006, although progress has oscillated along with the political situation around the Korean Peninsula and inter-Korean relations. At the Republic of Korea-Russia summit in 2017, President Moon proposed a strategy for power co-operation between the two countries, while the Russian Federation's power companies and the Korea Electric Power Corporation (KEPCO) have stated they are ready to continue discussions at the appropriate time (Lee and Jeong, 2017).

While a valuable body of research on the integrated NEA grid has been created around the concept of utilising the Russian Far East as the key supply base for China, Japan, and the Republic of Korea, the economic feasibility of a tripartite scheme for the Russian Federation, the Democratic People's Republic of Korea and the Republic of Korea has also been studied as a collaborative effort. This included a team of researchers at Hongik University of Seoul and used the Russian-originated Optimisation of Power Systems Expansion and Operating Modes (ORIRES) model to analyse and confirm the economic feasibility of the NEA Region Electrical System Ties (NEAREST) project (Chung et al., 2007). In parallel, the Russian counterparties with the Melentiev Energy Systems Institute of the Siberian Branch of the Russian Academy of Sciences performed a similar analysis, among others, with Skolkovo Institute of Science and Technology (Skoltech) and KEEI. Some of the results of these parallel studies were published in a joint study on the feasibility of cross-border transmission lines in the NEA countries (Voropai et al., 2019).

Voropai et al. (2019) also refers to the work done by experts at Korea Electrotechnology Research Institute (KERI) to compare several potential scenarios for electricity interconnections from the Russian Federation to the Republic of Korea. According to Voropai et al. the KERI team concluded that the construction of the ± 500 kV DC Vladivostok-Pyongyang-Seoul transmission line between the interstate power grid of the Russian Far East and the Korean peninsula is feasible.

Figure 4 Diagram for the interstate power interconnection in NEA



Source: Khamisov O. Podkovalnikov. S. (2018)

The modelling work of the Melentiev Institute has repeatedly confirmed the positive economic impact of an NEA regional interconnected system. Their principal and most often reported interconnection concept includes nine nodes, as described in the Figure 4.

On the side of the Russian Federation, nodes include: Siberia, west of Lake Baikal; the Russian Far East; and the Sakhalin peninsula. Southern Siberia is a potential major source of electricity with the region, as it has the five largest hydropower stations in the Russian Federation. Those are located on the Yenisei and Angara rivers, north of Mongolia. The hydropower plants include Sayano-Shusenskaya (6.4 GW), Krasnoyarsk (6.0 GW), Bratsk (4.5 GW), Ust Ilimsk (3.8 GW) and Boguchany (3.0 GW). Mongolia, the Democratic People's Republic of Korea, the Republic of Korea and Japan are each modelled as one node. China is represented in the model by two nodes, with supply and demand separately modelled for north China and northeast China.

In the model, power lines run from northeast China and the Russian Far East to the Democratic People's Republic of Korea. From there, an interconnecting line runs to the Republic of Korea. Japan is connected to the Russian Federation through Sakhalin in the north and to the Republic of Korea in the south.

The study on the prospects of interconnections between the Russian Federation and NEA (Podkoval'nikov, Savel'ev, and Chudinova, 2015) applies the institute's proven mathematical model for optimising the expansion and operation of a power system and interconnections. The study estimates that the integration of the NEA countries' systems through cross-border lines will result in total savings of more than USD 24 billion, annually. This includes over 65 GW of savings in installed capacity, along with savings of nearly USD 80 billion in investment costs. The impact of fuel savings amounts to USD 10 billion per year.

A subsequent, 2017 joint study by the Melentiev Institute and Skolkovo Institute of Science and Technology continued this work by analysing the impact of an interconnected system by country.

The study found such a system would have the greatest impact on Japan and China, which together accounted for more than two-thirds of the total effect. The share of the Republic of Korea remained small, however, at 7%. The system would have the largest impact on the Russian Federation in physical terms, i.e. as measured by exported TWh, but after investments in power plants, transmission lines and associated fuel costs are taken into account, the Russian Federation would receive about 10% of the total system effect as a result of realising the NEA interconnection (Podkoval'nikov, S.V. et al., [2018]).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A Melentiev Institute analysis by Chudinova, Podkovalnikov and Tofimov (2019) expands the modelling to include Central Asia as part of the NEA grid. This study confirms that the integration of Kazakhstan with the Russian Unified Power System (UPS) and the NEA integrated grid is also feasible.

In their *Shadow Price Analysis of Potential Northeast Asia Power System Interconnection*, Khamisov and Podkovalnikov (2019) approach the benefit of an NEA integrated system by defining this as the difference between electricity payment under either the isolated or jointly operated national power system.

The electricity costs (the term used in the study is "shadow price"), when presented by country in terms of US cents per kilowatt-hour, conveys the results to the readership in more tangible terms than when expressed as billions of dollars saved. The study determines that the weighted average cost for the national power systems equals up to USD 10 cents/kWh in the absence of the interconnected NEA power system. On the upper end of the average are Japan, with its estimated cost of USD 16.4 cents/kWh, and the Democratic People's Republic of Korea, with USD 11.3 cents/kWh. The weighted average cost would fall to USD 6.6 cents/kWh in the event of power interconnection. To put it another way, the benefit for electricity users would be USD 3.4 cents/kWh on average, with the result varying by country.

▶ Changing perspectives

The mid-2010s brought a change in perspective to NEA regional energy co-operation. Meeting in Paris in 2015, signatories of the United Nations Framework Convention on Climate Change (UNFCCC) agreed to accelerate their efforts against climate change, boosting investment and activity aimed at achieving a sustainable, low carbon future. The event brought a heightened awareness worldwide among politicians and the public on these issues, with the value of renewable energy as the key weapon in fighting global warming becoming increasingly appreciated.

Indifference to the harm caused by coal burning also began to fade. Yet, it is widely understood in NEA that coal combustion has underpinned much of the region's economic growth. In China, coal is also valued as a domestic resource supporting local employment and energy independence. Poor air quality due to coal combustion and its health consequences in cities throughout the region, however, could not be ignored. Today, China, the Republic of Korea and Japan have set green development targets in which the share of coal in the energy mix is to be gradually reduced.

Another impetus for new sources of energy resulted from the 2011 earthquake that led to Fukushima Daiichi nuclear power plant explosion and the evacuation of the nearby population. Popular support for nuclear power generation took a major hit, forcing decision makers in both Japan and the Republic of Korea to consider alternatives to nuclear power.

At that point, Masayoshi Son – the founder and CEO of Japanese telecom giant SoftBank – presented the idea of a continent-wide electricity transmission ring, the Asian Super Grid. This would be associated with intensive renewable energy development in remote areas. Since then, the Renewable Energy Institute (REI) in Japan has fostered the concept.

The idea is to connect Japan, China, the Republic of Korea and the Russian Federation with an international power grid that would use solar and wind-generated renewable energy from Mongolia as its principal power source.

In this context, renewables deployment, the creation of large balancing areas for the variable output of wind and solar energy, energy efficiency, and diversification of energy sources all began to determine many of the plans for NEA interconnectivity development.

Renewable electricity development is taking central stage at the NEA interconnectivity development studies. Future studies should reflect the ongoing global energy transformation further.

In 2016, the Stage Grid Corporation of China (SGCC), KEPCO, SoftBank and Rosseti signed an MOU for joint promotion of power grid interconnections. KEPCO established a permanent task force to analyse and promote the plan, while the same year, the Global Energy Interconnection Development and Co-operation Organisation (GEIDCO), a non-profit international organisation, started operations from its headquarters in Beijing.

Following these developments, several pre-feasibility and feasibility studies were launched, many of which have not been made available to the public. Yet, research institutions and companies throughout the region did engage in study activities with a view to intertwine regional renewable energy and interconnectivity development. In 2017, KEPCO, SGCC, and GEIDCO signed a joint project development MOU to develop China-Republic of Korea interconnection within the framework of the Mongolia-China-Republic of Korea-Japan power grid interconnection project. At the time of this report, the project parties are negotiating a joint development agreement in order to move forward to implementation.

► Gobitec and the Asian Super Grid: Renewables take central role

The Gobitec and Asian Super Grid study on renewable energy in NEA (Energy Charter et al., 2014) is inspired by the dormant Desertec project. This aimed to interconnect the great potential renewable electricity resources of the Middle East and North Africa with Europe. Dr Bernhard Seliger, from the Hanns Seidel Foundation, and Professor Gi-Eun Kim, from the University of Westminster and Sookmyung Women's University, were first in taking this dormant project up, back in 2009, and applying it to the context of an electricity-hungry NEA and the resource-rich Mongolian Gobi Desert (Gobitec, 2020).

Then, following a Gobitec conference organised in collaboration with the Mongolian Energy Commission in 2012 and a consequent series of events in 2013, five partner organisations from Japan, the Republic of Korea, Mongolia, and the Russian Federation – together with the Energy Charter Secretariat – commenced a regional study for renewable energy in NEA.

The role of the Mongolian government was crucial in promoting the fusion of two regional initiatives – Gobitec and the Asian Super Grid – in this joint initiative. The promoters of the study then included the Ministry of Energy of Mongolia, the Energy Charter Secretariat, the KEEI, the Japan Renewable Energy Foundation, and the Energy Systems Institute of the Russian Federation. Germany's Frauenhofer Institute for Systems and Innovation Research ISI and Institute for Solar Energy Systems ISE acted as project consultants.

The study built on the concept of having 100 GW of renewable energy developed in the Gobi Desert for export to China, the Republic of Korea, and Japan with the scheme to be operational in 2030. The associated grid connects Irkutsk in the Russian Federation with Beijing, Shanghai, and Seoul in the south, and Japan through a northern line via the Sakhalin peninsula in the Russian Federation, which also passes through the Republic of Korea in the south. The cost of the infrastructure was estimated at USD 294 billion and the annual operation and maintenance at USD 7.3 billion. The total unit cost of supply was estimated at USD 0.10/kWh to USD 0.13/kWh, with average capacity factors of renewable energy production ranging from 40% to 30%. Since the time of the study, the technical performance and costs of associated technologies, such as point-to-point high voltage DC lines, onshore wind turbines, and solar PV, have also developed favourably.

The study was seminal. Its holistic approach covered not only technologies, costs, and financial benefits, but also the necessary legal frameworks, environmental and social benefits – such as job creation – and the risks and opportunities associated with such a megaproject. The study also recognised the need to mobilise balancing capacity to smoothen the variation of wind and solar PV power in South Gobi. Existing fossil-fuelled electricity supply, concentrated solar power (CSP), thermal power plants and hydropower in the Russian Federation were all seen in this role.

The need to assess the spatial distribution of renewable energy production, to reduce sudden ramp-ups and downs in production, was identified as a topic for further studies. Furthermore, the study left it for later researchers to assess the renewable energy potential in the South Gobi area and how it could be deployed. Secondly, it also encouraged the analysis of the overall policy framework and identified the existing weaknesses hampering the initiative. The study recommended a strategic start, then developing smaller projects and aligning them with the Gobitec/Asian Super Grid vision.


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► APERC: Refined modelling and scenario analysis

The Gobitec/Asian Super Grid analysis was quickly followed by modelling work by the Asia Pacific Energy Research Centre (APERC, 2015). This estimated the economic and environmental benefits of an interconnected system for NEA, giving four scenarios in addition to the base case of "no grid extension." The work is reported in APERC (2015) and in *Energy Policy* (Otsuki, 2016).

The APERC study was of a quantitative nature, rather than a holistic one, in that important factors surrounding NEA interconnection plans were not discussed. These factors included technical challenges, geopolitical issues, regulation, and social impact. The APERC analysis does, however, provide a more detailed account of what would happen if the interconnections were realised, how the loads would flow and what the impact would be of the assumed new renewable energy capacity in Mongolia and the Russian Federation on the participating countries' generation mix. One scenario studied aligns with the Energy Charter et al., (2014) concept, as to the supply side capacity and location in South Gobi, and serves as a valuable review, endorsement and addition to what was achieved by that study.[6]

The APERC research team developed a multi-region power system model covering all the NEA countries to quantify the economic benefits of power grid interconnection and renewable energy expansion. The model pursues the overall system cost, assuming forecast unit costs at a 2030 level that is mainly based on IEA estimates. It also considers seasonal and daily electricity load patterns in the region, as well as renewable energy outputs in the Gobi Desert. The study reports the optimal generation mixes and level of power trade, assuming representative daily load curves for each season. The resulting changes in the generation and fuel mixes are reported separately for each economy.

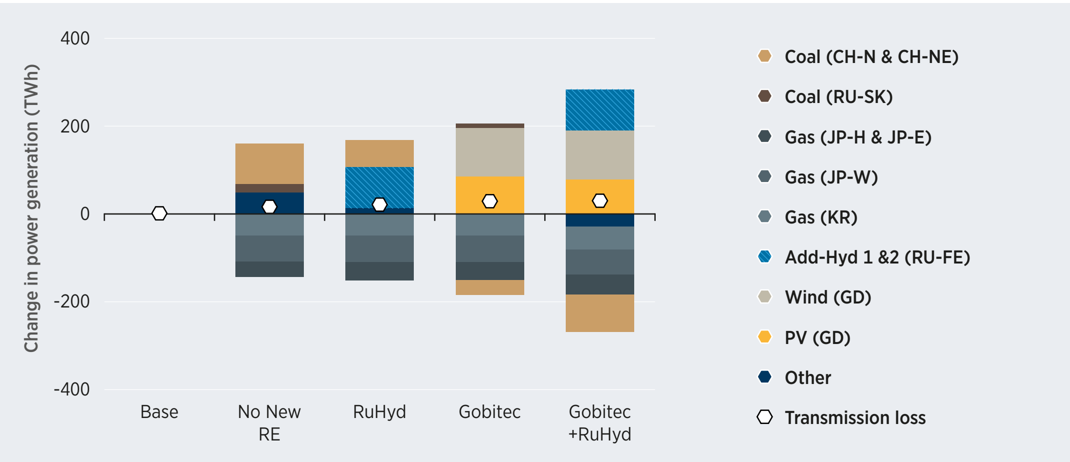
The study takes into account several different scenarios: first, a base scenario with no grid expansion; second, a 'NoNewRE' scenario with new interconnections and fixed renewable capacity to the base scenario assumptions; a 'RuHyd' scenario with additional hydropower development for exports in the Russian Federation; the Gobitec scenario proposed by Energy Charter et al. (2014); and lastly, the Gobitec+RuHyd scenario, which takes both the Gobitec and the RuHyd cases into account.

[6] *It should be noted, however, that cost assumptions and grid configuration by APERC (2015) are different from those of Energy Charter et al. (2014).*

The study quantifies an evident but important consequence of developing regional interconnectivity. That is, that energy sources of low marginal cost tend to replace the use of high marginal cost generation, adding coal-based electricity to the system, if renewables are not developed. In all scenarios, the fuel mostly replaced is natural gas, whether by coal or renewable energy. Increased renewable energy supply will replace coal only after the potential to reduce natural gas is exploited. This result follows even when a model assuming a carbon emissions cost of USD 30/tonnes CO_2 equivalent as its base assumption. Consequently, without adding the Russian Federation's hydropower, or wind and solar PV energy from Mongolia into the mix, interconnection development would increase regional CO_2 emissions by 2.3%. In the scenario with both the Russian Federation's and Mongolia's renewable energy resources included, CO_2 emissions are estimated to fall by 149 Mt $CO_{2,}$ or by 5.3%.

According to the study, additional investments of USD 300 billion and USD 390 billion respectively are needed to implement the Gobitec and Gobitec+RuHyd scenarios, when compared to the base scenario. The former includes 100 GW of renewable capacity in the Gobi and the latter includes both Gobi and hydropower capacity in the Russian Federation. The study assumed 13 GW and 5 GW of available hydropower in the Russian Far East and Siberian grids, respectively. The assumed investment cost of transmission lines in the Gobitec and Gobitec+RuHyd scenarios is about USD 200 billion. In these cases, there would be an increase in the share of renewable energy in the NEA region from 12% to 18%. Breaking increased share down, the Russian Federation would supply 2% by hydro, while the remaining 4% would come from solar and wind power in the Gobi Desert.

Figure 5 Changes from the base scenario by scenario in NEA power generation



Source: APERC (2015)

The study indicates rather moderate economic benefits to the scheme analysed. With the base assumptions for the initial costs, fossil fuel prices and CO_2 cost, the option which includes renewable energy development in the Gobi and Russian Federation is feasible, however, providing net economic benefits of USD 3 billion annually, with the capital recovery factors for investments calculated at an assumed discount rate of 3%.

The study also raised interesting proposals for future work, including additional study of other types of renewables (e.g. biomass in Northeast China) and their contribution to emissions reductions in the NEA region.

Finally, the study noted that it would be necessary to find ways to share, in an appropriate fashion, the cost-burden amongst different NEA countries, as well as the credit gained from emissions reductions.

► The Asian Super Grid and REI

Japan's REI was founded by Masayoshi Son with the aim of promoting renewable energy through researching, developing and advocating policies, measures, and business models that are based on the dynamics of markets and society. The institute acts as the secretariat for the Asia International Grid Connection Study Group, which was established to support power interconnections in Asia. In accordance with its mission, the study group has released three reports about NEA interconnectivity development, with a clear focus on interconnections involving Japan. – specifically, transmission connections from the Russian Federation to Japan and from the Republic of Korea to Japan.

The first, Interim Report sets the scene by describing the concept of an international power grid, explaining the current status of interconnectivity in the NEA region and drawing preliminary conclusions for Asia from the experiences of the European Network of Transmission System Operators for Electricity (ENSTO-E) interconnected system (REI, 2017).

The Second Report (REI, 2018) provides background to the interconnectivity study by giving an account of ongoing changes in the Japanese electricity market. These include the unbundling of vertical utility companies and a market system reform which brings competition to both the wholesale and retail levels.

The report discusses Japan's possible interconnectors with the Russian Federation and the Republic of Korea, as well as their costs. It carries out line route planning as an on-desk exercise by optimising line options by length and cost. The analysis simultaneously pays attention to some marine cable issues (e.g. fishery rights, rocky sea beds). Specific cost estimates are drawn from the experiences of relevant Japanese and overseas transmission line projects.

The examination leads to the identification of three alternative connections to the Republic of Korea and four alternatives for a connection to Sakhalin in the Russian Federation.

Having identified the possible connection routes, the report discusses various interconnection business models and the social benefits and legal frameworks associated with them. The report describes North American experience with long transmission lines, many of which are transboundary. It gives a view of the contrasting European and North American situations. EU linked institutions and national governments play a leading role in the development of European interconnections, whereas in the United States and Canada, state or provincial governments and businesses have moved forward these initiatives on a commercial basis. The authors note that the North American setups offer insightful references for NEA.

The Second Report also provides a highly valuable discussion, description, and preliminary quantitative analysis of five different interconnection business models for the seven identified transmission line routes between Japan and the Republic of Korea, as well as Japan and the Russian Federation. The calculations are made for both 1 GW and 2 GW connections. It also examines the social benefits the interconnectors will provide and the legal frameworks needed to establish them.

The study finds that the constructions costs of a 2 GW capacity interconnector between Japan and the Russian Federation and Japan and the Republic of Korea are expected to range between USD 4.1 billion and USD 5.4 billion, and USD 1.9 billion to USD 2.3 billion, respectively, depending on the route. Operation and maintenance costs were assumed to vary between 1% and 3% of capital expenditure (CAPEX).

As a concise summary, the various business models gave the following results:

- Under the **supplier-dedicated line** model, electricity is sold one-directionally from the Republic of Korea or the Russian Federation to the JEPX wholesale marketplace in Japan. The difference between the JEPX price and the free-on-board (FOB) cost of electricity at the source is to be used to pay back the cost of the transmission line. The FOB cost includes the seller's generation and transmission cost at the sending end. Reasonable returns (with an internal rate of return [IRR] of around 5% and above) can be collected, if the FOB price is no more than USD 0.066/kWh or USD 0.085/kWh for a 2 GW line from the Russian Federation and the Republic of Korea, respectively.
- In the **regulated grid tariff model**, the cost of infrastructure is borne by transmission operators on both sides (the cost is socialised). In this business model, electricity consumers should pay around USD 0.08 /kWh in their electricity bill to cover the cost of interconnection at a reasonable return requirement.

- In the **power transmission rights auction**, the right to use the line is sold to power producers or electricity retailers. The income provided by the auction of the transmission right then goes to recovering the cost of investment. According to the study, the investment in the Russian Federation line will be paid back, if the rights are sold at USD 0.0096/kWh or more. The connection to the Republic of Korea requires the rights to be sold at approximately USD 0.0057/kWh or more.
- In the **congestion charge model**, the congestion charge is calculated by multiplying the volume of transmitted energy by the wholesale price difference between the sending and receiving markets at any moment. The power flows in two directions, depending on the hourly prices of the KPX (the Republic of Korea) and JPEX (Japan) markets. The study estimates that, with line capacity factors of 50% or more, the differences in market prices between the Republic of Korea and Japan are sufficient to recover the investment in the transboundary line.

According to the analysis' conclusions, there are no significant problems of a technical or physical nature when it comes to constructing interconnectors that would link Japan to the other network. The simulations also show that the construction costs of 2 GW interconnectors are quite recoverable under various business models.

The identification by the Asia International Grid Connection Study Group of four possible business models then spurred some continuation studies.

Kimura and Ichimura (2019) discussed the transmission rights auctions and congestion charge models. Regarding the latter, the authors noted that this would require the markets of the Republic of Korea and Japan to be coupled, which would lead to a smaller difference between the wholesale prices of the two markets, and thus affect the profitability.

Zissler and Cross (2020) then presented an economic assessment of power exchange prices for an interconnection between Japan and the Republic of Korea. Again, the authors predicted greater competitiveness in the market, leading to a lower cost of electricity for suppliers and consumers, but also to a reduction in the profitability of the line.

The Third Report (REI, 2019) discusses a range of non-financial benefits and counterarguments for cross-border interconnectors from the Japanese perspective. It highlights the point that international grid connections increase supply stability by sharing reserve capacity. They also promote the deployment of renewable energy, as they help balance the variability of renewable energy output. The report also discusses energy security concerns associated with cross-border trade of electricity, but finds most of them irrelevant.

► The NAPSI Strategy Study

The Gobitec study (Energy Charter et al., 2014) brought into focus Mongolia's South Gobi as the potential source of clean renewable energy for the whole NEA region.

Mongolia is geographically located between the hydropower-rich Russian Siberia region and North China and thus along the shortest route to interconnect these two. Mongolia is also politically neutral and keen to develop NEA region-wide energy co-operation. Logically, therefore, Mongolia attaches high priority to the development of its energy resources and regional interconnections. The State Policy on Energy of 2015 declared that its vision for Mongolia is for it to become an energy exporting country with efficient and environmentally friendly technology.

In 2015, the government of Mongolia sought technical assistance from the Asian Development Bank (ADB) to prepare a strategy for NEA power system integration (NAPSI) using Mongolia's abundant renewable energy resources. The ADB assigned a consortium of Électricité de France (EDF) in partnership with China Electric Power Research Institute (CEPRI) and Hangzhou Dianzi University in China, as well as Nova Terra LLC Mongolia, to carry out the study. NEA regional transmission utility companies, such as Rossetti PJSC, KEPCO and SGCC, also supported the project intensively, giving guidance, data, and information.

The study includes five distinct areas of analysis:

- An electricity market analysis in an interconnected NEA system associated with a cost/benefit analysis of an interconnected system opposed to an isolated regional system, as well as with and without solar and wind power capacity located in the Gobi Desert. The modelling and simulation methodology supporting this analysis bears a resemblance to the methodology of APERC (2015) and various modelling works by the Melentiev Institute (EDF, 2018a).
- An analysis of the wind and solar power potential of Mongolia, which was at the time the most comprehensive one carried out for the country, covering the technical and commercial potential through a multi-stage ranking process (EDF, 2018b).
- A least-cost generation expansion plan for Mongolia (EDF, 2018b).
- An analysis of transmission grid development towards NEA interconnection, considering scenarios based on 5 GW, 10 GW and 100 GW of renewable power capacity in the Gobi Desert. The grid analysis includes: discussion and comparison of the merits of High Voltage Alternating Current (HVAC)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and HVDC transmission systems; new subsea cable technology allowing a shorter route from Russian Far East to Japan; and load flow and fault current analysis of various grid extension options. This part of the coal-based analysis also sought to identify the most feasible cross-border interconnections and landing points for submarine interconnection cables (EDF, 2018c).

- A discussion of regional interconnections as implemented elsewhere in the world, business models applicable for NAPSI, investment recovery mechanisms and power sector regulation (EDF, 2019a). In this discussion, the recommended business models are drawn mainly from the European context.

The electricity market analysis shows that the regional interconnection would be cost effective on the basis of the assumed marginal costs between the five involved countries, even with the existing generation set-ups. The injection of renewable energy capacities shows that the solar and wind power from Mongolia would find a market in the four other countries under a scenario of at least 10 GW of production. Small capacities of renewable energy proved unfeasible in the simulation during the early years of the planning period. In scenarios of 10 GW and more, however, the net benefits of the renewable energy deployment became evident.

The model does not include policy-based constraints for the use of coal-fired capacity, nor for the need to maintain gas-fired capacity in the participating countries. The marginal costs in the simulation also did not include any policy-based costs, such as the CO_2 price. Consequently, in the first stage, low marginal cost coal-fired capacity and renewable energy are anticipated to replace gas-fired capacity. Only when the volume of renewable energy is allowed to grow to high levels in the model does it also start reducing coal-based electricity production.

The system optimisation model estimates the annual net benefits of the integrated system at about USD 3.4 billion, when the renewables capacity located in South Gobi is 10 GW. The annual benefits would increase to USD 10.6 billion if the renewable power capacity were to increase to 100 GW. The large, 100 GW scheme, equivalent in that respect with Energy Charter et al. (2014) and APERC (2015), would cost USD 148 billion to develop and result in the reduction of regional CO_2 emissions by 210 Mt (-5%). Three quarters of the CO_2 emission reductions were attributable to reduced gas use and one quarter to reduced coal combustion.

The investment cost of USD 149 billion compares to the USD 300 billion in the Gobitec scenario in Energy Charter et al. (2014) and APERC (2015). The CO_2 reduction in the Gobitec scenario of APERC (2015) is 84 Mt and that of Energy Charter et al. (2014) 187 Mt annually.

The NAPSI Strategy Study also completed the resource estimation for wind and solar PV in South Gobi, which was suggested as future work in Energy Charter et al. (2014). A robust Geographic Information System (GIS) model was employed, using the latest available wind and solar resource data on locations and technologies, in order to select suitable sites. A set of technical, environmental and regulatory constraints were taken into account in order to filter out areas incompatible for future wind or solar PV development.

The process found high quality resources located within 20 kilometres (km) to 50 km from existing 220 kV substations that totalled 22 GW of wind and 484 GW of solar PV. The total economically viable resources were estimated at 191 GW of wind and 1 166 GW of solar PV. The study validates the belief that renewable energy produced in Mongolia meets the prerequisites for being the lowest cost in the NEA region.

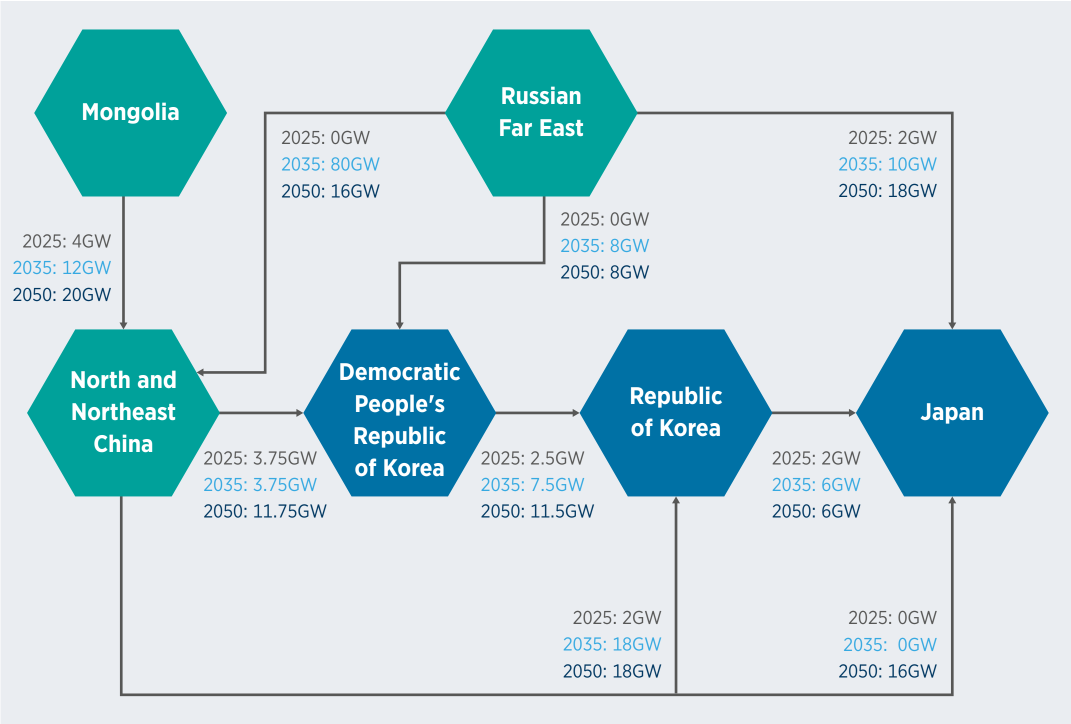
► **GEIDCO's vision**

GEIDCO's vision for NEA grid integration is based on clean energy development, which in turn relies on two megatrends. The first is the clean replacement of production, a process of accelerated replacement of fossil fuels with clean alternatives, such as solar and wind energy. The second is electricity replacement on the demand-side, in which electricity replaces other energy carriers, most notably direct use of fossil fuels. Both processes are placed in the context of NEA energy complementarities and national energy policy targets in the 2018 presentation, *Recent Research Achievements of Northeast Asia Energy Interconnection* (GEIDCO, 2018).

GEIDCO's vision on the supply side includes distributing clean energy bases in pre-selected areas, with this including 2 hydropower, 19 wind energy, and 5 solar energy bases with a total technical generation potential of 990 GW. Hydropower resources are identified from along the Lena and the Heilong-Amur Rivers, with the technical potential of 40 GW and 14.5 GW, respectively, of which 10% has been utilised. Wind energy bases are distributed over the Sea of Okhotsk, Sakhalin Island, Southeast Mongolia, and North and Northeast China, with a total technical potential of 430 GW. Solar energy generation is planned to take place in five bases in South Mongolia, with a total technical potential of 510 GW.

Two scenarios are outlined for the period up to 2050. The 'low-carbon scenario' is aligned with ambitious clean energy targets, aiming at renewables taking an 80% share in total capacity by 2050. The 'normal scenario' assumes that current plans for thermal power plants and renewables development are realised. Solar and wind power is mainly anticipated to serve domestic demand. The share of renewables in total capacity would then be 54% in 2050.

Figure 6 Electricity exchange between nodes in 2025, 2035 and 2050



Source: GEIDCO (2018)

In 2050, GEIDCO sees potential for electricity exports to reach 20 GW from Mongolia and 42 GW from the Russian Federation. Exports from and through North and Northeast China are expected to reach 45.75 GW.

North and Northeast China remain the largest consumption base. With load centres in Beijing, Tianjin, Hebei, and Shandong, these regions represent 61.5% of total electricity demand. This would represent a total load of about 1500 GW. The second largest consumption bases would be Japan and the Republic of Korea, with 460 GW and 210 GW, respectively.

GEIDCO calls the scheme the NEA Electricity Interconnection (NEAEI). The interconnection structure is described as having a “three rings and one line” configuration (GEIDCO, 2018). The ‘one line’ is expected to be from Mongolia to North and Northeast China. The first of the ‘three rings’ runs from North China to the Republic of Korea, then to the Democratic People's Republic of Korea, and back through Northeast China to North China. The second runs through the Korean peninsula to Japan, from Japan to the Russian Far East, and back along the coast to the Republic of Korea. The third ring is formed by interconnections through the eastern side of Northeast China to the Russian Far East and back to North China via the western side of Northeast China.

GEIDCO presents quantified estimates for the environmental benefits of the scheme in terms of CO_2 emission reductions and ameliorated environmental pollution, as well as social benefits, including employment impact. GEIDCO estimates the overall cost reduction in generation cost at USD 0.02/kWh and a total savings in the regional electricity bill of USD 130 billion per year.

► Proposed grid configurations

Figure 7 illustrates the grid configurations of four initiatives for the year 2050, or 100 GW (the highest scenario) of new renewable energy capacity, as described above. Most of these configurations have common features, although important differences also exist.

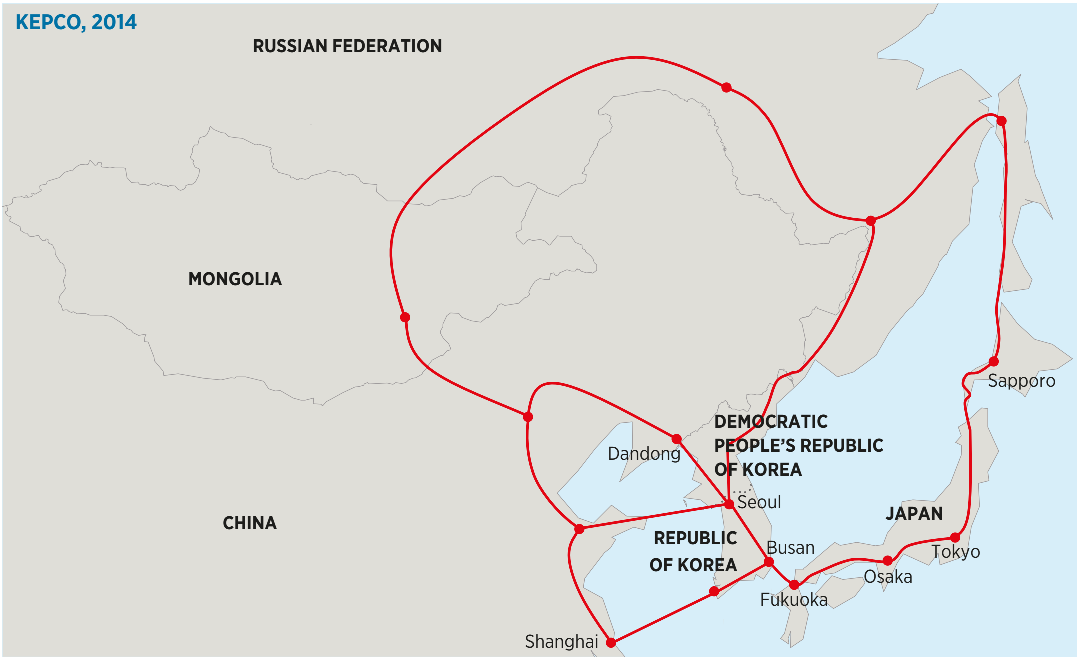
All initiatives include a route from China, or the Russian Federation via the Democratic People's Republic of Korea to the Republic of Korea. This reflects alignment with the foreign policies of the researchers' own countries. The Democratic People's Republic of Korea does not, however, currently participate in planning the initiatives and therefore introducing transmission lines through its territory is not grounded in current political reality. In alignment with the current and perceived near-to-medium-term circumstances, the supply routes to the Republic of Korea need to be planned via submarine cables, whereas the Democratic People's Republic of Korea interconnectors can remain as part of long-term projections.

More recent studies, such as those by REI (2018), GEIDCO (2018) and EDF (2018c), have carried out preliminary technical and financial analysis of several individual transmission line routes, taking into account key technical features of the line and converter technology. In the literature, there are also examples of studies investigating the feasibility of one or few point-to-point lines for power exports between countries. Except for strengthening transmission connection between the Russian Siberian Grid and Far East Grid, the NAPSI Strategy Study (EDF, 2018c) focused only on cross-boundary lines. Its total cost estimate does therefore not include domestic connections in the participating countries, whereas most other studies have included the total costs of the proposed ring configurations in the estimates.

Studies have identified that NEA regional interconnection is economically feasible and desirable from an environmental, social, and political perspective. The studies demonstrate that renewable resources would allow NEA interconnections to significantly lower regional carbon emissions.

Figure 7a Examples of proposed regional grid configurations

Source: Gobitec initiative (n.d.); based on UN Clear Maps.



Source: KEPCO, 2014[7]; based on UN Clear Maps.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

[7] *Configuration presented in APERC (2015) referring to KEPCO's Future Plans of Northeast Asia Supergrid, Presentation material at "Roadmap to Asian Super Grid", Jan 2014. KEPCO.*

Figure 7b Examples of proposed regional grid configurations

Source: APERC (2015); based on UN Clear Maps.

Source: EDF (2019b); based on UN Clear Maps.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Key take-aways of the review

Based on the literature and research discussed above, a few areas can be confidently identified in which there is a significant stock of congruent evidence.

Firstly, the research, modelling and studies have proven that NEA regional interconnection is economically feasible. More than that, the literature indicates that the proposed energy co-operation is also desirable from an environmental, social, and political perspective.

Secondly, detailed studies have verified the availability of renewable energy resources in Mongolia and have even identified the most promising sites for development. The renewable resources in the Russian Federation have also been substantiated, but have not been prioritised or ranked yet. While there may be room for targeted future investigation to prioritise the resources of the Russian Federation, the studies clearly demonstrate the presence of the renewable resources required to allow NEA interconnection to significantly lower regional carbon emissions.

The existing studies, therefore, have provided a solid foundation from which national energy authorities, energy companies and stakeholders of the five NEA countries can work to make NEA regional interconnection a reality.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The review of selected studies below also highlights, however, some limitations in the interconnection initiatives for the NEA region and in their associated studies. The heavily technical and economic focus of previous studies has left important gaps in our understanding of the NEA interconnection case. Future research must therefore seek new focus areas and dive deeper to understand various non-technical and non-economic impediments to NEA interconnections. At the same time, the assumptions that informed past research into costs and benefits and the previous modelling work do not reflect the ongoing global energy sector transformation. Despite the volume of existing studies, therefore, research into costs and benefits is not exhaustive and some of the past modelling work should be updated.

The role of wind power and solar PV in future scenarios has not been effectively evaluated

In some of the reviewed modelling studies, wind power and solar PV do not appear at all among the options for future system expansion, even though the NEA countries have demonstrated their commitment to renewable energy development by having a combined installed wind and solar PV capacity of 495 GW (IRENA, 2020a).

The studies that do engage with renewable energy sources often focus on development in a pre-defined location, most notably the Gobi Desert. Yet, renewable energy production potential is widely distributed in NEA. The Russian Far East, for example, holds substantial potential for wind energy which could be effectively developed if the northern route from the Russian Federation to Japan is considered. Offshore wind power on China's eastern coast may also prove an attractive proposition in the not-so-distant future. To a lesser extent, biomass-based power can also be considered in China's Northeast.

To gain an accurate understanding of the interconnection plans, modelling should be performed that takes into consideration the clear regional will to make use of wind and solar PV renewable energy, as well as the diverse options for obtaining these resources.

Cost projections for wind and solar PV are outdated

A review of the assumptions of the selected modelling studies shows that cost estimates for wind power and solar PV are outdated. Some cost estimates made for 2030 are higher than the on-the-ground costs in 2020. This is understandable, because the cost estimates stem from the international energy agencies, who are obliged to apply conservative assumptions in their scenario work, whereas during the 2010s the cost reductions that took place with solar PV and onshore wind technologies were dramatic, with few predicting them.

The difficulty of forecasting is appreciated, though, while an update of cost forecasts would, of course, be pertinent for all costs – including changes in fuel price outlook. As to renewables, IRENA's global cost studies are based on systematic tracking of renewables costs under different circumstances and highlight cost trends for all major renewable electricity sources.

Models allow coal-fired and natural gas-based capacities to develop endogenously, regardless of de facto *policy constraints imposed by the region's countries*

Many analyses have shown that the interconnection development is already feasible today, i.e. assuming the current demand and constellation of installed capacity. Under these analyses, however, a major part of the effectiveness of interconnection originates from creating the possibility for coal-fired capacity to replace natural gas-fired capacity. This replacement concerns both operational (fuel) expenses and capacity expansion. This replacement mechanism in the models, however, should be subject to policy constraints for both coal and natural gas in China, Japan, and the Republic of Korea. The existence of a large fleet of natural gas-fired generators in these countries is not an accident, but based on deliberate policies aiming at diversification of the energy mix, energy security, reduction of greenhouse gas emissions (GHGs), and controlling air quality. Furthermore, key renewable energy targets, as well as obligations for the power sector arising from Nationally Determined Contributions (NDCs) under the Paris Agreement, should also be incorporated in modelling, as applicable.

The outsourcing of coal-based power generation to the Russian Federation and Mongolia would also create a mixed reaction from the public and financing community in many NEA countries. There have indeed been plans for coal-based development in the Russian Far East, inter alia, in Transbaikalia and Amur Oblast, with several coal-fired power plants with a total capacity of 10 GW to 11 GW (Podkovalnikov, Savel'ev and Chudinova, 2015). Plans to develop massive coal-fired capacity at the Shivee-Ovoo or Tavan Tolgoi mines in Mongolia for exports serve as another instance. Whether or not such capacities, for example, are allowed to develop endogenously in the models under some of the scenarios, often cannot be tracked from the research reports. Capacity choices in the models, should however be considerately introduced as exogenous changes to match the real-life political, environmental and practical priorities of the governments. Currently decided and likely future changes in nuclear capacity should also be reflected.

Modelling studies should transparently report the resultant switches in fuel mix and their associated environmental impact. If there are no accurate policy-based ways to consider externalities (carbon tax, energy tax, an emissions trading scheme), the optimisation models should at a minimum apply shadow pricing for CO_2 emissions.

No unified view on the future grid configuration – national priorities dominate

The wide array of studies into NEA regional interconnection presents a similarly wide variety of national priorities and interests that often drive the focus of the studies. Many initiatives are committed to the idea of transmitting electricity to the Republic of Korea via the Democratic People's Republic of Korea. Whilst this choice aligns with constructive foreign policies and might reflect the preferred situation, it does not align with the current and perceived circumstances in the near or medium term. In order to elevate the readiness levels of the plans they need to be grounded on realities, whereas Democratic People's Republic of Korea interconnectors can remain in the long-term plans.

Many studies by institutions from the Russian Federation do not include in their analysis the currently most advanced NEA interconnection project, which is the submarine cable link between China and the Republic of Korea. Their focus is placed on the optimum transmission of Russian Far East energy to the markets in China, Japan and the Republic of Korea, and the latter is through the Democratic People's Republic of Korea.

The research community around NEA regional interconnection should seek converging views on the optimal regional grid configuration. The differences of grid assumptions can partly be understood from the national policy priorities and the consequent features in the countries' interconnection initiatives. It would be fruitful for research, however, if the studies could be complementary and challenge each other using a set of assumptions that is as unified as possible.

A unified view to grid development would also be more effective in promoting NEA interconnections among decision makers and the financing community.

Differences in market mechanisms for electricity and CO_2 need to be addressed

Electricity markets and CO_2 trading schemes vary significantly across the NEA region, not just between countries, but even across the regions of individual countries. While the studies reviewed engage with this difficulty, they have not fully explored the problem.

The electricity markets are changing rapidly in China, Japan and the Republic of Korea. There is already a mature day-ahead market in the Republic of Korea and a similar market developing in Japan. China is also experimenting with electricity markets.

As to emissions trading, the Republic of Korea's Emissions Trading Scheme (K-ETS) has been in operation since 2015 and is the second largest after the EU emissions trading scheme. Japan has a Voluntary Emissions Trading Scheme (JVETS), but has not proceeded to establish a nationwide initiative. In China, eight Chinese regional ETS pilots have been in operation. The country continues preparing for the Chinese national ETS.

In the Russian Federation, the Siberian region is part of the competitive nodal energy market where trading takes place hourly on a day-ahead basis, whereas the Far East region is under a separate system with regulated tariffs. The Russian Federation also has a parallel, year-ahead competitive zonal capacity market, applicable to the Siberia region, and regulated long-term capacity supply contracts for new capacities.

Future electricity interconnections in the NEA region will depend on the functional features of the above-mentioned markets. Therefore, future studies should consider business models that are compliant with the operational principles and evolving realities of the respective markets.

Future work needs to consider rapid cost declines of renewable energy as well as take a realistic view of the electricity market environment.

Future work should dive deeper

Further work needs to be carried out to establish clearer priority lists for transmission and generation projects to build up NEA regional interconnection based on clean energy production. This includes feasibility studies of individual lines and generation investments in well-founded priority order. Business models that consider the future market rules and enable dynamic trading in two directions should be studied and drafts brought to the negotiations between trading parties.

Deeper insights into the possibilities of utilising for economic benefit time of day and seasonal differences (summertime peak in Japan and the Republic of Korea versus winter peak in the Russian Federation, for example) are needed.

A vital issue for future work is also the need to establish the balancing power associated with variable renewable energy generation. Therefore, flexibility resources in the region should be identified and analysed in the context of planned renewables production, their location, and the associated grid configuration. A study concerning the use of hydropower capacity in Yenisei-Angara systems to balance the variability of wind and solar production in North China and Mongolia would, for example, be highly valuable.

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Yenisei River in Siberia, Russian Federation.

Power system integration stage models

Electricity interconnectivity in the NEA region

As the NEA region countries seek ways to advance cross-border electricity trading, there are examples worldwide of bilateral, multilateral, and regional electricity interconnections and cross-border trade to learn from. In fact, the region itself provides some points of reference, albeit not many, for long-standing trading with electricity and the development of associated physical transmission infrastructure. These existing systems within the region offer examples of the wide range of possibilities for cross-border interconnections and demonstrate the existing will and technical ability to achieve them.

Mongolia provides working examples of three types of cross-border trading with electricity. The first involves bi-directional trading between two grids synchronised with each other. The second consists of unidirectional imports of electricity, and the third represents a case where electricity is imported through a cross-border line to a large consumer, which is isolated from the main Mongolian grid and connected instead to the neighbouring Chinese grid.

Mongolia's Central Region Integrated Power Grid (CRIPG) is synchronised with the Siberian grid of the Russian Federation. Mongolia imports varying volumes of electricity from the Russian Federation to CRIPG through a 220 kV transmission line from Selendeuna in Buryatia. The line provides frequency and ancillary services, including balancing power for CRIPG – meaning that the line operation is bi-directional. In practice, Mongolia acts primarily as an importer of power through this line, but the Mongolian dispatch centre may intermittently export electricity to the Russian Federation, if there is surplus energy generation. This can occur because of high heat production in CHPs during a cold spell, or as a result of high wind power generation at times when thermal plants cannot reduce energy production to adequately balance the power flow.

Mongolia's Western Region Integrated Power Grid is also connected to the Russian Federation's grid, but through a unidirectional import line. This Mongolian grid imports the largest part of its electricity supply through a 110 kV line from Chadan in the Russian Federation. In addition, there are a few towns close to the Russian Federation's border connected to the Russian Federation's grid through medium voltage power lines.

In the south of Mongolia, a single large consumer, the Oyu Tolgoi copper-gold mine in the South Gobi region, is isolated from the Mongolian grid and receives its electricity through a 220 kV interconnector from China. This is an interim import arrangement and will be replaced by a PPA with a state-owned power producer at a later stage.

China and the Russian Federation also have similar types of bilateral trading agreements in China's Northeast Heilongjiang province. In this case, however, there is the notable difference that the two systems are not synchronised with each other. The trading arrangements between the Russian Federation and China include unidirectional imports from the Russian Federation. In one case electricity is imported to the Chinese system from a power plant located on the Russian Federation's side of the border, but connected to, and synchronised with, the Chinese system. This situation is the obverse of the Oyu Tolgoi case in Mongolia, in which a large-scale consumer is connected to the grid of the neighbouring country. In this case, a power producer is connected to the neighbouring country and isolated from the grid of its own jurisdiction.

The main import channel from the Russian Federation to China is, however, a 500 kV line. It is connected to a back-to-back converter station on the Chinese side, thus enabling grid-to-grid trading without the need to synchronise frequencies.

The national system of Japan demonstrates several important features of interconnectivity. Although Japan is not connected to any of its neighbours, it has put significant effort into interconnection focused on increasing the integration of its traditionally fragmented power market. The country is looking for higher interconnectivity between the nine previously vertically integrated electric power companies (EPCOs). The unbundling of EPCOs and the electric power industry of Japan has been completed in recent years, with TSOs established as impartial entities in their service areas. The country is also divided into two wide area synchronous grids. For historical reasons, the grid of eastern Japan (e.g. Tokyo, Kawasaki, Sapporo, Yokohama, Sendai) runs at 50 Hz, whereas western Japan's grid (e.g. Osaka, Kyoto, Nagoya, Hiroshima) runs at 60 Hz.

The Organisation for Cross-regional Co-ordination of Transmission Operators (OCCTO) in Japan is obligated to monitor the electricity supply/demand balance and frequency as well as ensuring a stable electricity supply. This is a role that could be seen as resembling that of a regional interconnection agency or administrator.

Several HVDC schemes are in commercial operation in Japan to fulfil nationwide power interchange between the interconnected regions and the balancing areas of the day-ahead marketplace, the JPEX. Although Japan's interconnections are national, rather than international, they still help demonstrate the existence of highly functional and efficient interconnections between non-synchronised regions.

These NEA examples, as well as the other international examples presented in subsequent case studies, show the many available options for establishing interconnectivity and active bi-directional and multi-party electricity trading between non-synchronised regions. They prove that there are no insurmountable technical barriers to interconnection, even across large regions with diverse existing infrastructures.

Integration stage models

The particulars of any international or regional interconnection system are always closely tied to the specific historical, economic, geographical, and political context of the participating countries. Before examining the case studies of existing networks, therefore, it is worth establishing an overview of the general categories of integration and their organisational requirements. This will help to illustrate the relationship between the potential benefits of increasing levels of integration, as well as the increased need for co-operation and centralised oversight at each stage.

The depth and comprehensiveness of regional power system integration can be categorised in integration stage models according to the characteristics of the power trade between the participants in the integration scheme, the characteristics of the supporting transmission infrastructure, the level of sharing of regulation, as well as the existence of common institutions and the level of authority the participating countries have vested in them.

These NEA examples, as well as the other international examples show the many available options for establishing interconnectivity and active bi-directional and multi-party electricity trading between nonsynchronised regions.

Figure 8 Integration stage models

Integration Stage Models

Parties	Co-operation in Trading and System Operation	Regulation	Example
Interconnection two countries	Bilateral, unidirectional	PPA Dedicated interconnector	Mongolia imports from China
	Bilateral, bidirectional	PPA, dedicated interconnector grid-to-grid trade, grid services	Mongolian CRIPG - Russia WAPP
Shallow Integration many countries	Multilateral, multidirectional trade among differentiated market	PPA, standard transmission tariffs/ wheeling charges and TSA	WAPP
	Multilateral multidirectional among harmonised markets	Standard PPAs, TSAs, partial supply competition, regional level regulation	SIEPAC
Deep Integration region	Unified market differentiated operations	Unified market, regional regulatory agency, common grid, differentiated operations	Nord Pool
	Unified markets and operations	Unified markets and operations	PJM

Source: Adjusted from IEA, 2019; ESMAP, 2010

The simplest integration stage is 'Interconnection', representing a direct link between two countries. In this situation, two countries – through a power producer in one country and a consumer in another country – enter into bilateral trading of electricity. Such arrangements may become feasible when, for example, the country of the selling party has excess capacity, or fewer constraints in developing a power source from which the buyer is interested in purchasing electricity.

Establishing these interconnections is often influenced by geographical distances. Examples of such trade currently taking place include Mongolia and China, Laos and Thailand, Bhutan and India, Nepal and India, and what used to be the bilateral trade between the Soviet Union and Finland. If the systems of the two trading countries are not synchronised, it is common that either the consumer at the receiving end or the power plant at the supplying end will be isolated from its own system in order to be able to connect with the trading partner, who is synchronised with its own system.

The contractual parties in these arrangements may not always be utilities. For instance, the purchasing party may be a large consumer – such as is the Oyu Tolgoi copper-gold mine in Mongolia – or the seller may be an Independent Power Producer (IPP), possibly a private sector entity that has taken the development risk for a power plant and sells the produced electricity to a market that is closer, larger, or more stable than the market of the jurisdiction of the investment. Interconnections in these cases are often developed opportunistically when demand and supply meet, through developing a cross-border interconnection that is the least-cost option and when the domestic supply alternatives are either not as practical or too expensive.

An edge case within the interconnection category is what is sometimes called grid-to-grid integration. These cases see a bilateral cross-border interconnection between two utilities that is not dedicated to satisfying a specific demand, nor sourced from a specific power plant. In most of these cases, the parties are utility companies or TSOs from the two participating countries, and the interconnection operates bi-directionally.

The commercial motivation for these interconnections may arise from trading with electricity based on temporary surpluses and deficits, but it may also be based on the exchange of system services. For instance, one party may provide frequency for the other, or both parties may exchange balancing power with each other, or the parties may share system reserves with each other. Indeed, the desire to share balancing power and system reserves was at the root of the interconnections developed between the Nordic countries in the decades leading up to the 1990s, at which point commercial motives came to dominate via market reforms. For historical reasons, the interconnection between the Russian Federation and the Mongolian CRIPG also has the characteristics of a grid-to-grid integration.

The next integration stage, 'Shallow Integration', means that a group of countries (or, more specifically, TSOs, utility companies, generating companies, and large consumers in these countries) start trading with each other through one or more interconnections between their systems. The qualifier 'Shallow' reflects the lack of overarching, harmonised rules governing trading in electricity between the interconnected countries. The participating authorities' governments – or vertically integrated utilities – must, however, allow power plants, large consumers and transmission line owners to operate in their markets and to have open access (known as 'third-party access') to the national power grids within the limits of available transmission capacity. The commercial agreements between parties are based on case-by-case considerations, rather than on harmonised and binding rules.

Trading with electricity takes place bilaterally on the basis of PPAs, which may cover various time horizons. As investments in power generation are capital intensive and characterised by long payback periods, PPAs tend to be long-term commitments. One of the simplest forms of shallow integration takes place between three countries, with two countries trading with each other on the basis of a PPA while a third-party country's grid provides a transmission channel between the two on the basis of a transmission services agreement (TSA).

A step deeper in integration, the shallow integration model can encompass a wide spectrum of institutional integration and regulation. For instance, the 'harmonised bilateral trading model' is a case of shallow integration with significantly developed centralised co-ordination. While trading remains bilateral, standard templates for PPAs and TSAs are developed and enforced, possible spare capacities of transmission connections are managed and overseen by a single entity, and minimum technical requirements are set for the market participants – for example, in terms of how they should maintain system reserves (IEA, 2019).

In this harmonised bilateral trading model, it is particularly important to have a standardised methodology for establishing transmission fees (known as 'wheeling charges'). Such shared methodology helps market participants plan their energy options and investments in generation and transmission, as one important cost element is not completely subject to case-by-case commercial judgement. For such harmonisation to happen, a regional organisation, established by the region's governments or major utilities, is typically needed to plan and propose, enforce and oversee rules and regulations to guide regional electricity trading.

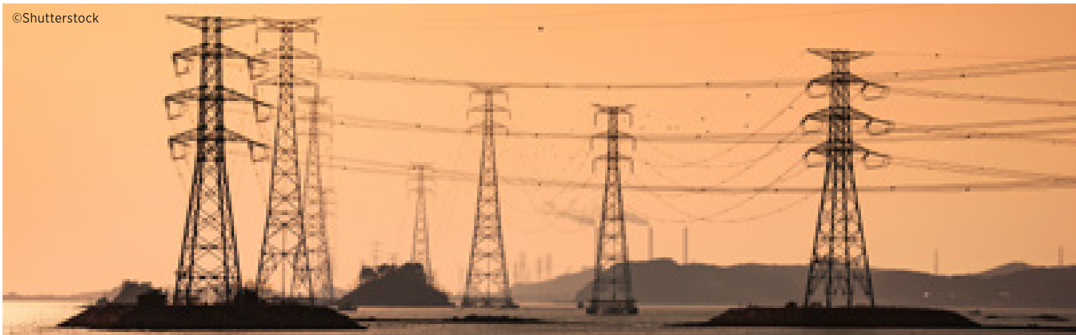
A harmonised bilateral trading model with a secondary trading system has been proposed by the IEA for the Association of Southeast Asian Nations (ASEAN) (IEA, 2019). Secondary trading model is applied by the Central American SIEPAC system described later as one the case studies of this document. The secondary trading system allows countries to maintain their traditional market structures, but builds a competitive regional electricity market that works in parallel as a superstructure on top of them. Depending on the market design, participants of national markets may join the regional market with their spare capacities of *ad hoc* demands, but there can also be power generators, traders, and large consumers who rely fully on the regional market. A secondary market requires more significant oversight from regional-level institutions. Transmission services need to be regulated and to be transparent, non-discriminatory and equal to all market participants. The trading itself also necessitates the creation of a market operator, as well as a central clearing entity.

The third integration stage model, 'Deep Integration', includes regional trading and, consequently, a regionally set power plant merit order and dispatch. This requires a central marketplace, which receives both supply side and demand side bids. This marketplace then establishes the market equilibrium points between the bidding sides and the costs of generation at those points – for every hour, half hour, or 15 minutes, as the case may be – on a day-ahead basis.

A truly regional marketplace brings efficiency to the generation sector, helps lower the electricity cost, enables tapping into renewable energy resources from a distance, and creates diversity in the energy mix. It also reduces the volumes – and thus total costs – of balancing and reserve capacities, as they can be shared across the region.

The operation of such a regional primary market does not necessitate a ban on other kinds of trading, provided the primary market has a sufficient number of participants to prevent manipulative and speculative bidding. In the Nord Pool, for example, direct sales through PPAs are possible, but are generally not practical for the market participants. The vast majority of trade flows therefore still go through the central marketplace.

The mechanisms of trading largely determine what kind of potential benefits can be achieved through electricity integration. As the IEA (2019) has stated, "The greater the degree of integration, the greater the potential benefits – but also the greater the complexity of organisation". Deep integration would therefore seem to be the most attractive option, but the long-term nature of regional interconnectivity investments creates significant issues. The benefits of greater interconnectivity are realised in the long-term, once the infrastructure and institutions have sufficiently evolved. Each step towards that goal, however, needs to be financially feasible and desirable on its own so that the sector operators will take the necessary steps. Given that the development of regional integration to a substantial level has proven to require significant lengths of time, it is logical that political decision-makers, governments, and ministries in charge of energy should begin work to realise the prospect and foster the necessary initiatives to bring the interconnectivity agenda forward.



Case studies

Introduction

The following section presents three case studies – WAPP, SIEPAC, and Nord Pool – which have a high share of renewables in their power generation mix, or at least have already set ambitious renewable energy targets at the regional level.

These cases have been selected to demonstrate the essential issues relevant to the different integration stages, as per Figure 8. WAPP and SIEPAC exemplify different grades of 'Shallow Integration', while Nord Pool exemplifies 'Deep Integration'. The three may therefore provide insights and options for the different stages of future development pathways in NEA electricity interconnection. A description of the different contexts of the evolution of WAPP, SIEPAC and Nord Pool – and an understanding of their differences to NEA (including how renewable energy is present in the interconnection plans) – may improve understanding of the challenges and options the NEA region has in its interconnectivity development.

Each case study provides a brief overview of the political and energy-economic context in which the integration scheme has been created. This is then followed by a description of the decision making and investment process that has led to the current state of affairs. The studies also describe the physical cross-country electricity transmission infrastructure that has been constructed to support regional trading. The studies then identify the key institutions involved in the interconnection scheme, as well as when and why those have come to play a role in the integration process. Finally, a description of the type of market that has been created in the region and goals for its near-term development conclude each case study.

The Hand of Fatima rock formation in Mali.

WAPP

► Country contexts

The West African Power Pool (WAPP) is an institution dedicated to regional power system integration and the realisation of a regional electricity market in West Africa. WAPP is, however, not a sovereign entity, but one of several specialised institutions of the Economic Community of West African States (ECOWAS). The 1975 Treaty of Lagos established ECOWAS as an economic union with the goal of more rapidly developing the West African economy through the promotion of economic co-operation. The 15-member organisation consists of eight French-speaking states, five English-speaking, and two Portuguese-speaking. Its member countries cover an area of 5.1 million km^2 and have a combined population of 387 million, along with a total GDP in 2019 of USD 689 billion (World Bank, 2020a).

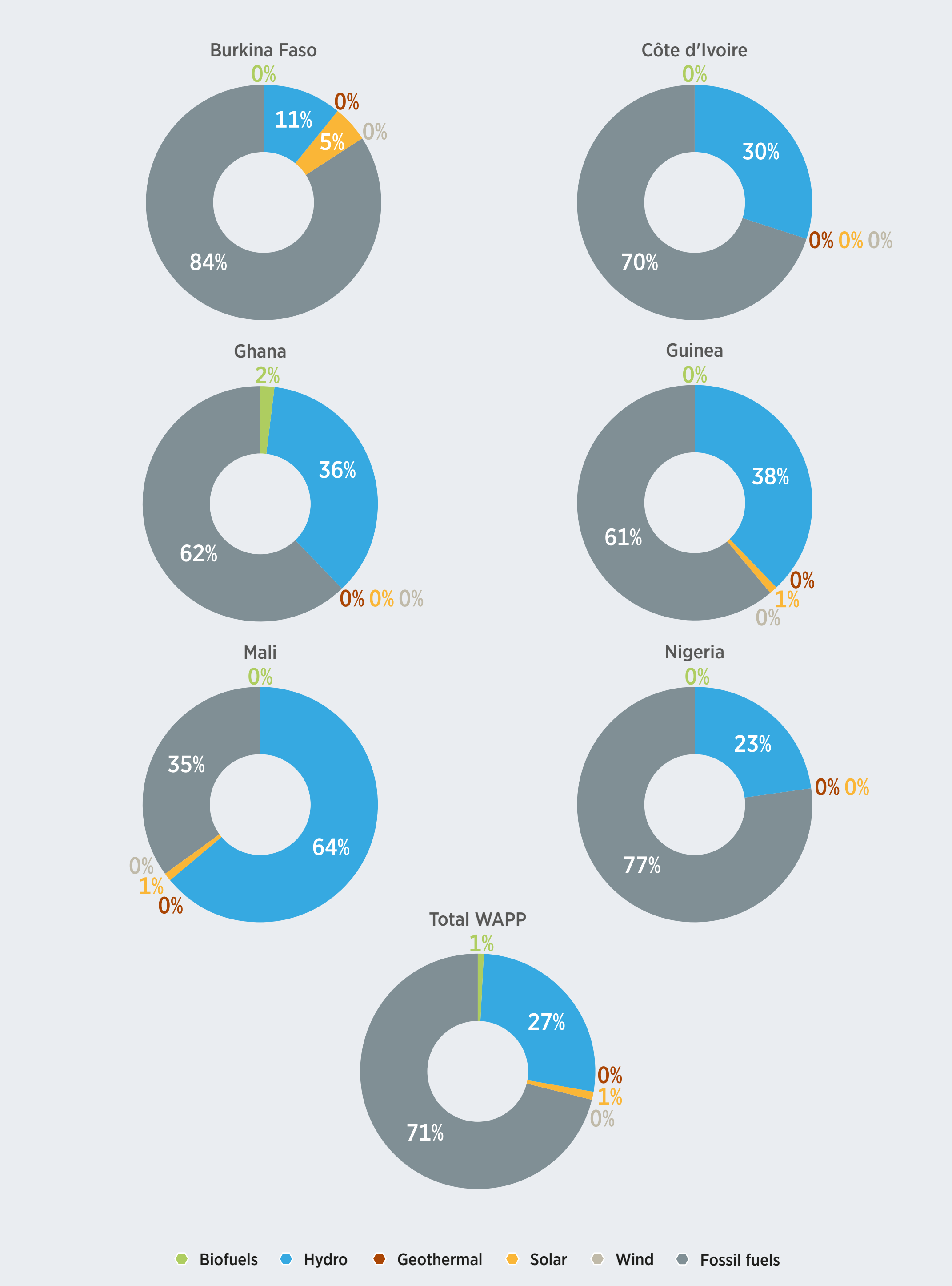
During ECOWAS' 45-year history, economic integration has progressed slowly, but the effort has been sustained. Developing the community has been hampered by challenges encountered by some of the member countries, with these sometimes of a political nature. With its robust institutional structure and reliance on political backing at the highest-level amongst its members, however, ECOWAS has continued on its course, supported by the persistent work of its institutions. Consequently, the community has still grown in relevance and pushed the countries gradually towards deeper integration.

ECOWAS has also expanded its authority beyond trade to other social and foreign policy issues, making it no longer just an economic block. The community has institutions and agencies from health to justice, while it also carries out peacekeeping activities.

The organisation has three arms of governance – executive, legislative and judicial, with its operations led by the heads of state and government of the member countries. This gives its decisions definite authority.

While the ECOWAS member states have diverse geographic, demographic, linguistic, religious, and cultural characteristics, they have fairly similar economic bases. These rely mainly on agricultural products, with no striking differences in the developmental status of the member countries. Exports of agricultural products include various fruits, vegetables, coffee, cocoa, palm oil and others. Nigeria is a major producer of crude oil, petroleum products and natural gas. Many of the region's countries export mineral products, precious metals, and timber. These countries also share sufficient common ground in the ways their diverse cultural and demographic qualities display themselves, in that they have developed important cultural connections across borders, significant geopolitical ties, and declared a desire for increased unity through co-operation under ECOWAS and other regional institutions.

Figure 9 Electricity generation mixes in WAPP and in four selected WAPP countries



Source: IRENA (2020a)

The three largest countries by population – Nigeria, Ghana, and Côte d'Ivoire – have the highest GDP, representing 84% of the regional total. They also have the highest GDP per capita (PPP), ranging between USD 5 000 and USD 6 000 for the three countries. This is significantly higher than the Sub-Saharan average of USD 3 919 (World Bank, 2020a). The other 11 countries of the WAPP are included on the United Nations (UN) list of the least developed countries and all have a GDP per capita of between USD 1 300 and USD 3 600. Their shares of total regional GDP range between 0.3% and 3.4% (World Bank, 2020a).

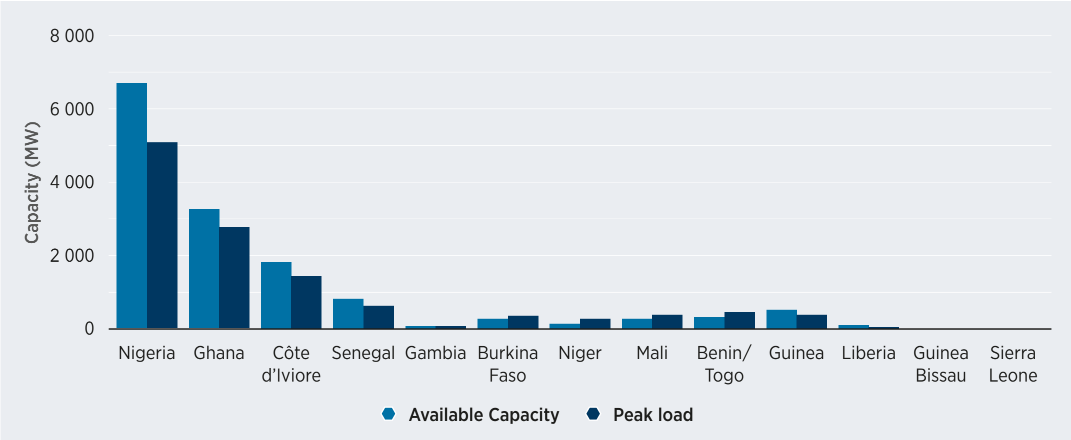
The conventional energy assets of the region are largely concentrated in the three largest economies. Indeed, the possession and utilisation of oil and gas resources has enhanced economies in these countries – particularly in Nigeria, but also in Ghana and Côte d'Ivoire. With its annual production of about 100 million tonnes of crude oil, Nigeria is the 12th largest oil producer in the world (BP, 2020). Nigeria also has proven natural gas resources, as do Côte d'Ivoire and Ghana, which both already produce natural gas, primarily for their domestic consumption. Senegal has made significant recent offshore natural gas finds, but has no production, as yet.

Unsurprisingly, therefore, Nigeria, Ghana, and Côte d'Ivoire also dominate electricity exports among the WAPP countries. Another important electricity generation base combined with a dedicated interconnected grid with cross-border electricity exchanges – the Manantali Interconnected Network – was developed by the Senegal River Basin Development Organisation (*Organisation pour la Mise en Valeur du fleuve Sénégal* – OMVS). The original members of OMVS include Mali, Mauritania and Senegal, with Guinea having joined the organisation more recently.

The total available capacity of WAPP at the end of 2019 was 12 666 megawatts (MW) (ICC, 2020). About 71% of member states' generation is based on fossil fuels, primarily on natural gas, and 27% is based on hydropower, with the balance made up of biofuels and solar PV, each of which has a nearly equal share (IRENA, 2020a).

Energy poverty and access to electricity remain pressing issues within the region. The electrification rate (access to electricity per capita) is the highest in Ghana (82%) and is over the Sub-Saharan average of 50% in Gambia, Côte d'Ivoire, Mali, Nigeria, Senegal and Togo. In the other countries of the region, the electrification rate is below 50%, with the lowest rate being only 14% in Burkina Faso (WB, 2020a).

Figure 10 Available capacity versus peak load in 2019



Source: ICC (2020)

As the low electrification rates indicate, a substantial infrastructure deficit plagues the region. If UN Sustainable Development Goal 7 (SDG 7) – "Ensure access to affordable, reliable, sustainable and modern energy for all" – is to be achieved, urban and rural electrification in this region will require major investment in generation, transmission, and distribution. The need to substantially and rapidly extend the electricity service will also require improving the performance of sector institutions, utilities, and companies. Furthermore, whilst hydropower and natural gas-fired electricity generation dominate in the main grids, smaller countries and remote grids are still supplied by oil-fired power plants and small generation units, which are inefficient and polluting. This is particularly the case outside the coastal areas and in landlocked countries, such as Mali, Burkina Faso and Niger, which rely more on heavy fuel oil (HFO) and diesel than on natural gas.

Finally, even in countries and localities of the region that are electrified, the electricity services are often poor quality and the electricity costs are among the highest in the world. The region's average retail tariff of USD 0.25/kWh (World Bank, 2020b) is well above the average for electricity tariffs in most other parts of the world. The high cost is attributable to several factors, including, among others, the high cost of fuel and maintenance of remote oil-fired generation assets, long transmission distances and various governance issues. The tariff levels suppress eligible electricity consumption so that countries are not able to tap all the socio-economic benefits potentially available from access to electricity.

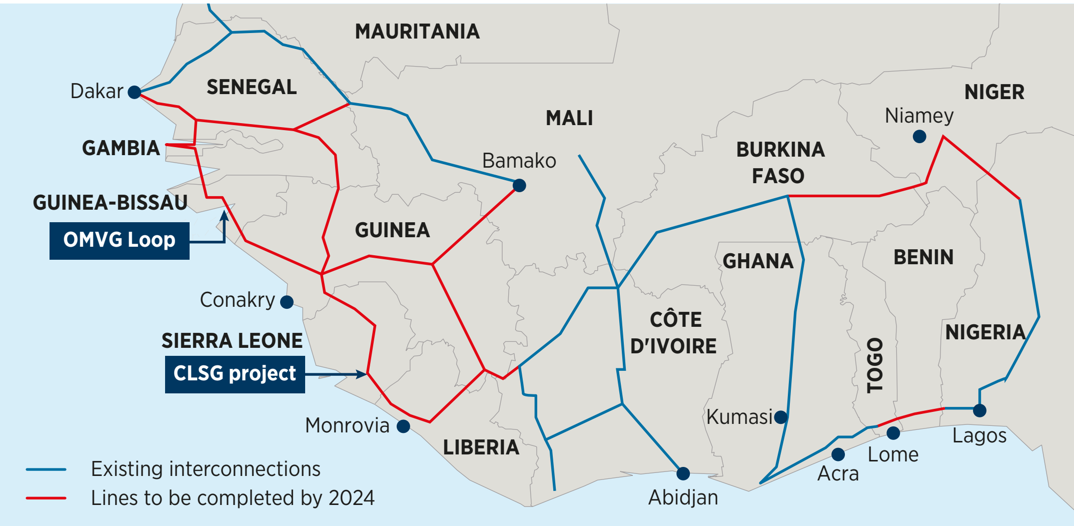
Developing regional electricity interconnectivity is linked to the efforts to achieve SDG7 in West Africa. Through interconnections, utilities gain access to a larger pool of generation units and are therefore able to provide a more secure supply for their consumers. Interconnections also ensure access to markets and the possibility of scaling up supply-side investments, thus increasing efficiency and reducing the cost of supply. In doing so, interconnections also help accelerate deployment of the region's domestic renewable energy resources.

These are likely to have an increasingly significant role in total electricity production in future, too. A masterplan developed by ECOWAS targeting the development of the region's infrastructure for power generation and transmission, gives an estimate of 38% of West Africa's total electricity production coming from renewable sources by the late 2020s. This breaks down into a 24 percentage point share for hydropower, a 13 point share for solar photovoltaic and a 1 point share for wind power (WAPP, 2018).

► Evolution of interconnections in West Africa

At the time WAPP was established, the power systems of most of the 14 mainland members of ECOWAS were isolated. During the last ten years, however, the planning, construction, and commissioning of interconnections and regional generation facilities has largely taken place, with those activities now in full swing and expanding.

Figure 11 West Africa interconnected grid and its near-term expansion



Source: Extract from World Bank (2020b); based on UN Clear Maps.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

The WAPP Business Plan 2020-2023 shows 11 transmission interconnections of 132 kV, 225 kV, and 330 kV, which were completed by mid-2019, interconnecting nine countries as segments of the planned WAPP transmission lines (WAPP, 2019). The projects that are currently under construction and shown by red lines in Figure 11, include projects that will result in the complete interconnection of all the WAPP member states by 2022. Prominent among these are the Côte d'Ivoire, Liberia, Sierra Leone and Guinea (CLSG) project, connecting these states, and the Gambia River Basin Development Organisation (OMVG) Loop, connecting The Gambia, Guinea Bissau, Senegal, and Guinea.

The CLSG project involves the construction of a 1 303 km-long, 225 kV power line, a 54 km-long, 66 kV power line, 11 substations of 225/33 kV, a dispatch centre in Guinea, and sets of compensation and frequency regulation equipment. The project also incorporates an electrification component, as a social mitigation measure, through the construction of transmission lines and substations that will provide 115 communities access to electricity (World Bank, 2017).

The CLSG project exemplifies a new mechanism for implementing a multi-party regional project within WAPP. For CLSG, WAPP decided to pursue a special purpose company (SPC) as a way to, among others, ensure timely and effective implementation of the project, as well as sustainable operation and maintenance, once commissioned. A treaty was signed by the four participating countries, which was then ratified. This also established a regional transmission company, known as TRANSCO CLSG. This was given the mandate to develop and operate CLSG's transmission interconnection line.

The creation of TRANSCO CLSG helped to realise the project in challenging conditions. These included a post-conflict environment with an extremely low level of infrastructure, governments facing substantial financial challenges, and power industry experience being limited to constructing power lines of 60 kV and below. TRANSCO CLSG has been operational since 2014 and is headquartered in Abidjan, Côte d'Ivoire.

PPAs were negotiated and concluded to provide initial loading for the interconnection line. The first PPAs were for 81 MW, including three agreements, each for 27 MW, to be exported from Côte d'Ivoire to the other three countries. Thirdly, TRANSCO CLSG signed transmission service agreements (TSAs) with the three purchasing countries (GIH, 2019; World Bank, 2017).

The OMVG Loop consists of a 1677 km-long, 225 kV transmission loop interconnecting the four countries, 15 substations, and a dispatching centre for the management of power flow (WAPP, 2019).

In parallel with the development of electricity interconnectivity through transmission lines, WAPP has had a major role in driving forward a number of regional electricity generation projects.

Table 1 provides a list of on-going hydropower projects that have a prospect of being taken on-line by the end of 2025. Many of the projects are truly regional, as the river systems they belong to are sub-regional and jointly managed. Linked to the OMVG project, for example, is the construction of the Sambangalou hydroelectric plant (128 MW, 402 GWh/year) on the Gambia River, located 930 km upstream from the mouth of the river. The dam will be located in Senegal, and part of the 185 km^2 reservoir will be in Guinea.

Indeed, plans for generation development up to 2025 are dominated by hydropower projects. The ECOWAS masterplan includes 75 regional projects totalling USD 36 billion of investment, 29% of which is for transmission line projects and 71% for electricity generation. The plan includes the accelerated deployment of solar and wind energy in the region, especially after 2025.

In the list of regional priority projects, which are limited to – among other criteria – those over 150 MW capacity, renewable energy projects represent 69% and solar and wind projects 20% of the total. The balance of 31% includes mainly gas-fired power projects. Some countries such as Burkina Faso, Mali, Niger, and The Gambia aim to attract private investments for these projects through an auction mechanism.

Table 1 WAPP priority projects under construction and to be commissioned by the end of 2025

Project	Country	Capacity (MW)	Year
Zungeru	Nigeria	700	2021
Souapiti	Guinea	450	2021
Gouina	Mali	140	2021
Sambangalou	Guinea/Senegal	128	2023
Mambilla	Nigeria	3050	2024
Amaria	Guinea	300	2024
Kooukoutamba	Guinea	294	2024
Balassa	Guinea	181	2025
Boureya	Guinea	160	2025
Total	**WAPP**	**5403**	**2025**

Source: WAPP Business Plan 2020-2023

Electricity trading within the WAPP is on a bilateral basis. Table 2 below provides an overview of power exchanges on the WAPP interconnected system. In July 2020, the installed capacity amounted to 22.3 GW and the combined peak load of the region to 11.8 GW. Energy generation was 43.2 TWh.

Table 2 Energy exchange by country

Country	2018		2019	
	Import (GWh)	Export (GWh)	Import (GWh)	Export (GWh)
Nigeria	0.0	-3 002.6	0.0	- 2 327.2
Côte d'Ivoire	77.6	-1 186.6	76.6	- 1 234.8
Ghana	143.8	636.4	127.0	-1 235.4
Senegal	338.2	-2.1	468.4	0.0
Burkina Faso	783.4	-0.3	1 024.7	-0.2
Niger	984.2	0.0	1 048.8	0.0
Mali	1 186.0	0.0	1 302.2	0.0
Benin/Togo (CFB)	2 307.4	0.0	1 996.9	0.0
Sogem[8]	0	-1 128.9	0.0	-1 057.2
EEEOA	5 820.6	-5 908.9	6 043.5	-5 854.7
Exchange/Generation	8.6%		8.6%	

Source: Activity Report of the Secretary General of WAPP, November 2020

As the foundational infrastructure enabling the beginning of a competitive electricity trading system within the electricity market of the region – and including a day-ahead market – there are three projects: first, the continuing CLSG Loop, second, the OMVG Loop, and finally, the WAPP Information and Co-ordination Centre (ICC).

► Institutions

In the energy field, ECOWAS has three specialised institutions and agencies, as follows:

- WAPP,[9] created in 1999, and conferred in 2006 by decisions of the Authority of ECOWAS heads of state and government as a specialised institution of ECOWAS.

[8] *SOGEM is a utility company which is created by the OMVS member countries.*

[9] *WAPP's membership is mainly 14 out of the 15 countries of ECOWAS: Benin, Côte d'Ivoire, Burkina Faso, Ghana, The Gambia, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. Cabo Verde is not currently covered by WAPP, as it is an island state in the Atlantic Ocean and a cost-effective electricity interconnection with mainland Africa is not currently feasible.*

- The ECOWAS Regional Electricity Regulatory Authority (ERERA), established in 2008.
- The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), established in 2010.

Following a decision in 1999 to establish an integrated power pool in West Africa, in 2003, the members of ECOWAS concluded an energy protocol that included a strategy to achieve the vision of integration by putting in place a legal framework. This included institutions such as WAPP and ERERA, with the aim of promoting long-term co-operation in the ECOWAS energy sector. WAPP and ERERA principally govern the regional electricity integration process of West Africa and their operations are closely interlinked, as they co-operate closely to operationalise the regional electricity market.

WAPP was created to realise and secure an integrated, regional electricity market and is an international organisation, charged with acting in the public interest. Its membership includes public and private generation, transmission, and distribution companies and utilities involved in electricity sector operations in West Africa. As of the end of 2020, WAPP had 38 members. Membership is open to any entity, public or private, with control of regionally meaningful electricity generation, transmission, or distribution assets (generation of 20 MW or more, major transmission and distribution facilities, regional electricity facilities), or with a stake as a distributor or substantial consumer of electricity conveyed through these assets.

The ECOWAS department in charge of energy co-ordinates the WAPP's activities, with these undertaken in collaboration with ECOWAS entities such as ERERA and ECREEE.

WAPP has its own governance structure, as follows (WAPP, 2020):

1. **General Assembly (GA):** The highest decision-making body, composed of all member utilities and companies.
2. **Executive Board (EB):** Implements the decisions of the GA and is composed of 15 members, including 13 representatives of ECOWAS power utilities, the secretary general of WAPP, and an honorary member.
3. **Organisational Committees (OCs):** Provide expertise for the EB by developing common rules and practices on multiple technical issues. The OCs include the Engineering and Operations Committee (EOC), the Strategic Planning and Environment Committee (SPEC), the Distribution and Commercial Committee (DCC), the Finance Committee and the Human Resource and Governance Committee.

4. **General Secretariat (GS):** In charge of management of the daily activities of WAPP. It has three departments: Information and Co-ordination Centre (ICC); Administration & Finance (A&F); and Planning, Investment, Programming and Environmental Safeguards (PIPES).

Out of the GS' operations, the ICC will have a growing role in WAPP's day-to-day trading operations once WAPP assumes its full role as the regional system and market operator (SMO). The ICC is now in the process of building the necessary infrastructure, technical equipment, systems, and capacity to carry out that function.

WAPP has a major responsibility in mobilising and co-ordinating resources for both electricity generation and transmission investments in West Africa. Having the ECOWAS heads of state and other high-level political decision-makers formally endorse and sign on to regional power investment plans ensures visible political buy-in and increases the chances of a follow through with regional planning investments.

WAPP's technical and financial partners include most of the major bilateral and multilateral financing agencies operating in the region. Its strategic priorities are expressed in project concepts, papers, road maps, and regional power system masterplan studies, which serve as important guidance for major bilateral and multilateral financing agencies' infrastructure operations in West Africa. The latest WAPP masterplan, approved in 2018, covers the period 2019 to 2033.

WAPP's Planning, Investment, Programming and Environmental Safeguards (PIPES) Department has the responsibility to prepare priority projects, demonstrate their bankability, mobilise financing for their implementation and monitor and co-ordinate their implementation by participating ECOWAS member states through appropriate institutional frameworks. For transmission line projects, the frameworks more and more reflect the deployment of single entities to implement multi-country projects in order to ensure, among other objectives, harmonised implementation.

Apart from pushing forward key infrastructure investments in the region, WAPP has held a crucial role in preparing rules and regulations for more harmonised regional market practices. It has also been crucial in preparing template contracts for power purchase and transmission services, developing market rules, and tackling various regulatory issues that have impeded cross-border power trade or investments in the region. WAPP has, among other achievements, addressed market governance issues for which it has developed documents upon the approval of ERERA. These issues include regional market rules, market procedures, operation manuals, market participant application procedures, market participant agreement, transmission tariff methodology, and model bilateral contracts for the short and long term (WAPP, 2019). Other rules and guidelines have also been prepared and are under review by ERERA.

WAPP also drafted the *Directive on Securitisation of Cross-Border Power Trade*. This is an important document designed to tackle issues of non-payment – which discourages regional trade – and to establish trust among the market participants and project financiers on these matters. The document was adopted by the ECOWAS Council of Ministers in 2018.

The regional transmission tariff methodology is another vital regulation, as it provides a prerequisite for investors and utilities as they assess the feasibilities of developing cross-border transmission lines, or the costs of using these services. The methodology ensures transmission operators reasonable cost recovery for developing such infrastructure.

Under this, too, revenue that accrues from those who have purchased bilateral trades for transmission tariffs and losses is collected by the regional system and market operator (SMO/WAPP). ECOWAS regulates the operational levies for the regional electricity market, and from this, determines the revenue requirements of ERERA and SMO, fixing a rate per kWh traded. TSOs then receive the transmission tariff and losses revenue allocated to them from the SMO (ERERA, 2015a).

ERERA is the regional regulator of the cross-border power trade, as well as power interconnections in West Africa. The regulation of interstate electricity exchanges and the provision of support appropriate to national regulatory bodies are its main objectives.

Governance of ERERA is exercised the Regulatory Council, its top decision-making entity. This has all the necessary powers for the accomplishment of the agency's mission, with that set by an ECOWAS Council Regulation issued in 2007, which also covers the agency's governance and operation. The Regulatory Council is composed of five members, one of whom acts as the chair, who are appointed by the ECOWAS Council of Ministers. Regulatory Council members are appointed for a one-time tenure of five years and serve on a full-time basis.

► **Power market**

According to the market rules approved in 2015, the development of a regional, West African market for trading electricity is planned to evolve in three phases, as follows (ERERA, 2015b).

Market Phase 1: Trading with electricity and transmission services takes place on the basis of bilateral agreements, but under the regional market rules approved by ERERA. The difference to 'Phase 0' is that contracts are standardised, based on templates and a transmission cost methodology prepared by WAPP, rather than concluded on a case-by-case basis. The bilateral agreements can be for the short, medium, or long term.

An important precondition for standardisation is that a transmission pricing methodology is in place. Transmission capacity is allotted on a first come, first served basis. ERERA is responsible for enforcing the regulations. IPPs may be permitted to be market participants after special approval by ERERA.

Phase 1 also includes guidance for preparatory work for the transition to Phase 2, including more extensive regulations and procedures for operational and commercial transactions. Finally, Market Phase 1 assumes that a designated institution to carry out the SMO functions is furnished and functional. The WAPP ICC assumes responsibility for those functions.

Following the intensive regulatory development carried out since the establishment of WAPP, all conditions necessary for Market Phase 1 were assessed as having been met. In June 2019, there was therefore a formal launch of Phase 1 of the market (WAPP, 2019).

Market Phase 2: Standard contracts are used as a basis for bilateral trading, transiting through third-party countries. Transactions can take place between individual agents of these countries. The significant step from Phase 1 is that a day-ahead market will be introduced for short-term exchanges. At this stage, transmission pricing is regulated by ERERA and it is no longer possible to create bilateral transmission pricing agreements. To operate a day-ahead market and for other functions of system and market operations, the SMO is fully operative, with responsibilities established by regional market rules.

The commissioning of the OMVG Loop and the CLSG project will, together with the system and capacity building of ICC and approval of certain regulatory documents that are still being processed, create the basis for the region to move to Phase 2, possibly by the mid-2020s.

Market Phase 3: The introduction of a competitive regional market in West Africa. The market must be liquid, with a sufficient number of regional producers and consumers as market participants for regional trading, underpinned by a robust cross-border transmission infrastructure. Phase 3 provides an opportunity for countries to voluntarily put their resources under regional unit dispatch. Phase 3 also introduces new products to the electricity market, such as various reserve products, balancing power, and financial products.

Box 1 WACEC: The West Africa Clean Energy Corridor

West African countries have excellent renewable energy potential for developing hydropower, solar PV and wind energy. As the region works to expand access to affordable electricity, renewable electricity is an increasingly cost-efficient and flexible solution for both utility-scale and off-grid electrification. The West Africa Clean Energy Corridor (WACEC) was developed following a consultative process that began in 2015 between IRENA, ECOWAS, and ECOWAS' specialised agencies: ECREEE, ERERA, and WAPP. The initiative was approved by the ECOWAS energy ministerial in 2016 and endorsed by the heads of state in 2017.

The WACEC focuses on supporting the first objective of the WAPP energy masterplan, by pursuing optimal integration of variable renewable energy resources into the electricity systems of West Africa. The WACEC action plan directs IRENA and ECOWAS co-operation on resource assessment and zoning, regional and national energy sector planning, capacity building, and creating an enabling environment for facilitating renewable energy investments in the region.

In December 2016, IRENA released its *Investment Opportunities in West Africa*, which provides a region-wide pre-feasibility assessment of the solar and wind opportunities in that region. The technical potential is not a constraint. The identified potential for solar PV and wind energy, both on-grid and off-grid, vastly exceeds the long-term requirements of the region. The analysis was later narrowed down by carrying out a financial viability and suitability analysis for specific project sites that have been earmarked for development.

Starting with its *Planning and Prospects for Renewable Energy in West Africa* report, back in 2013, IRENA has supported long-term power sector planning in the West Africa region. This document resulted in a sequence of collaborative activities to build long-term, regional planning capacities. Working together with the International Atomic Energy Agency (IAEA) and the UNFCCC, IRENA began a 6-month capacity development programme in 2016. This involved 10 ECOWAS countries, from which 25 designated energy planning officers were drawn. As a system planning tool, this programme used IRENA's SPLAT-W, which assesses future energy mixes from an economic, technical, and environmental perspective. A series of three training courses was also organised in Sierra Leone specifically to enhance energy planning capacity within its national institutions.

In 2018, a regional capacity building programme was also launched to enhance the planning and operation of power systems with higher shares of variable renewables. This was preceded by a gap analysis and scoping study, which led to the 2018 training programme. This was carried out for all 14 ECOWAS countries on those grid integration issues that had been identified and was held separately for the English and French speaking members of WAPP. In parallel, two rounds of regional capacity building trainings on renewable energy PPAs were also conducted. Further training on these topics is under development.

IRENA has channelled support to renewable energy investment in the West Africa region through its project facilitation mechanisms and capacity building for entrepreneurs. The IRENA/Abu Dhabi Fund for Development (ADFD) facility has approved eight loans, totalling USD 80 million, to finance solar PV and mini-grid solutions for rural electrification in Burkina Faso, Mali, Niger, Senegal, and Togo, grid-connected solar parks in Burkina Faso and Sierra Leone, and a hydropower project in Liberia.

SIEPAC

► Country contexts for SIEPAC

The Central American Electrical Interconnection System (*Sistema de Interconexión Eléctrica de los Países de América Central* – SIEPAC) was originally set up by the governments of Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama with the support of the Inter-American Development Bank (IADB) and the Spanish government through Endesa, the largest electric utility company in Spain. The member countries established the public-private consortium Enterprise Owner of the Regional Electric Grid (*Empresa Propietaria de la Red* – EPR) to own and build the SIEPAC interconnection system.

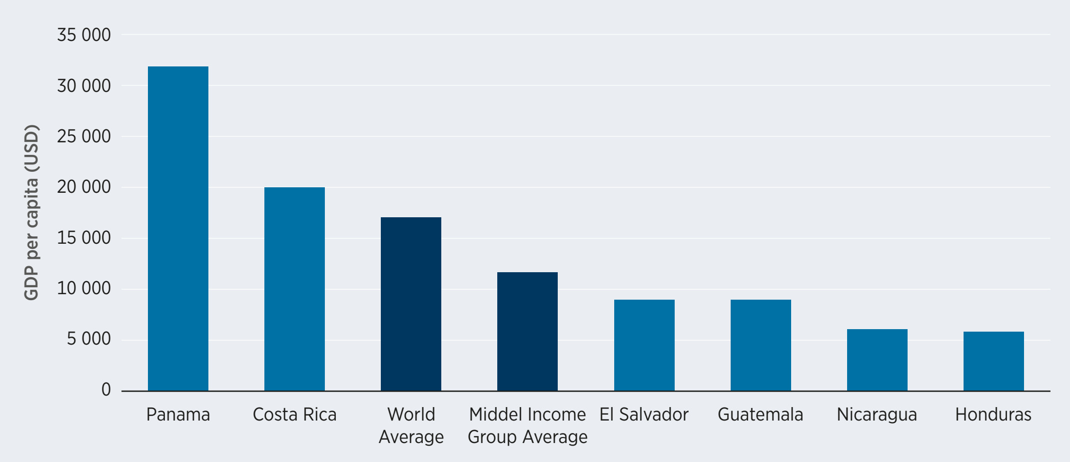
In 2005 and 2009, respectively, Mexico and Colombia joined the SIEPAC scheme as shareholders through their leading utility companies, bringing the total number of shareholders up to nine. Mexico and Colombia have, however, not yet become participants in system operation and trading under SIEPAC. Mexico is interconnected to the region through its connection with Guatemala, but it is not connected to the SIEPAC line or its market. Colombia is also not yet physically interconnected to the other SIEPAC countries. This discussion on the country context will therefore focus primarily on SIEPAC's six founding member states.

These six have distinct national characteristics, but also share profound similarities, making political and economic integration logical endeavours. The countries share significant similarities in, for example, their geography, all being located between Atlantic and Pacific Oceans. They also share a similar natural environment, with rich biodiversity and a tropical climate. There is also a shared culture, in religion, historical heritage and official language –Spanish. These countries are also similar in their ability to accommodate a mixture of ethnicities, traditions, and religions.

Between them, the six countries have a total population of 48 million (2018), with Guatemala having the highest, at 16.3 million. In all of the six economies, services, commerce, tourism and trading take the largest shares of GDP. The industrial sector's contribution ranges from one fourth to one fifth of the economy, followed by agriculture. In exports, textile products and agricultural products, such as fruits, vegetables, coffee, sugarcane and palm oil, play important roles.

Country-specific differences certainly exist, however. In the less developed economies of the region, for example, foreign remittances represent an important contribution to the local economy, whereas in the wealthier economies, such as Panama, for example, tourism, banking and the Panama Canal contribute significantly to the economy and employment.

Figure 12 GDP per capita (PPP) of Central American countries in 2018

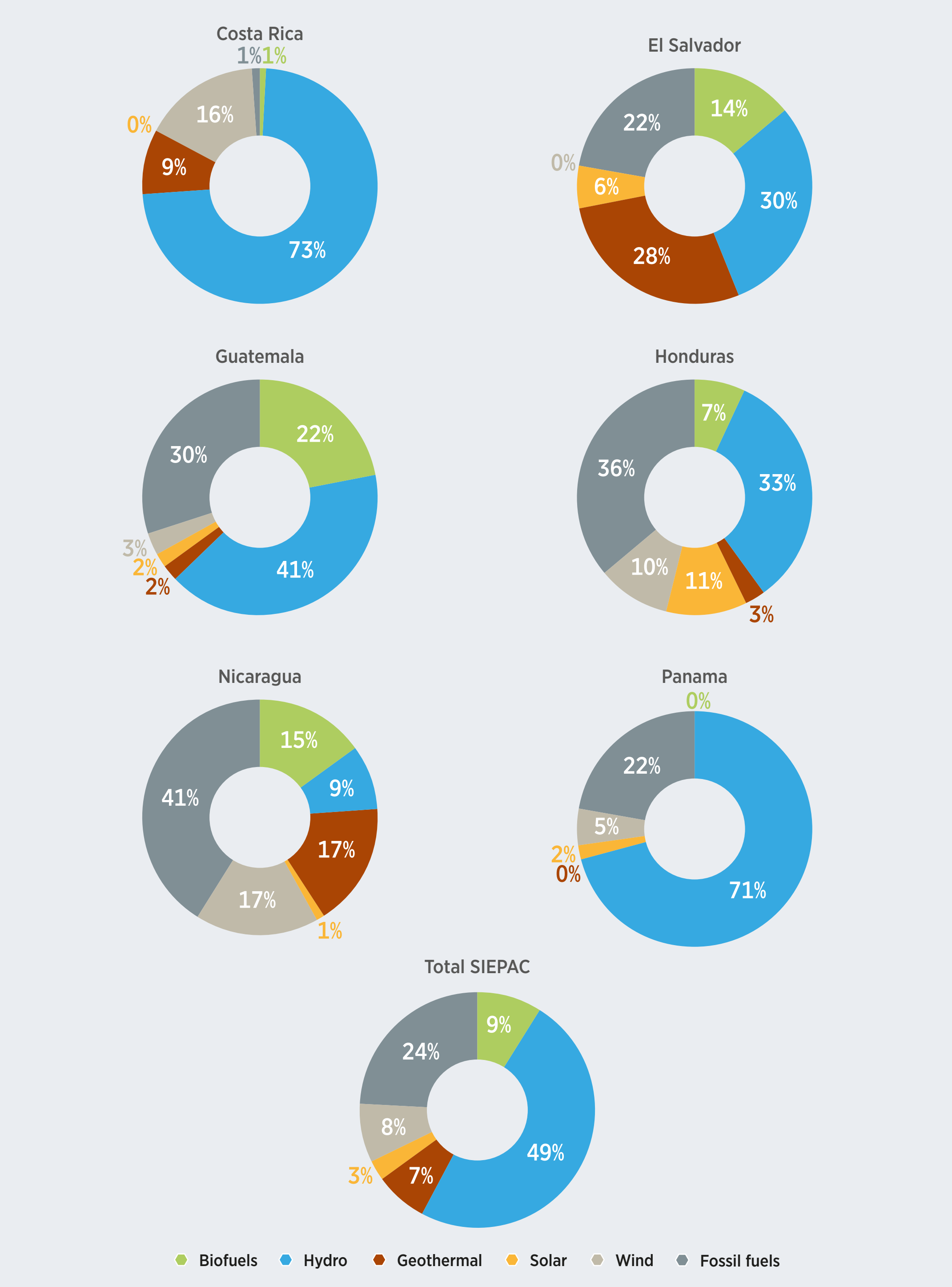


Source: World Bank, World Development Indicators (October 2020)

Five countries are categorised as middle-income countries except Panama in high-income countries according to the World Bank, although the range of this metric is rather wide. Honduras and Nicaragua, for instance, are at the lower end of the middle-income group of countries and continue to struggle with significant development challenges, with large segments of the population living in poverty. GDP per capita (PPP) in 2018 was USD 5 806 in Honduras and USD 5 829 in Nicaragua. Costa Rica and Panama, on the other hand, have per capita incomes higher that the USD 17 018 (PPP) world average, at USD 19 873 and USD 31 782 respectively.

The power sectors of these countries share three characteristics influencing the Central American electricity integration process. First, in the 1990s, some countries implemented many of the recommendations of the Washington consensus. These included the privatisation of state enterprises in the electricity sector, as well as sector deregulation. A requirement of that was to unbundle the formerly vertically integrated utilities so that competition could be introduced, at least to the electricity supply subsector. Four of the six countries - El Salvador, Guatemala, Panama, and Nicaragua - opted to open their electricity sectors to private investments through total or partial privatisation and the introduction of market mechanisms for competition, efficiency, and the rationalising of electricity costs for consumers. Costa Rica and Honduras decided to maintain their traditional models, allowing only limited private sector entry into the power generation sub-sector (Castro et al., 2017) .

Figure 13 Electricity generation mixes in SIEPAC countries in 2018



Source: IRENA data and statistics

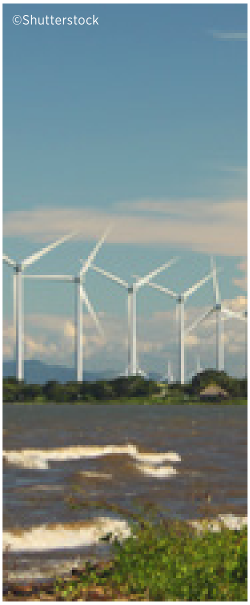
The generation profile of the six countries is a second significant characteristic. Much of the thermal power capacity of these countries is old and based on conventional and rather inefficient technology. Furthermore, many of the power plants are oil-fired, instead of LNG, gas or coal, and are therefore costly, polluting, and subject to fluctuations in oil price. The region itself is not an oil and gas producer, and therefore depends greatly on the importation of these products, making the cost of thermal generation dependent on international oil prices. The continued use of thermal power plants has led to a high level of installed capacity and consequently wide reserve margins. The average capacity utilisation rate for the fossil fleet is only 28%.[10]

Finally, renewables-based power generation represents a high share in the total electricity production mix. Regionally, only 24% of power supply is covered by fossil fuels-based generation. This renewable energy portfolio is quite diverse. Hydropower takes the highest share, representing 49% of the regional portfolio, but biofuels, geothermal, solar, waste combustion, and wind energy all have a substantial presence in the Central American electricity supply portfolio. The Costa Rican supply sector is nearly totally decarbonised, with just 1.4% fossil fuels-based generation, while there is a 73% share for hydropower. Hydropower is also the dominant primary energy source for electricity generation in Panama, with a 71% share of supply. Geothermal energy takes up the highest share of the country's electricity mix in El Salvador, with 28%.

The SIEPAC system continues to receive a growing number of connection demands from renewable energy plants, especially from the growing number of wind and solar parks in the region. Since the mid-2010s, there has been a rapid increase in wind power and solar PV deployment. Honduras has the largest solar PV capacity, totalling 511 MW, with wind at 231 MW. Costa Rica and Panama have also developed significant capacities, as well as El Salvador (IRENA, 2020a).

SIEPAC countries have on-the-ground experience of utilising a variety of renewable energy resources, hydropower, geothermal, wind, and solar, and some of the countries have shown high-level commitments to renewables deployment. Currently, variable renewable power (solar and wind) accounts for an average 13% to a maximum 27% in the SIEPAC power trade market. It is also not uncommon, however, for stakeholders in the region to be highly protective of fossil fuel industries. In some countries, power capacities have grown faster than demand. In this environment and with an increasing supply of low marginal cost electricity, new demands have arisen for a more effective regional transboundary electricity market.

[10] IRENA data and statistics for electricity consumption. Capacity by Rivas (2019).



► Evolution of interconnectivity in Central America

The development of electricity interconnections and the associated electricity trading in Central America have been closely interlinked with the economic and political integration of the region.

This integration agenda stems from 1951, when the Organisation of Central American States (ODECA) was established by Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua. The organisation sought to promote economic growth through free trade and a customs union.

ODECA endured the political turmoil and violence of the late 1970s and 1980s. In 1991, after the Esquipulas II Accord – a peace treaty signed by the heads of states of the five countries – a renewed effort to encourage economic development, peace, and democracy in the region was launched with the establishment of the Central American Integration System (SICA), under the former ODECA framework (Castro et al., 2017; Encyclopedia.com, 2020). SICA was established through the signing of the Tegucigalpa Protocol, which amended the ODECA Charter of 1962.

The Tegucigalpa Protocol was soon followed by several other protocols between 1993 and 1995, which aimed at promoting economic and social integration, sustainable development, and democratic security (SICA, 2020). In 1993, the SICA countries expressed their intention to establish an economic union in Central America by signing the so-called Guatemala Protocol. The Guatemala Protocol accommodated various subsystems for economic co-operation, including the development of electricity interconnectivity. Consequently, in 1996 the six countries concluded the Central American Framework Treaty on the Regional Electricity Market (REM).[11] This treaty was signed in Guatemala City, forming the basis for a series of agreements and regulations for SIEPAC.

The principles of the framework treaty of the REM include the treaty being governed by the principles of competition, gradualism, and reciprocity, which are defined as follows (Rivas, 2019):

- **Competition:** Freedom in the development of service provision based on objective, transparent, and non-discriminatory rules.
- **Gradualism**: Progressive evolution of the regional electricity market, in terms of incorporation of new participants, increased co-ordination of operation, development of interconnection networks, and strengthening of institutional set-up.

[11] *REM is an abbreviation based on the English "regional energy market." In the SIEPAC context it is more often abbreviated as MER coming from the Spanish equivalent "Mercado Eléctrico Regional."*

- **Reciprocity**: The right of each state to apply to another state the same rules and regulations that the state applies temporarily in accordance with the gradualism principle.

Two simultaneous political processes helped to bring about the REM. One process was founded on the economic theory that led to the liberalisation of the national electricity markets, which produced a model for a competitive electricity market that could also be applied at a regional level for efficiency and scaled-up competition. The second process was founded on the political will for the countries to increase economic, social, and political co-operation, which led the leaders of the six countries to seek concrete mechanisms – such as a power network shared by the region's countries – to turn the political vision into action. During the 1990s, however, the desired level of integration – given the need to protect the interests of national utilities – and the rules of the market remained a topic of studies and discussions between the parties.

In parallel with SICA, since 1991, the six countries have discussed various issues of common interest with Mexico, including economic integration under the Tuxtla Mechanism. In 2001, an extraordinary summit of the Tuxtla Mechanism in San Salvador agreed to pursue the Puebla Panama Plan (PPP), aiming at re-launching Mexico-Central America co-operation.

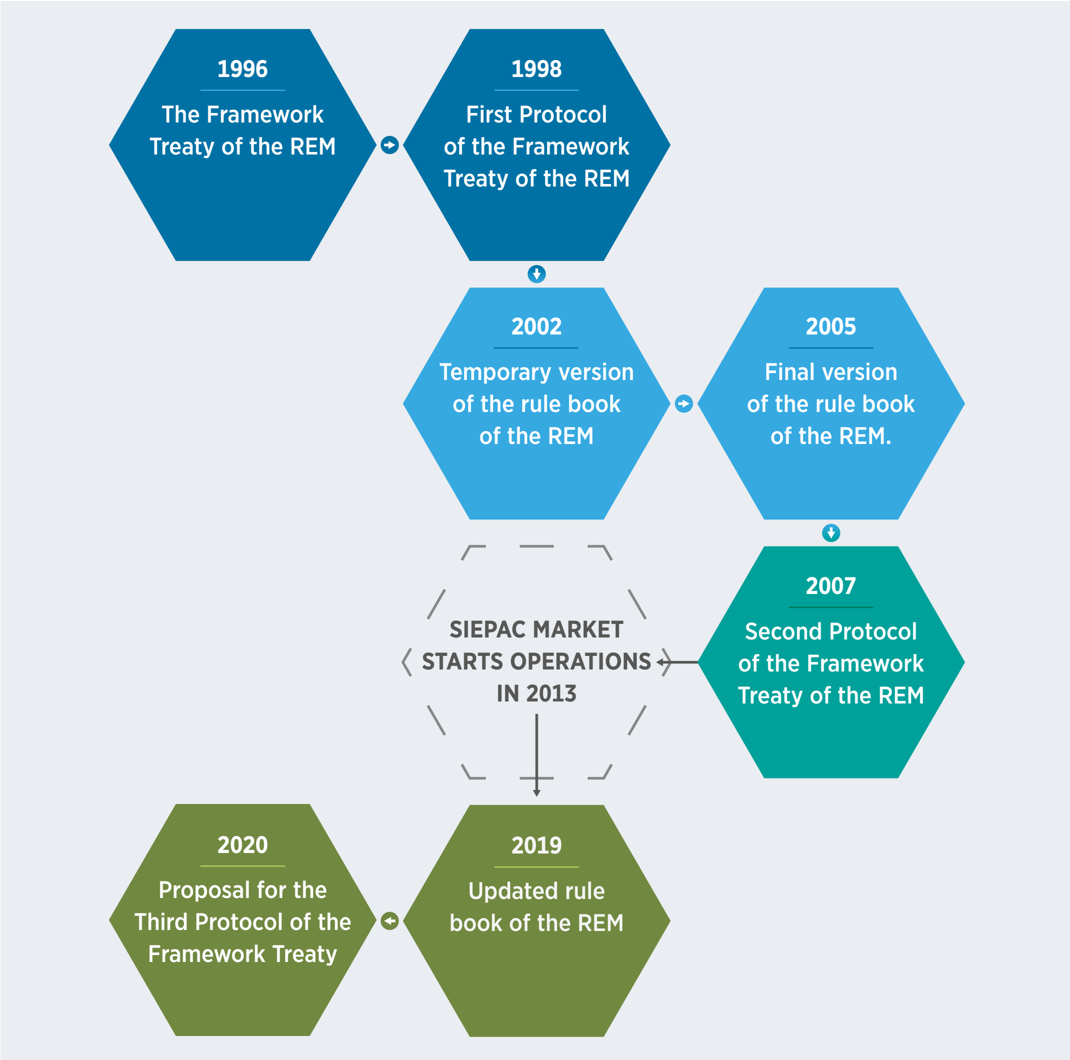
Under the PPP, eight initiatives were established, one of which was focused on energy and led by Guatemala. In 2009, the PPP was transformed into the Mesoamerican Integration and Development Project, or Mesoamerican Project (Proyecto Mesoamérica – PM). At this stage, Colombia and the Dominican Republic joined the Tuxtla Dialogue and the PM.

The PM strengthened the momentum for SIEPAC and the REM and led to Colombia becoming a shareholder in EPR, with the intention of becoming a member – like Mexico – and of building physical power transmission connections to the SIEPAC system. This still remains a matter under discussion.

Even though regional energy co-operation has been strongly driven by various foreign policy objectives, it has also been firmly grounded in the operational reality of the region's major utilities, which needed new solutions.

The electricity companies in charge of national systems have not been financially strong and the systems have been technically weak. They have experienced voltage instability and system-wide collapses, while lacking the financial resources to invest in better supply security. National systems operating in isolation also demand higher reserve margins than would be needed by interconnected systems. A regional market was seen as an option that would improve operational efficiency, reduce the fuel oil consumption needed for generation, spur greater competition in both domestic and international markets, lower the cost of electricity, and attract private investments in the sector (Rivas, 2019; EDF, 2019a).

Figure 14 West Africa interconnected grid and its near-term expansion



Source: authors

► Infrastructure

In order to enable the REM, the transmission infrastructure between the countries needed to be strengthened. The six countries of SIEPAC had already developed cross-border interconnections before the SIEPAC initiative, with the earliest interconnections lines built in 1976 between Costa Rica and Panama, as well as between Honduras and Nicaragua. Costa Rica was connected to Nicaragua in 1982, and Guatemala to El Salvador in 1986. A cross-border line between Honduras and El Salvador was built in 2002 (Urízar, 2019).

Following the Framework Treaty of 1996, EPR was established as an SPC for the construction and ownership of the regional transmission infrastructure. The utility companies CFE of Mexico and ISA of Colombia became shareholders when they joined SIEPAC later, in the context of the PM. The headquarters of EPR are in San Jose (Costa Rica), with representative offices in each SIEPAC member country (EPR-SIEPAC, 2020).

The first phase of the SIEPAC project consisted of strengthening those national grids and cross-border interconnections, leading to the construction of a 230 kV power grid from Guatemala to Panama. The length of transmission line is 1 790 km with a total of 28 access bays, with compensation equipment and telecommunication facilities for system control located in 15 substations distributed throughout the six original member countries. The carrying capacity of the single-circuit line is 300 MW and this became operational in 2013, 15 years after the First Protocol of the REM (CRIE, 2020).

The implementation of the SIEPAC project was keenly supported by IADB, as well as by the Central American Bank for Economic Integration (*Banco Centroamericano de Integración Económica* – BCIE), the CAF-Development Bank of Latin America (*Corporación Andina de Fomento* – CAF) and private banks. The total investment amounted to USD 505 million, of which about half, over USD 250 million, was invested as credit from IADB (Castro, Pineda and Santamaria, 2017; IDB, 2014).

In some of the SIEPAC countries, the main SIEPAC transmission line serves as an important domestic connection as well. This has created some challenges, such as from controlling the high variability of variable renewable energy generation, which have caused disturbances developing into regional blackouts. To accommodate a higher share of renewables while ensuring system stability, various measures are currently being considered at the national and regional level. These include advanced system operation, flexibility assessment, long-term transmission expansions, the implementation of grid codes for variable renewable sources, and capacity building for grid operators.

The Guatemala-Mexico interconnection was commissioned in 2010. It consists of a 99 km, 400 kV transmission line and a substation with an initial transformation capacity of 225 MW (EPR-SIEPAC, 2020).

► **Institutions**

The developers of the REM aimed to provide a regulatory environment that facilitates a competitive market at the regional level. This would contribute to expanding and ensuring a sustainable electricity supply for the benefit of the inhabitants of Central America. A solid foundation is provided for the SIEPAC project by a supporting institutional structure, detailed below:

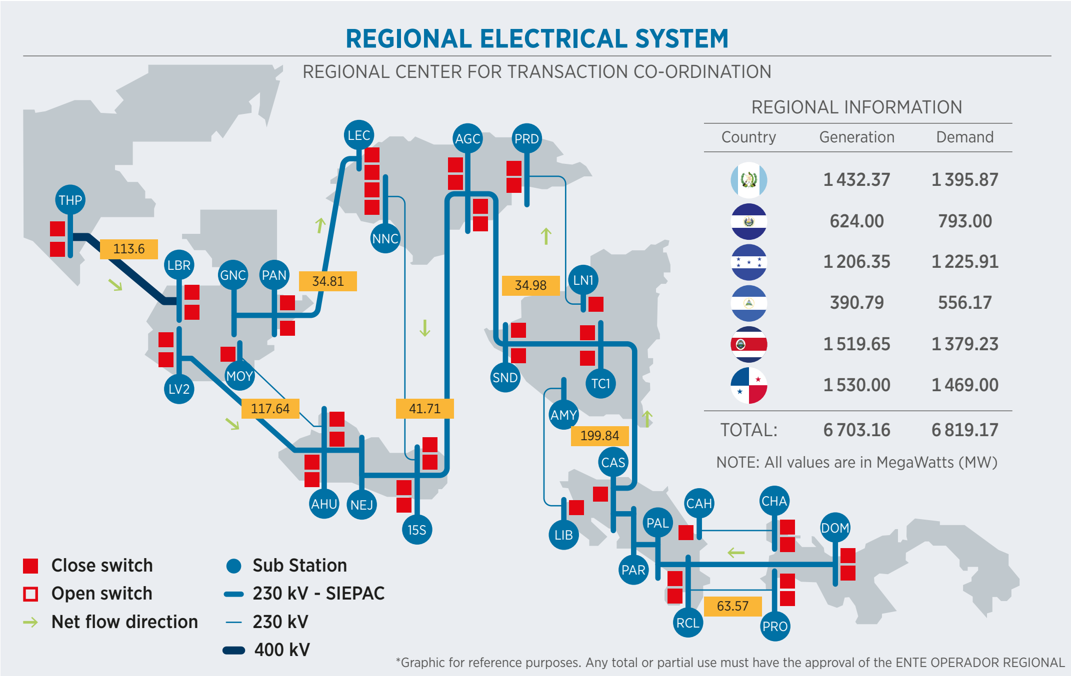
EPR: An SPC established for the development of the interconnection infrastructure, as described above. The EPR is hence a private-public company aiming to design, build and sustain the SIEPAC interconnection system. The EPR is headquartered in San José, Costa Rica.

Regional Operating Entity (*Ente Operador Regional* – EOR): The regional operator of the system. The EOR's mission is based on a legal mandate under Article 28 of the REM Framework Treaty, which lays out the general objectives of the EOR (2020) as:

- Propose to the Regional Commission for Electricity Interconnection (Comisión Regional de Interconexión Eléctrica – CRIE) procedures for the operation of the market and the use of regional transmission networks.
- Ensure that operation and regional energy dispatch is carried out with economic criteria, seeking to achieve adequate levels of safety, quality, and reliability.
- Carry out the commercial management of transactions between market agents.
- Support, through the provision of information, the processes of market developments.
- Formulate expansion plans for regional generation and transmission, providing for the establishment of regional reserve margins and making these available to market players.

The EOR is headquartered in San Salvador, El Salvador.

Figure 15 Status of SIEPAC power flows on 20 October 2020 at 14:45 GMT



Source: EOR (capture from www.enteoperador.org/).

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

CRIE: According to the REM framework treaty, article 19, the CRIE is the regional regulatory agency, a regulatory and norm-setting entity of the REM, its own legal person, economically independent, functionally independent, and will carry out its functions impartially and transparently. CRIE is responsible for regulating commercial relations between public and private institutions that connect to the SIEPAC system and for setting rates. It has authority to intervene in the market to prevent abuse, but only for electricity trading through the REM. Each member country selects one commissioner for the regulator, with decisions traditionally taken via consensus approach (CRIE, 2020).

CDMER: This body is the REM board of directors, the high-level organisation that aims to develop the REM and facilitate compliance with the commitments established in the Second Protocol to the REM framework treaty. It also co-ordinates interrelation with the other regional organisations: CRIE and the EOR. As established by the Second Protocol of the REM framework treaty, the CDMER has one representative from each member government. Each member of the board has the authority within their own government to co-ordinate national policies related to the MER (CRIE, 2020).

The bodies listed above are supported by SICA's Council of Ministers of Energy, which, among other activities, carries out the guidelines of the regional energy sector policy.

► Power market

The regional power market involves actors from each member country, including generators, distribution companies, transmission entities, electricity dealers, agents, and large-scale consumers. There is full, third-party access to the regional grid. As of October 2020, 281 authorised agents were participating in market transactions, of which 150 were generation companies (EOR, 2020).

Initially, the member countries were weighing two options for the market. The first was to move directly to a fully integrated regional market, which would have absorbed the national markets. The second option, which was selected, is more cautious and in alignment with the framework treaty's principle of gradualism. In this second option, trade takes place multilaterally between countries that differ in terms of market structures. The regional market operates on top of the national markets, in what is known as "6+1=1" model. In effect, the six national markets plus one superposed regional market function the same as one regional market.

In the "6+1=1" model, the regulatory demands on the national markets are limited to such principles as are necessary for the operations of the REM. These include open access of market participants in the regional and national transmission networks, and the freedom to buy and sell electricity without any discrimination domestically or regionally.

The regional market started operations in 2013. It maintains two trading mechanisms. First, fixed transmission rights to the SIEPAC line are auctioned at monthly and annual auctions, with bidding starting in 2015. As a result of the regional contracts market, sellers and buyers enter into bilateral electricity sales contracts through the SIEPAC line. The contracts market covers about 66% of total transactions.

Secondly, the REM operates as a secondary market, in which electricity in the national markets, which was not dispatched in their day-ahead hourly markets, can be made available to the REM through injection bids. The EOR then prepares a least-cost regional dispatch plan for the available excess generation to satisfy the received regional withdrawal bids from buyers. If a generator is dispatched by EOR, it receives the regional clearing price. Other generators, which were dispatched under the national markets, receive their local clearing price.

In 2018, about 2 600 GWh was traded in the REM. This represented 4.7% of the aggregate domestic electricity supply of the six countries. Between 2014 and 2018, market participants from Guatemala, Costa Rica and Panama have predominately been selling, whereas actors in El Salvador, Honduras, and Nicaragua have been predominantly purchasing. Guatemalan companies have consistently been the largest sellers, representing 65% of the electricity injections into the system, while market participants in El Salvador have been the largest purchasers, representing 70% of the withdrawals (Urízar, 2019).

► SIEPAC: The state of play

The SIEPAC project is a result of an extraordinarily complex political process. Its institutional set up and regulation are products of intensive studies and negotiations at professional levels.

SIEPAC started operations based on a pre-planned and pre-agreed set of institutions, regulations and market rules, which had been designed and agreed upon during the project gestation process. Implementation of the project has been subject to a wide range of intricate and often conflicting political, economic, and social interests. Therefore, given the hurdles, the project can be deemed successful by the mere fact that the REM is today operational, both commercially and technically, and has delivered towards the objectives of the original scheme.

This success is also demonstrated by the fact that SIEPAC continues to evolve institutionally, commercially, and in its physical infrastructure to meet the developing needs of the region.

Since 2015, CDMER has been working on a planned, Third Protocol to the Central American Framework Treaty on the Electricity Market. This will address many of the existing development needs. An adjusted proposal for the Third Protocol was issued by CDMER in November 2019, and has the following focus areas (CDMER, 2019):

- Strengthening governance and leadership, based on a stronger role for CDMER and on establishing an impartial mechanism for raising or reviewing regional regulatory decisions.

Note: CRIE and EOR are technical, professional entities, and they have not always proven effective in solving certain issues in REM operations. The need for a higher-level body, which has clear political backing from the member countries, has long been recognised, and this led to the establishment of CDMER. CDMER's role is proposed to be further strengthened.

- Greater co-ordination of the planning and implementation processes of national transmission expansion with the planning and implementation of regional transmission expansion. This to be coupled with a more defined commitment for the strengthening of national transmission and for the recovery and maintenance of regional transmission capacity, as well as for the development of effective mechanisms for the promotion of regional-scale generation projects.

Note: This objective is largely self-explanatory. It reflects the fact that generation investments in member countries do not take place in a co-ordinated manner, and regional-specific investments have been slow to develop. It is also important that national grids are strengthened, so that the SIEPAC line is released from national transactions to serve the regional market in a more dedicated manner. As to regional-scale investments, the contract periods in the REM are regarded as too short (monthly or yearly) considering the capital intensive and long-term nature of power generation investments, i.e. they are not secure enough to support investment decisions for new generation capacity.

- Establishing an institutional mechanism that channels governmental commitments to a sustained and gradual harmonisation towards the achievement of the treaty's objectives.

Note: These updates to the protocol are to promote and articulate a more determined process of gradual development of the regional electricity market and regulatory harmonisation of national markets.

- Establishing the possibility of interconnections and extra-regional exchanges, through mechanisms for co-operation and harmonisation of the REM with neighbouring markets and electrical systems.

The updates of the proposal for the Third Protocol aim to tackle some of the challenges arising in the Central American electricity landscape. The increasing deployment of variable renewable energy will set requirements for more robust and dynamic dispatch methods, as well as supervision, control and data acquisition and energy management systems (SCADA/EMS), so that flexibility resources can be mobilised. To address these issues, EOR has established a roadmap focusing on more effective planning, digital transformation, and greater stakeholder engagement (BNAmericas, 2020).

Extending the contract durations is an important agenda item so that more secure contracts can incentivise regional generation investments.

The competitive market favours those countries with comparatively better primary energy resources and a more modern generation fleet. Their regulation and investment environment is more conducive to the development of new power plants and draws export-driven generation investments to these countries. Therefore, the divide between sellers and buyers gets wider, as power at the lowest marginal cost is provided by those with a modern fleet. It can already be seen that the installed capacities in Guatemala and Panama have been growing faster than their domestic demand (Trujillo, 2020). The abilities of member countries to attract new electricity generation investments can be made more equal by harmonising regulation, controlling government incentives for new power plants, and regionally co-ordinating plans to expand electricity generation.

On the investment front, the SIEPAC project plans two major investments (ERP-SIEPAC, 2020). One is to upgrade the existing SIEPAC 220 kV line from single-circuit to double-circuit, which would thus double the load carrying capacity of the line to 600 MW. The upgrade project is in the feasibility study stage. A small section in San Salvador between two substations has already been implemented.

After completion of the Mexico-Guatemala 400 kV interconnection in 2010, the line between Panama and Colombia remains in the investment pipeline as the second major project. The approximate route of the line will be 500 km and its capacity 400 MW. The project will be developed using HVDC technology.

Tikal National Park, Guatemala.

Box 2 CECCA: Clean Energy Corridor of Central America

In partnership with SICA, IRENA has launched an initiative called the Clean Energy Corridor of Central America (CECCA). This has the objective of furthering the integration of renewable energy into the power system of Central America. This strategic collaboration is based on an MOU signed in May 2014 between IRENA and SICA. The CECCA strategy was then endorsed by SICA's Council of Ministers of Energy in December 2015.

The REM has been receiving an increasing number of demands for connection to the SIEPAC line from wind farms and solar parks. This has resulted in a need to ensure system reliability, unrestricted access to the market for renewable capacity, and continued investor confidence in the REM and the national systems for renewable energy deployment.

The areas of support given have been articulated within five pillars: an enabling framework for investment (technical and regulatory components); country and regional power system planning for cost-effective renewable energy options; zoning and renewable resource assessment; capacity building for power system operations with increasing variable renewable energy (VRE) shares; and information dissemination and public support for energy transition.

Panama was selected as a pilot country for the preliminary phase of CECCA implementation, in synergy with the simultaneous conduct of IRENA's Renewables Readiness Assessment process in the country. Co-operation under CECCA has since then been expanded to the regional level.

In 2015, IRENA organised a training course for Central American grid operators on best practices for managing electricity systems with high shares of VRE. The activity was conducted in co-ordination with Spain's transmission system operator, *Red Eléctrica de España*, and covered key topics such as VRE integration, generation characteristics, and forecasting, among others.

With respect to its engagement with the pilot country, in 2017, IRENA conducted a gap analysis for Panama's power system operations and planning. Based on this analysis, IRENA held a training for Panamanian power system operators, which focused on using power system simulator for engineering (PSSE) network analysis software to assess and model the impacts of increasing VRE penetration on the stability of the national power system. Operator training continued in 2018 and 2019, focusing again on VRE models for grid studies and their specific applications, now in Central America, and with the participation from all six SIEPAC countries.

In terms of regulatory environment, IRENA developed a financial model to evaluate investment incentives resulting from the renewable energy PPA design. Following the implementation of this tool, which accounted for Panama's unique regulatory environment and power market structure, IRENA created a report for the government detailing possible adjustments to the PPA structures that would strengthen investment frameworks for solar and wind energy.

In 2018, IRENA carried out a FlexTool analysis to determine the need for flexibility resources in the Panamanian system in order to integrate more VRE into the system. The system is characterised by a high share of hydropower and the flexibility issues are limited. Considering supply and demand forecasts, however, IRENA's analysis suggested investing by 2030 in additional solar PV and battery storage, which would reduce total system costs and decrease carbon dioxide emissions. Beginning in 2019, and with an expected 2021 date of conclusion, IRENA began developing a joint assessment of the flexibility of Central American power systems with a regional REmap analysis using FlexTool.

Nord Pool

► Nordic context

Nord Pool was the first wholesale power market in Europe to cover multiple countries. It now covers the four countries of Denmark, Finland, Sweden, and Norway – which initiated the pool – the three Baltic countries of Estonia, Latvia, and Lithuania, who joined Nord Pool between 2010 and 2013, Central-Western Europe and the UK. Since January 2021, Poland has also been a member.

Nord Pool has been a significant player in the process of creating a pan-European, cross-zonal, day-ahead electricity market. Notwithstanding some references to the more recent European market integration, this presentation, however, places its focus on the early stages of electricity interconnectivity and electricity market development in the Nordic region.

Co-operation in the Nordic area has a long history, stretching back over 100 years. Both grid development in this region and the development of the power exchange have been considered successful and taken as examples for many other regions.

From a geographical perspective, the Nordic region,[12] including Scandinavia and Finland, contains a multitude of natural resources. These range from marine environments off the Norwegian and Danish coasts, to large, forested areas in Finland and Sweden and fertile agricultural lands in Denmark. The climate also varies widely, from the Arctic tundra of the north to the warmer, temperate parts of the south.

With the exception of Denmark, which has 130 people per km^2, the region is sparsely populated, with only between 16 and 21.8 people per km^2 in Sweden, Norway, and Finland. The total population of the four Nordic countries is slightly over 25 million (Sweden has 10.3 million, Denmark 5.8 million, Finland 5.5 million, Norway 5.4 million). This population shares significant cultural and linguistic ties, with the languages of Sweden, Norway, and Denmark being closely related and Swedish being a minority language in Finland.

Although sparsely populated, the free education systems in the Nordic countries lay the foundation for a highly skilled population, in alignment with the commonly shared Nordic welfare ideal. Science and technology are highly valued and investments, especially in research, are world leading. This supports the development of a modern, high-tech society. Employment levels are relatively high, with both men and women participating in work life.

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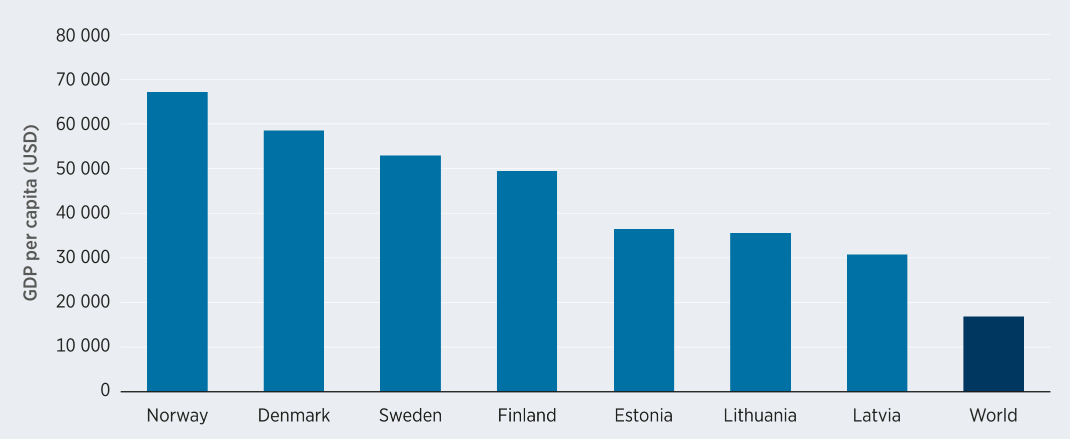
[12] *The Nordic Region consists of the sovereign states of Denmark, Finland, Iceland, Norway and Sweden, as well as autonomous countries and regions of the Faroe Islands, Greenland, and Åland. Iceland is part of the Nordic region and a participant in Nordic co-operation under the Nordic Council and the Nordic Council of Ministers. In most of this discussion, however, the Nordic region is used as synonymous for its electrically interconnected area, even though that only includes part of Denmark, Finland, Norway and Sweden.*

Figure 16 GDP per capita (PPP) of Nord Pool countries in 2018



Source: World Bank, 2020

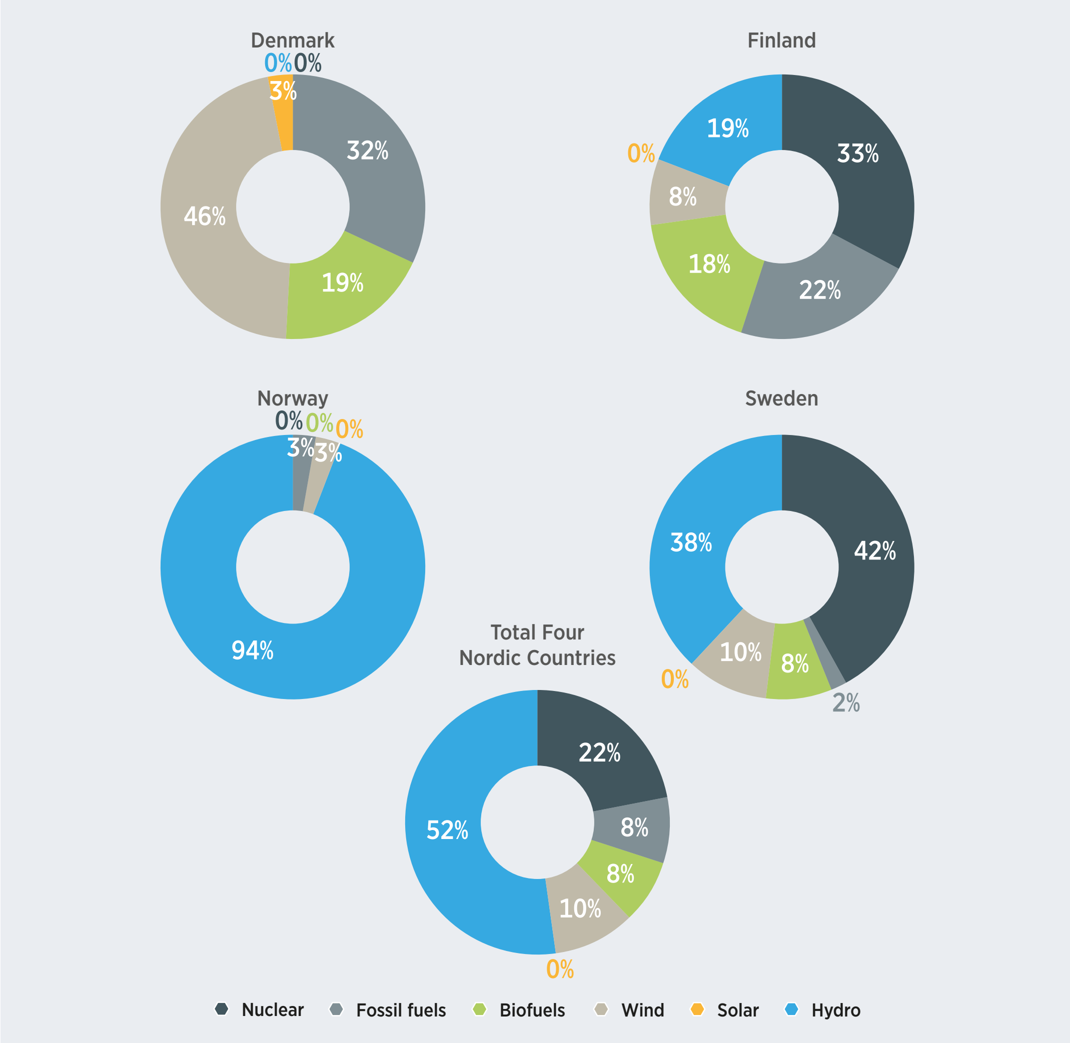
GDP per capita (PPP) in all of the current Nord Pool countries, also including the Baltic States, is relatively high, and in 2018 it ranged from USD 30 644 in Latvia to USD 67 640 in Norway, all producing more than the world average of USD 17 018 per capita (PPP) (World Bank, 2020).

The power sector in the Nordic countries is diverse, shaped partially by the specific renewable energy resources available to each country (Figure 17). Denmark has been able to benefit significantly from its wind power potential and has as much as 46% of its power production portfolio dedicated to wind power – one of the highest percentages of wind power generation in the world. Norway has likewise made use of its ample hydropower potential and gets 94% of its power mix from that source. In Sweden, nuclear (42%) and hydropower (38%) dominate the generation mix, but the deployment of wind energy is also growing fast.

Finland and Sweden, being largely covered by forests, also benefit from their biomass resources. Indeed, in Finland, biomass has a significant role, along with nuclear power, natural gas, coal-fired CHP and hydropower.

The four Nordic countries in total have 70% of renewable energy in their electricity generation mix. The wide balancing area coupled with substantial hydropower resources enable high shares of variable renewable energy in the system.

Figure 17 Electricity generation mixes in the Nordic countries in 2018



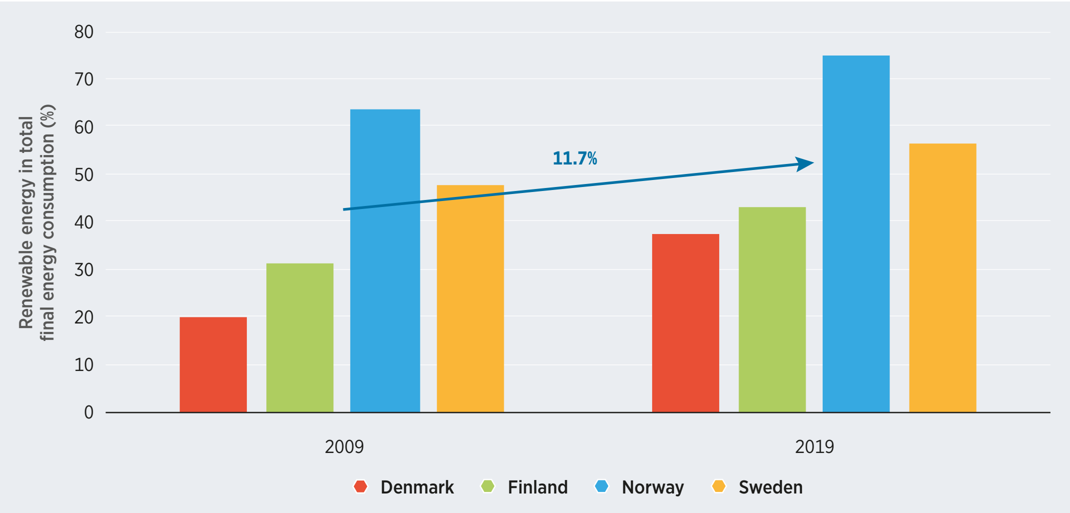
Source: IRENA, 2020a

Due to the Nordic countries latitudes, significant resources for heating are required during cold periods. At the same time, with the presence of power-intensive heavy metal, engineering, and pulp and paper industries, the Nordic countries feature relatively high levels of energy consumption, compared to their population and to European standards.

The Nordic countries pursue a broadly similar energy policy agenda, although each country may feature differences in prioritisation. This shared agenda features a strong push to reduce CO_2 production and increase the share of renewable energy in the total energy mix.

All four countries appear near the top of lists discussing shares of renewable energy in total national energy, as well as lists discussing the strength of countries' climate commitments. The Nordic region has steadily decoupled its GDP from energy-related CO_2 emissions in recent decades, while also achieving a steady decline in CO_2 intensity in the overall energy supply. Deployment of wind power, now accelerating also in Finland, and a fuel shift from fossil fuels to biomass have been key factors in this transformation. As Figure 18 shows, the share of renewable energy in the primary energy supply at the regional level has risen from 41.8% in 2009 to 53.5% in 2019. The increased use of bioenergy is a major contributor to this trend. Altogether, the last decade has seen a reduction of more than one-third in CO_2 emissions from power sector (Nordic Energy Research, 2020).

Figure 18 Share of renewables in total primary energy supply between 2009 and 2019 (%)



Source: Eurostat (2020)

▶ Evolution of electricity interconnectivity in Nordic countries

The national grids of Finland, Norway, and Sweden are significantly influenced by the countries' shapes, with a dominant north-south direction, as can be seen in Figure 17. This is particularly true in Norway, where the national transmission grid was developed to support the production of local hydropower, which is available in most parts of the country.

The elongated shape of Norway is mostly characterised by rugged coastline and Scandinavian mountains that arise from the shoreline and collect rains from the Atlantic Ocean, resulting in an abundant hydropower endowment. The national grid is therefore designed to connect local radial grids that are built around large load centres and production units. Many of these grids were originally self-sufficient local grids.

Long transmission lines between north and south also characterise the Swedish main grid. In Sweden's case, this allows for the national distribution of hydropower from its generation locations, mostly in the northern and central areas, and nuclear power from its stations, mostly in the central and southern parts of the country. Very few transmission lines cross the country in an east-west direction.

The Finnish main transmission lines also follow this pattern. This enables the transmission of hydro power from northern Finland to cities and industrial sites in southern Finland. Denmark, on the other hand, has two separate grid systems. The eastern system is synchronous with the Nordic grid and the western system is synchronous with the continental grid.

Nordic electricity co-operation began in 1912, when the first interconnection operation agreement was signed between two power companies, Sydkraft in Malmö, Sweden and NESA in Copenhagen, Denmark. The agreement was that surplus power from Sweden would be supplied to Zealand in Denmark. A 60 kV AC interconnection was later built, in 1929, between Northern Germany and Jutland. In 1959, another AC interconnection between Sweden and Finland was also commissioned.

All the Nordic countries then saw substantial increases in electricity consumption during the 1960s. This gave greater impetus to increased electricity co-operation and interconnection. This co-operation was largely motivated by various complementarities in the types and primary energy sources of power generation and by the possibility of creating shared reserve capacities in the synchronised Nordic power system.

New interconnections between Sweden and Norway were completed in 1960, together with a joint power plant project. An HVDC cable from the Swedish coast to Jutland, was then laid in 1965.

Further connections included a transmission line between Finland and the Soviet Union, laid in 1961. After two wars between these two countries during the period of the Second World War, Finland and the Soviet Union countries developed mutual trade, despite having different economic and political systems. In this, electricity interconnectivity played an important part. Two additional 400 kV lines and back-to-back converter stations were built in the 1980s to enable a unidirectional supply capacity of 1 000 MW from the Soviet Union to Finland.

Further developments included an HVDC link connecting Norway and Jutland, which was installed in 1976 and then increased in capacity in 1993. In 1989, a link between Sweden and Finland known as the Fenno-Skan HVDC, was also built (Nordel, 2007).

This leads us to today's picture of a Nordic network that is not only thoroughly tied together but has also extended its interconnections outside the Nordic countries. At the moment, there are several DC connections between Denmark (Jutland) and Sweden, Norway, and Eastern Denmark. Interconnections have also been developed between Sweden and Germany and from Sweden to Poland and Lithuania. In addition, a DC connection has been run from Norway to the Netherlands and the UK.

Finland and Sweden are connected via two 400 kV AC connections, while Finland is also connected to Norway via a 220 kV AC connection. In addition, running on submarine cables between Finland and Sweden, the Fenno-Skan 1 and 2 high-voltage direct current (HDVC) connections add 1200 MW of interconnection capacity to the electricity market. A 100 MW DC connection owned and operated by Kraftnät Åland also runs from Naantali to the Åland Islands, which are located between Finland and Sweden.

Finland also acts as the hub for a series of lines that extend Nordic interconnection to the east. Finland, and as such the Nordic grid, is still strongly connected to the Russian Federation's grid, with three, 400 kV transmission links from the southwest of Finland to Vyborg in the Russian Federation. In addition, the Russian Federation and Finland are connected by two 110 kV connections, one running from Ivalo (north) and the other from Imatra (southeast) in Finland.

More recently, the Estonian grid has established new interconnections with the Nordic grid through Finland. The EstLink 1 and 2 submarine HDVC cables between Finland and Estonia have a 1000 MW transmission capacity. In similar fashion, Lithuania became connected with Sweden and Poland in 2015.

There is also now a target date of 2025, set by the Baltic countries, for disconnecting from the wide-area synchronised grid of the Russian Federation and Belarus. At the same time, the Baltic states will commence synchronous operations with Europe. Meanwhile, the development of these states' domestic grids and interconnections with other EU states continues.

Future development projects in the Nordic countries include national projects of Nordic importance, as well as cross-border projects within the Nordic area and interconnectors to other synchronous areas (Statnett et al., 2019). In addition, 'transmission corridors of interest' have been identified as an early outlook for possible future grid investments in five Nordic corridors. What makes these corridors of interest is that they contain borders that will likely see potentially large increases in electricity flow, mainly due to increased integration of renewable energy production.

Figure 19 Nordic area transmission system

Source: Svenska Kraftnät (2020)

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Many of the cross-border lines currently under development link the Nordic area to the UK, the Netherlands, and Germany. Within the Nordic countries themselves, grid development will be greatly impacted by the rapid increase of wind power development in Sweden and Finland, and possibly also in Norway, as offshore wind power becomes more feasible. The best prospective areas for wind development are located far away from load centres, so grids will need to expand to accommodate the increased desire for tapping these resources.

► Institutions

European Union

Developing rapidly in the Nordic countries, a trend in favour of free competition and privatisation has been underway in the EU and wider world since the 1980s. Whilst large, state-owned, vertically integrated power utilities also existed in the Nordic countries, they have never had a complete monopoly over their respective national markets. Private sector entities and municipalities have always been involved in the region's electricity markets, owning power plants, regional transmission lines, and distribution grids. Therefore, whilst there has been some competitive element to the market, the systems administration has historically required collaboration by the market participants.

In Europe, energy market restructuring, third-party access and generation competition were adopted as part of the European agenda after many EU member states had already liberalised their power markets in some way. These changes at the EU level came approximately a decade after markets had been reformed in the Nordic countries, during the 1990s. These issues came onto the EU agenda late because prior to the milestone Lisbon Treaty, signed in 2007 and entering into force in 2009, the EU had no jurisdiction over the member countries in energy matters. The Lisbon Treaty introduced this authority in the energy chapter of the Treaty on the Functioning of the European Union (TFEU).

The documents following the Lisbon Treaty clearly established promotion of the interconnection of energy networks as one of the EU's set priorities (IEA, 2019; ClientEarth, 2010). According to article 176A of the TFEU, the Union is to "ensure the functioning of the energy market, ensure energy security, promote energy efficiency and development of new and renewable energy, and to promote interconnections of energy networks".

This was soon followed by the EU's Third Energy Package (2009), which contained two directives:

- Directive 2009/73/EC concerning common rules for the internal market in natural gas
- Directive 2009/72/EC concerning common rules for the internal market in electricity.

Paragraph 12 of Directive 2009/72/EC states the following:

“Any system for unbundling should be effective in removing any conflict of interests between producers, suppliers and transmission system operators, in order to create incentives for the necessary investments and guarantee the access of new market entrants under a transparent and efficient regulatory regime and should not create an overly onerous regulatory regime for national regulatory authorities” (EC, 2009).

The work of promoting interconnections and the harmonisation of electricity regulation started immediately. In 2014, the EU requested member states achieve interconnections of at least 10% of installed power capacity by 2020 and endorsed a target of 15% by 2030. They underlined that these targets are to be achieved through Projects of Common Interest – priority projects of the EU eligible for public funding by EU institutions – in energy infrastructure. The Nordic countries have already achieved this goal, with cross-border exchange of electricity amounting to about 15% of their aggregated electricity supply in 2018.

As a consequence of the Lisbon Treaty, the EU’s authority in the electricity sector was also institutionalised in 2009 through the establishment of two new entities – the European Network of Transmission System Operators (ENTSO-E) and the Agency for the Cooperation of Energy Regulators (ACER).

The Lisbon Treaty and the associated Third Energy Package were followed by the Clean Energy Package of 2019. Between the Third Package and the Clear Energy Package, from 2015 to 2017 the EU issued and published the first generation of the EU electricity network codes and guidelines. These can be categorised as market codes, connection network codes and operation codes, and all three are commonly referred to as ‘the network codes’ including seven pieces of regulation. The Clean Energy Package refined some roles of the European energy institutions and brought further changes to the existing and future network codes and guidelines (Meeus et al., 2020).

ENTSO-E

ENTSO-E was established by European TSOs and began its operations in April 2009. Its set role is to develop the electricity market within the EU and to intensify TSO co-operation. Representing 42 electricity TSOs in 35 countries across Europe, ENTSO-E is governed by an Assembly representing those TSOs as well as by a Board consisting of 12 elected members (ENTSO-E, 2020). Its secretariat is located in Brussels.

According to its mission statement, ENTSO-E is "committed to developing the most suitable responses to the challenges presented by a changing power system, while maintaining security of supply". ENTSO-E members share these objectives and aim to set up the internal energy markets of their respective countries and to ensure their optimal functioning, along with supporting the ambitious European energy and climate agenda (ENTSO-E, 2020).

In the Nordic context, however, these common goals were already co-ordinated by Nordel, a joint entity of the Nordic TSOs. This body was founded in 1963 to do the groundwork for Nordic electricity market development via increased co-operation between TSOs in Denmark, Finland, Iceland, Norway, and Sweden. With the EU then assuming a leading role in electricity sector regulation and co-ordination, however, Nordel's operations were transferred to ENTSO-E in 2009.

ACER

ACER was established in 2011 and is headquartered in the Slovenian capital of Ljubljana. The purpose of the agency is to "achieve a transition of the European energy system in line with the political objectives set, reaping the benefits of increased energy market integration across Europe, and securing low-carbon supply at least possible cost for European businesses and citizens." (ACER, 2020).

In practice, the agency promotes a more competitive, integrated market; efficient energy infrastructure and networks; and a transparent energy market.

National TSOs

Statnett is the system operator in the Norwegian energy system. Since the end of 2018, Statnett SF has been owned by the Ministry of Petroleum and Energy (MPE) of Norway. In its current form, Statnett acts in three primary roles: TSO, network owner, and power system planner. Its supervisory authority is the Norwegian Water Resources and Energy Directorate (*Norges vassdrags- og energidirektorat* – NVE). Statnett's operations were part of the NVE until 1986, when it was spilt off from the directorate as the Statskraftverkene. In 1992, Statskraftverkene was further split into two entities: one for the grid, which came to be known as Statnett, and the other responsible for power production, which came to be known as Statkraft (Statnett, 2020; Fortum, 2019).

In Denmark, the owner, operator, and developer of the electricity and natural gas transmission systems is Energinet, which was founded in 2005, merging power grid operators and the natural gas TSO. The Danish Ministry of Climate and Energy owns Energinet, although it is an independent public enterprise. It has been charged with ensuring the expansion and efficient operation of the gas infrastructure and main electricity grid. (Energinet, 2020; Fortum, 2019).

Svenska kraftnät (SvK) is a state-owned enterprise tasked with maintaining and developing the Swedish national grid for electricity. Using its authority over the company, the government issues an appropriation bill specifying more detailed work content on a yearly basis. SvK was created as a spin-off from Vattenfall, the joint generation-transmission-supply entity owned by the government, back in 1992, a few years before market liberalisation in 1996 (Svenska kraftnät, 2020; Fortum, 2019).

Fingrid Oyj is the transmission system operator in Finland, a public limited company currently owned by the Finnish state and Finnish pension insurance companies. Its creation followed an agreement between the Finnish government, the state-owned power company Imatran Voima Oy (currently known as Fortum) and Pohjolan Voima Oy – a private sector power company – decided to pull all transmission network infrastructure and operations into one entity, back in 1996 (Fingrid, 2020; Fortum 2019).

Nordic co-operation

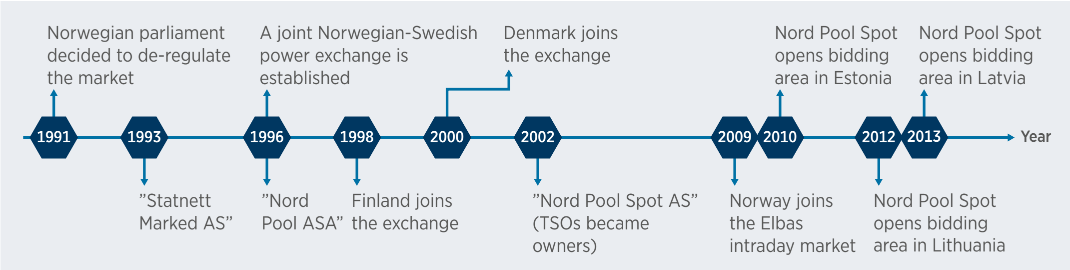
The Nordic TSOs have a long history of collaboration in finding solutions to power system challenges. This has mainly taken place in three areas: Nordic energy policy covering high-level political co-operation and regulatory harmonisation; common system solutions covering power markets and security of supply; and dedicated solutions covering technical issues (Statnett et al., 2018).

The Nordic TSOs publish a common Nordic grid development plan (NGDP) every second year. The NGDP functions as a bridge between the national planning processes and the ENTSO-E Ten-Year Network Development Plan (Statnett, 2019). The Nordic TSOs have collaborated in research and development since the early 1990s on the basis of a jointly agreed roadmap for research and development (R&D). The roadmap focuses on areas of market, balancing, grid, and information and communications technology. In 2018, the Nordic TSOs had 14 ongoing joint R&D projects (Statnett et al., 2018).

Market institutions

Beginning with Norway back in 1991, the Nordic countries decided bring competition into electricity production. They also decided to unbundle still-regulated natural grid monopolies into independent specialised companies, according to function. Nord Pool was formed in 1996 (Figure 20) as a joint venture between Norway and Sweden. A well-functioning electricity market and a strong tradition of co-operation contributed to the further development of the open common Nordic electric power market. Between 2010 and 2012 the three Baltic countries – Estonia, Latvia, and Lithuania – joined the Nord Pool wholesale market after the establishment of the HVDC lines connecting Estonia and Finland.

Figure 20 Nord Pool history with main milestone events



Source: Nord Pool (2020)

Today, Nord Pool is owned by Euronext (66%) and a joint holding company (34%) that represents the four Nordic TSOs (Svenska kraftnät, Statnett, Fingrid, and Energinet), along with Litgrid, the Lithuanian TSO (Nord Pool, 2020). A notable change over the past few years has been that the European power exchanges no longer have a monopoly in their previous geographical regions. Therefore, Nord Pool has wide-ranging operations across Europe, while similarly, other operators – such as the Paris-based EPEX Spot – entered the Nordic region, in 2020.

► Electricity markets

Nord Pool holds a place among the world's major power exchange platforms, such as the European Power Exchange Spot (EPEX), Japan Electric Power Exchange (JPEX), Italian Power Exchange (IPEX), Indian Energy Exchange (IEX) and others. Furthermore, Nord Pool is known be one of the earliest successfully functioning power exchanges in the world and an ideal model for a standard design of an electricity-only competitive marketplace.

Four contributing factors have been identified in the success of the Nordic grid development: the successful dilution of the power of the market; a market design that is simple, but also sound; strong support from political leaderships for deregulation; and a voluntary power industry commitment to public service (Shah & Chatterjee, 2020; Amundsen & Bergman, 2005).

Despite the variety of actors and the available flexibility of trading, Nord Pool demonstrates the appeal of the day-ahead market under the deep integration model, once proper regulation and institutional support is established.

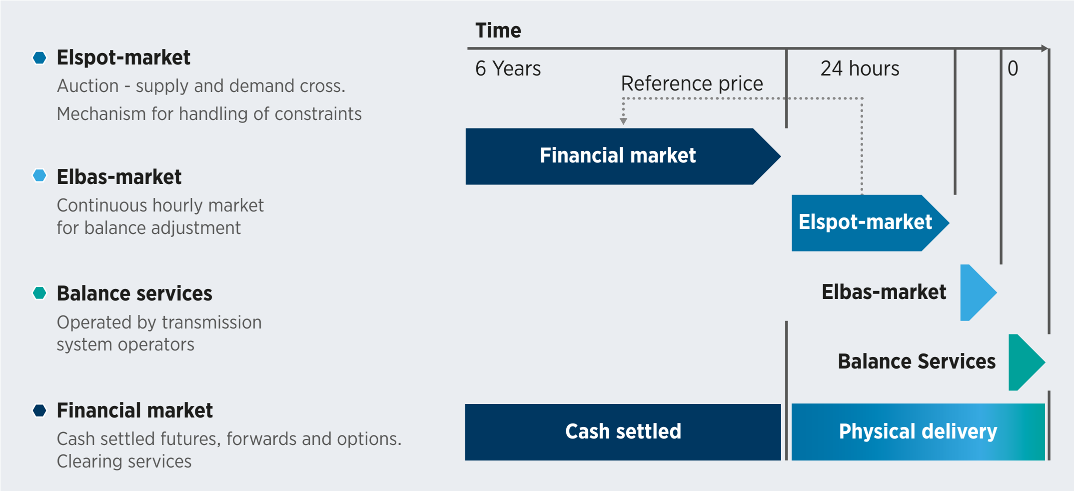
Currently, 360 companies from 20 countries trade in the Nord Pool markets, spread across the Nordic and Baltic regions, Germany, and the UK. During 2019, a total of 494 TWh of power was traded, of which 381.5 TWh were traded through a day-ahead market in the Nordic and Baltic countries (Nord Pool, 2020). In 2019, too, the total electricity production of these countries amounted to 419 TWh (IEA, 2020), representing 91% of the traded volume. Even though direct sales and long-term PPAs are permissible, the vast majority of electricity produced in the region is traded through the day-ahead market.

The market operates on a day-ahead schedule in one hour intervals for every hour for the next day. Bids for production and consumption are submitted by 1 p.m. for the auction managed by Nord Pool. The exchange then establishes the market equilibrium point, where supply and demand meet, and the highest production bid of that point then determines the system price for the entire Nordic trading area. The system price is then published. For the majority of contracts, this then becomes the Nordic reference price in their trade and clearance.

Supply and demand may not be fully balanced in all instances by the exchanges established by the day-ahead market for the day. The following additional markets co-exist to complement the system:

- The balancing market is for intra-day trading and revisions needed in dispatch.
- TSOs maintain balancing reserves for which both generation and demand side market participants can propose capacities. In Finland, for example, Fingrid provides five types of balancing and reserve products to the market. Some of those draw from demand-side flexibility resources.
- The financial electricity product market offers cash settled futures, forwards, and options.

Figure 21 Power exchange concept



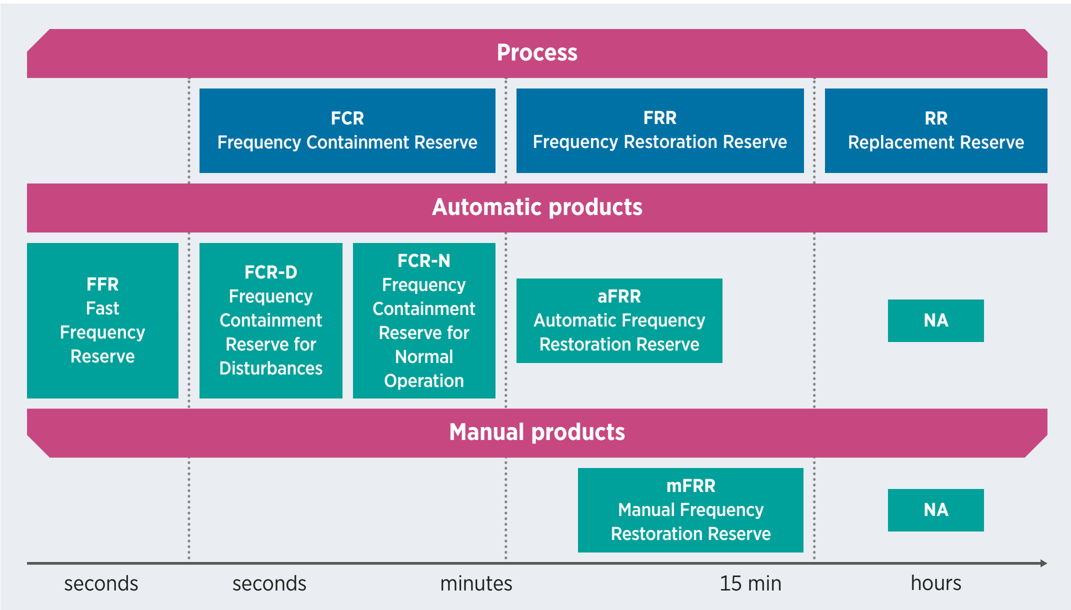
Source: Nord Pool (2009)

In the EU area, the market is covered by several power exchanges, of which three, namely, Nord Pool, EPEX, and the Iberian Energy Market Operator, Polo Español S.A. (*Operador del Mercado Ibérico de la Energía, polo español S.A.* – OMEL) are the largest. Each power market has its own primary area, but different pools are permitted to operate within each other's areas. Nord Pool delivers trading within the Nordic, Baltic, Central Western European, and UK markets. Additionally, it provides intra-day trading within the Nordic, Baltic, UK, German, French, Dutch, Belgian, and Austrian markets. The power markets in Bulgaria, Croatia and Poland are also serviced by Nord Pool.

EPEX SPOT SE and its affiliates operate markets in Central Western Europe and the United Kingdom. In 2018, they traded 567 TWh. The common electricity market of Spain and Portugal is managed by OMEL.

Since 2014, European electricity market exchanges have progressively adopted a common algorithm to couple their respective markets with other markets and create a single, pan-European, cross-zonal, day-ahead electricity market, through single day-ahead coupling (SDAC). An integrated, Europe-wide, day-ahead market has elevated the overall efficiency of power trading and use of interconnection infrastructure through increased competition, increased liquidity and a more efficient utilisation of generation resources across the continent. In early 2021, the mechanism involves 31 European TSOs, including all Nordic ones, and 16 nominated electricity market operators (NEMOs), including Nord Pool.

Figure 22 Products of the balance services market: The Fingrid case



Source: Fingrid (2020)

In a similar way to SDAC, the European intra-day markets are being integrated in three waves – 2018, 2019 and 2021. Single intra-day coupling (SIDC) will allow buyers and sellers across Europe to trade electricity continuously on the day the energy is needed.

The issue of capacity payments

The kind of widespread interconnected network and deep integration that Nord Pool represents can also produce complex emergent issues to be resolved. For many years, thermal power capacity has been under the competitive pressure created by the efficient Nordic electricity market, which is able to deliver significant volumes of low marginal cost hydropower and wind energy to the marketplace over great distances.

At the same time, the marginal costs of thermal power plants are subject to the European emission trading scheme and various kinds of taxes on fuels. Maintaining thermal capacity that is poorly dispatched becomes, over time, a burden for the owners, which has led to early capacity retirements. From an environmental standpoint, this may be seen as beneficial, but on the other hand, this development reduces the available reserve capacities, the maintenance of which is the responsibility of the TSOs.

Additionally, the low marginal cost of renewable capacity is often supported by feed-in-tariffs, or through guaranteed floor prices against the risk of system price variation. Significant volumes of renewable capacity can therefore increase the risk of developing other types of capacity that do not receive these guarantees against low system prices. This further complicates the need to maintain sufficient reserve capacity, especially in the face of the variability of renewable energy sources.

This issue of maintaining reserve capacity is debated all across Europe. Various kinds of capacity mechanisms have been proposed and are in use in different countries to reduce investment risks by having extra payments for maintaining and providing generation capacity to the market, regardless of the energy produced. Trading in Nord Pool, however, continues to be based only on energy, i.e. there is no compensation for capacity by the market operator, and the energy-only system has been widely considered by its members to be functional and efficient.

Finland and Sweden do not have a capacity mechanism, but both countries maintain strategic capacity reserves that are paid for and activated by TSOs only in the case of system faults or disturbances. Since 2004, it has become possible for power plants in Sweden to be strategically reserved. According to Meeus et al. (2020), there an administrative decision is taken to reserve a certain amount of capacity, and the price of that capacity is set in an auction. Power plants that would otherwise be taken offline can then stay on the system and be used in times of shortages.

This mechanism then became the most popular mechanism in Europe, even though it has also been criticised. The fear has been that governments or regulators would be tempted to use their strategic reserves to reduce price peaks. This would then act as a *de facto* price cap in wholesale markets and cause a missing money problem for the other power plants that did not receive payments from the strategic reserve fund. In Sweden and Finland, reserve activation only happens, if there is a curtailment situation. TSOs in both countries decide together which resources to use in the case of shortages. Apart from power plants, a large part of the strategic reserve is composed of demand response by heavy industries (Meeus et al., 2020).

The European situation shows that integrated energy markets can be functional with or without capacity markets, but if two markets with different market designs are to be coupled, then differences with capacity payments or non-payments affect the functioning of market coupling. This creates the possibility of distortion if, for example, one market pays premiums to strategic reserve capacities that activate only in the event of insufficient generation, while the neighbouring market has a capacity market. In this case, when markets are coupled, the energy-only market with strategic reserves would benefit from the spare capacities of its neighbour without participating in paying the capacity premiums.

This can be seen in the initial coupling of the Russian Federation and Nordic markets. The Russian Federation has a functional modern electricity market, but it trades with both energy and capacity. This has effectively increased the overall cost level of trading in the Russian Federation, making its participation in the Nordic electricity market less competitive, despite the fact that it meets the technical prerequisite of having a bi-directional interconnection with Finland.

In 2011, a new direct exchange trade scheme was put into use for trade from the Russian Federation to Finland. This model allows a market participant in the Russian Federation to buy electricity from the Russian Federation's day-ahead market and sell it directly to the Nordic day-ahead market. The market participant can also continue to trade in the Nordic intra-day market, or the Russian Federation's exchange, if the capacity offered was not dispatched by a Nordic NEMO, which at the time was Nord Pool. The volume of trading is limited to 140 MW, while conventional bilateral trade reaches 1160 MW. The maximum trade capacity from Finland to the Russian Federation is 320 MW.

Cost recovery of interconnections and national grids

Electricity interconnections are key enablers for an efficient electricity market. They enable the coupling of sub-markets into a larger marketplace, which increases the number of competitors, reduces the market power of exceptionally large companies, and lessens the likelihood of anti-competitive behaviour. Developing this infrastructure requires significant investment, however, and the cost recovery structures of the market can influence the development of future interconnections.

In the European context, the electricity markets are divided into price zones, which usually follow national borders. Even though the day-ahead bidding will result in a system price, which covers the whole supra-national trading area, in practice the limited interconnection capacity leads to different prices within the sub-markets.

In Nord Pool, the different sub-markets are called bidding areas or zones. Finland and the Baltic States are each a bidding area, whereas Denmark, Norway, and Sweden are each divided into several bidding areas. The available interconnection capacity between the bidding areas may vary and this can lead to congestion in the electricity flow between bidding areas. Therefore, once the system price has been established, the market operator also calculates the aggregated supply and demand curves for all bidding areas separately. Prior to that, the TSOs have informed the market operator of the available capacities of interconnections.

If the supply and demand situation in two neighbouring bidding areas is such that there is surplus capacity in one area at a cost that falls below the calculated equilibrium price of the neighbouring area, then this surplus can be transmitted to the neighbouring area, which has a higher price, provided sufficient interconnection capacity is available. In that case the areas will have common equilibrium and the same price, which is calculated by the market operator, and electricity will run from the low-cost to the high-cost area.

If there is congestion, in that the capacity of the interconnection limits the ability of the low-cost surplus to flow to the higher cost area, the line will be used to its full capacity, but a price difference between the two bidding areas will remain. In this event, however, the price difference will be reduced because the flow through the interconnection changes the supply-demand balance in both areas, by increasing demand in the low-cost area and by increasing supply in the high-cost area.

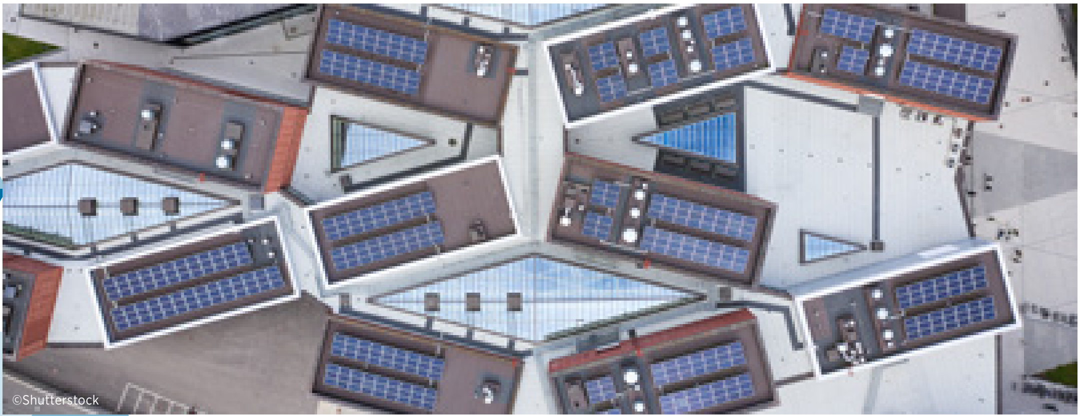
This method of determining price and interconnection capacity through one auction is called an implicit auction, as there is no separate auction for the rights to use interconnections. In some other European markets, there were (explicit) transmission capacity auctions, while between the systems of the Nordic and Baltic countries there have not been long-term transmission rights for cross-border trade. The implicit auction mechanism has recently become dominant in European electricity markets, and it is called simply 'market coupling'.

When congestions cause a price difference between two bidding areas, it is the TSO which benefits. Although the importer pays the higher price set for its bidding area, the exporting supplier receives the price set for its own bidding area. The difference between these prices is collected as a congestion charge by the grid operator from the higher price paid by the importer for the transmitted energy. A TSO can, but is not obliged to, earmark the congestion charges for investments aimed to relieve congestion, such as for new interconnections.

As to continued development of cross-border interconnections, Supponen (2011) found that cross-border transmission investments can be influenced by the interests of states and companies. Certain European states have seen some vertically-integrated TSOs make a priority of investments that increase exports – and thus boost their owner's income. This has sometimes been done at the expense of import interconnections that may also be profitable, but are left undeveloped. Even within the Nordic market, where there are no longer vertically integrated utilities, a tendency to assess investments primarily from a perspective of national interests and prioritisation cannot always be avoided, even in joint projects. Indeed, even though a cost-benefit methodology exists in the Nordic region, with this also being used, common benefits may not be prioritised over national interests.

Overall, the TSOs receive their revenues from grid service fees regulated on a cost-plus basis by national regulators. The way grid service fees are set is harmonised by EU directives. The way the cost recovery is divided between two TSOs for cross-border lines is also regulated.

The level of grid service fees to TSOs is relatively low. In Finland it is less than EUR 3.5/MWh, excluding the winter peak-time fee and fees for reactive power (Fingrid, 2020). In the Nordic grid, market participants trading through Nord Pool do not require any transmission service agreement (TSA) with the TSOs for day-to-day trades.



Lessons learnt from the case studies

This section draws together the key experiences and characteristics of WAPP, SIEPAC, and Nord Pool to identify and discuss lessons learnt and success factors in the formation and operation of the three regional interconnected electricity systems and markets. The discussion focuses on the enabling conditions that have allowed the three schemes to become reality. It is also important to understand the barriers encountered that may have caused delays or changes in direction. The discussion is motivated by the need to understand these issues in light of the contextual differences with NEA, as the ultimate goal is to find pathways for the accelerated development of electricity interconnectivity among the NEA countries.

The differences in the contexts of the four regions for electricity interconnectivity are described by a few key indices in Table 3.

The striking difference between NEA and the three other regions is its size, in terms of population, economy and power system, as well as the political might of the region's countries. NEA accounts for 22% of the world's population and 25% of the world's GDP. Four of the five NEA countries are members of the G20 grouping and China and the Russian Federation are among the five permanent members of the UN Security Council.

Table 3 Key indices of the four regions/regional markets

	Installed capacity (GW)	Sum of domestic supply (TWh)	Renewable electricity share (%)	Country Cross-border trade (%)	Population (million)	GDP (USD billion)
WAPP	16	70	28	4-9	386	695
SIEPAC	16	57	76	7	49	214
Nord Pool	111	409	70	15	27	1,742
NEA	2 759	9 926	22	0.3	1 723	21 004

Source: IRENA (2020a), IEA (2020), Word Bank (2020)

Note: Trading approximated by the share of the average of imports and exports in the total domestic supply of the region. Trading also includes trading of members with countries not belonging to the specified interconnected system.

This discussion begins by addressing the political benefits of interconnectivity and then describes the economic and financial benefits of cross-border trading, the benefits of a more competitive market, and the potential for increased reliability. Finally, the role and importance of regional institutions is addressed.

Foreign and economic policies

► Underlying politics of the three reference cases

All three interconnected systems, SIEPAC, WAPP, and Nord Pool, have arisen from foundations based in the member countries' explicit commitments to free trade, economic co-operation and integration, as well as political collaboration and partnership on issues extending beyond the strictly economic sphere.

The histories of SIEPAC and WAPP have roots in the processes through which the regions' countries have aimed to combine forces, both politically and economically. The end of the strife and violence in and between some of the member countries, which took place in the 1980s and the 1990s in both Central America and West Africa, marked a turning point for both regions. Peace and security became a part of the primary agenda, together with economic development.

Political integration is not, however, as notable an undercurrent for Nord Pool. Before entering into deep integration, the Nordic interconnections were driven mainly by practical economic and technical considerations, underpinned by problem-free political relations between the four Nordic countries. A power system integration scheme can sometimes be seen to represent an effort of political good will, building trust through economic interdependence. In the Nord Pool context, however, political trust was already present as an enabler of deeper integration, rather than one of the aims of the scheme.

SIEPAC began under the auspices of SICA, which followed from the signing of the Tegucigalpa Protocol, amending the old ODECA Charter to focus on regional peace, political freedom, democracy, and economic development. The Central American Framework Treaty on the Regional Electricity Market was signed in 1996 and an initial agreement to finance the SIEPAC was signed in 1997. Even though economic integration has a central role in SIEPAC, political and social integration processes were, and continue to be, interlinked with this.

WAPP is a specialised agency of ECOWAS. ECOWAS is an economic co-operation organisation of the West African States. Fifteen regional heads of state established the organisation by signing the 1975 Treaty of Lagos. While originally, economic co-operation was the focus, the scope of ECOWAS was expanded and revised in 1993, for political reasons. Today, the roles of ECOWAS are wide-ranging and are clearly beyond the limits of economic integration.

The governance of the organisation by various bodies also reflects its political significance, bearing some resemblance to the structure of governing bodies of the EU. ECOWAS is led by the authority of heads of state and government, underscoring its political nature and weight. The character of ECOWAS as a political alliance and superstructure is also echoed in the subordinate bodies, including the Council of Ministers; the Community Parliament; the Economic and Social Council; the Community Court of Justice; and the ECOWAS Commission.

Nord Pool was established as a result of a rapid sequence of events following the liberalisation of energy markets in the Nordic countries, starting in Norway in 1991. Swedish and Norwegian TSOs established the pool in 1996, followed by Finland joining in 1998 and Denmark in 2000.

This process was not linked to EU membership. Finland and Sweden joined the EU in 1995, but Denmark had already been an EU member since 1973, and a Norwegian referendum rejected EU membership in 1994. Furthermore, the EU was granted authority in energy issues through the approval of the Lisbon Treaty in 2009 – more than ten years after the start of Nord Pool co-operation.

The Nordic countries are often perceived as a political block, despite also having notable foreign policy differences. Denmark and Norway, for example, are members of the North Atlantic Treaty Organisation (NATO), whilst Finland and Sweden are militarily non-allied and have maintained neutrality in many international foreign policy issues, particularly during the Cold War era. It should also be noted that while Norway has a close relationship with the EU due to its membership of the European Economic Area (EEA) – which had its founding treaty signed in 1992 and was established in 1994 – it is not an EU member state.

The internal policies and outlooks of the Nordic countries do, however, share many similarities, and energy co-operation between the countries has continued for decades, led by state-owned utility companies. This has been facilitated by the fact that the countries have maintained similarities in power sector structures. This is evident in that private ownership and the role of municipalities in the generation, transmission, and distribution subsectors has always been lawful and commonplace. Under the framework of the Nordic Council ministerial meetings, the countries have discussed and exercised broadly similar policies in a multitude of fields, in addition to developing the shared ideals of the welfare state. Freedoms such as traveling without passports in the region, working without work permits, and residing in the region's countries had already been in effect since the 1950s.

Since 2009, Nord Pool co-operation has aligned with the energy policy targets and regulatory harmonisation of the EU, as well as the ways in which this guidance has been reflected in the national legislations and regulations of Nord Pool member countries.

Although each of the three reference cases must be understood within its own context, the three systems share similarities in the relatively even distribution of political influences between members. All three regional systems can be seen as partnerships of largely similar kinds of economies that are not overly different in economic and political power, as well as partnerships of like-minded peoples with respect to cross-border co-operation with neighbouring countries. It is worth noting an exception, however: in the ECOWAS region, the political and economic weights of Nigeria, Ghana and Côte d'Ivoire are considerably greater than those of some of the smaller member states. The countries of the three reference cases also have vital similarities in culture, religion, history, tradition, and working languages, even though West Africa and Central America also demonstrate a rich variety of cultures, languages, and ethnicities.

► Implications for NEA interconnection

The underlying economic partnerships of SIEPAC, WAPP, and Nord Pool are deep and political. They not only cover the economic spheres of industrial production, trade, logistics, transport, energy and climate, but also agriculture, science and technology, and culture. These partnerships even have their own judicial systems. The key conclusion is that there is no regional economic co-operation organisation comparable to SICA, ECOWAS, or the EU in the NEA region that could act as the wellspring for electricity interconnectivity in a comparable manner. The development of cross-border co-operation in the NEA electricity sector therefore must rely on entirely different kinds of political and economic partnerships. Furthermore, WAPP and SIEPAC also demonstrate that regional co-operation under the collaborative systems of ECOWAS and SICA can continue to develop, despite the experiences of war and political instability within their respective regions.

The NEA region has a weak sense of regional identity. The people of its countries hold strong national identities, senses of history and patriotic sentiments. Even though the cultures of China, Japan, Mongolia, and the Republic of Korea share some common roots, over centuries they have developed unique social and cultural features that differ from each other in significant ways. To add to these cultural problems, the countries do not share a common working language.

Geopolitically, Japan and the Republic of Korea are militarily allied and have broad partnerships in multiple fields with the United States. There are still some territorial disputes between China, Japan, and the Republic of Korea and between Japan and the Russian Federation, and all three countries harbour some historical mistrust of one another.

Some of the existing collaborative bodies, such as the Asia-Pacific Economic Co-operation (APEC) or Shanghai Co-operation Organisation (SCO), which are sometimes suggested as a means for these five countries to establish co-operation in renewable energy based interconnected systems, are not well suited for such a role. APEC's fields of operation are wide, as is its geographical coverage, but Mongolia is not a member. SCO, in turn, is a Eurasian political, economic, and security alliance that also has a very wide geographical coverage, but Mongolia, the Republic of Korea, and Japan are not members.

The low level of trust between the countries – in comparison to, for instance, Northern Europe – and the lack of an economic organisation or a permanent political forum dedicated to economic and political co-operation in NEA, create a unique situation. Advocates of electricity interconnectivity suggest, therefore, that realistic expectations for building NEA regional interconnectivity should include a gradual bottom-up approach, which may take some time to develop (Kim & Lee, 2018).

The Taedong River in Pyongyang, Democratic People's Republic of Korea.

That said, there are several positive political forces in action in support of electricity interconnectivity in the region. These should form the basis for the future multilateral interconnectivity agenda of the NEA, as summarised below:

1. There are strong, heads-of-state level commitments to regional energy co-operation and electricity interconnectivity.
2. China, Japan, and the Republic of Korea are active proponents of free trade principles in the global economic arena and are beneficiaries of them. The Russian Federation's economy in turn is highly dependent on international co-operation in the energy markets.
3. A multitude of bilateral agreements on energy co-operation between the NEA countries confirms the countries' willingness for cross-border electricity sector co-operation.
4. Fruitful dialogue on the status, opportunities, and next steps for NEA electricity interconnection has continued and evolved in recent years. This has taken place, for example, under the North-East Asia Regional Power Interconnection and Co-operation (NEARPIC) forum of ESCAP, as well as through various research and study initiatives, such as the NAPSI Strategy Study of Mongolia and studies from the ADB between 2015 and 2020.
5. Desire for renewable energy development forms a common denominator for NEA countries, which can help reduce the political barriers to interconnection arising from concerns over energy security and the geopolitical features of electricity interconnection.

► High-level support

Strengthening regional electricity sector co-operation has indeed been on the agenda of the highest-level political leaders of NEA. China's President Xi Ji Ping has promoted the Asian Super Grid concept as part of his government's broader vision under the Belt and Road initiative (BRI), introduced in 2013. GEIDCO was established in 2016 as a non-profit international organisation to promote global electricity Interconnection (GEI) worldwide. Even though GEIDCO has a global membership and reach, it has also actively proposed solutions for the NEA region that feature China in a central role.

In Japan, direct government involvement in cross-border power system integration has been limited. The private sector and various research institutions, however, have taken an active role in analysing and promoting regional interconnections and the power trade. Japan wishes to continue its prominent role as an investor in Asia and launched its Asia infrastructure investment plan in 2015.

President Moon Jae-in of the Republic of Korea encouraged regional electricity interconnection at the Eastern Economic Forum in 2017, in the context of regional economic co-operation and the development of a multilateral security system. The Republic of Korea is an active advocate of energy co-operation, shown through institutionalised interconnectivity work. The state-owned power company has maintained a permanent unit to study and develop NEA electricity interconnection (the Super Grid concept). In addition, based on the country's Eurasia Initiative of 2013 and the New Northern Policy of 2017, the Presidential Committee on Northern Economic Co-operation was established to pursue economic co-operation and investment in a multitude of economic sectors in NEA.

Mongolia has been an active backer of regional interconnection, hoping to export renewable energy and coal-based electricity through the system. Mongolia issued its Steppe Road Initiative in 2014 – with plans to extend railways, modernise gas and oil lines and update the electricity grid. In collaboration with the ADB, the country also launched the NAPSI Strategy Study, which confirmed the economic rational of the plan. In 2018, Mongolian President Khaltmaa Battulga announced his government's decision to bring the interconnection plans a step forward by establishing a regional organisation to pursue the implementation of the concept.

The Russian Federation's President Vladimir Putin has systematically placed high importance on regional energy relations. In several instances, President Putin has mentioned a desire to develop an Asian super grid in his bilateral meetings, as well as at the APEC forum and the annual Eastern Economic Forum gathering in Vladivostok. The development of Russia's Siberian and Far Eastern regions is an important goal defining the Russian Federation's policies. This was demonstrated, for example, by the Great Eurasian Partnership initiative of the Russian Federation, in 2015.

This high-level political support is a necessary, but not sufficient condition for interconnection development. The co-operative proposals established so far have failed to produce co-ordinated and substantial progress towards cross-border electricity grids – which would be combined with the accelerated development of the region's renewable energy resources – as anticipated in the leaders' shared vision. One key missing piece has been the lack of any signing of multilateral agreements for the development of electricity interconnection. The high political capital that the leaders place on their specific national initiatives for the region may guide the countries to competitively seek a profile of the leadership position in interconnection development. This may risk slowing down efforts to find a practical, yet multilateral and gradual, way forward.

► Bilateral arrangements

The third positive force mentioned above is the existence of a multitude of bilateral agreements for electricity interconnections. Such agreements have been concluded, for example, under bilateral commissions for trade, economic, energy, scientific, and technical co-operation. The Russian Federation and China, for instance, have a sectoral commission specifically for energy co-operation and a joint working group on co-operation in electric power. The work of these bilateral forums may form a basis for a future multilateral framework. Energy dialogues between China, Mongolia and the Russian Federation, for example, have already led to some long-term, formal and binding interconnection developments, which are described in the section on electricity interconnectivity in the NEA region.

► Energy security and renewables

The fifth political endorsement identified for NEA regional interconnection in the list above relates to the way renewable energy is perceived in the context of energy security.

In general, the importance of concerns over energy security may sometimes have been overstated in the debate on barriers to NEA electricity interconnection. Considering the expected level of energy trade through an interconnected NEA, the system is unlikely to present a serious threat to any individual country's energy security, in the near future. China and the Russian Federation in particular, are large countries and trading with electricity in NEA would represent just a minor part of their total electricity supply. As an example, a 5 GW export/import transmission connection trading 20 000 GWh annually, would represent a share in total electricity supply of 0.3% for China, 1.9% for Japan, 3.4% for the Republic of Korea, and 1.8% for the Russian Federation. This contrasts with the 4%-15 % currently traded cross-border in the SIEPAC, WAPP, and Nord Pool systems.

Notwithstanding that oil, LNG, and coal are imported products just like imported electricity, the energy security contribution of domestically located thermal power capacity is perceived to be higher than that of electricity imports. The often-mentioned argument is that the ability to store fossil fuels, at least for the short term, gives them more value to energy security than imported electricity that can be instantaneously interrupted. Fossil fuels, however, are often sourced from distant locations and their seaborn transportation is subject to political and other risks beyond the region.

The political perception of renewable energy-based electricity imports is considerably more favourable, particularly among the public. From the perspective of Japan and the Republic of Korea, importing electricity from and through China, Mongolia and the Russian Federation, the associated commercial partnership would be among neighbours. Such a regional approach is protected from the global risks of energy crisis, unrest in far-away oil producing areas, or along the main shipping routes. Secondly, the region's countries are committed to the goals of the Paris Agreement, with China, Japan, and the Republic of Korea having already pledged net-zero GHG emission targets by 2050 or 2060. Renewable energy-based, cross-border electricity imports would align with the countries' high-level climate policies, while also helping to mitigate local air pollution for domestic coal combustion.

Finally, geopolitical concerns can be mitigated by the participatory potential of regional renewable energy and transmission line development. The NEA countries have complementarities not only in renewable energy resource endowments, but also in capacities for innovation, technology, engineering, procurement and construction (EPC), asset operation, and financing. A foreseeable option would be to have a regionally collaborative approach to implementing renewables-based interconnections with the aim of investments being open to companies across borders. Therefore, the public good of interconnectivity would be shared by all countries, as some of the renewable energy generation and transmission assets – regardless of their location – can be owned and operated by private companies, public-private partnerships, and the region's major TSOs and generation companies, across borders.

Economic and financial benefits

► Motives to trade

A fundamental motive for trade is a cost differential between trading partners. Most often, without a cost differential, trading will not take place.[13] In SIEPAC, cost differentials exist because of the highly diverse production mix of electricity. There, 75% of produced electricity is renewable, with this including bioenergy, geothermal, hydro, solar, and wind. Utility-scale solar PV and wind power development is also increasing. Secondly, the market, albeit small, has 281 participants with 150 generation companies in six countries, which makes an efficient market possible. At all times, there are sellers and buyers with converging electricity price expectations. Thirdly, between the six countries there are structural differences in the power sector that support trading. Guatemala injects the largest volumes of electricity into the REM, which stems from the fact that the country, historically, has a large surplus of installed capacity.

[13] *Cases exist where cross border electricity interconnection and trading are based primarily on maintaining system security and stability. Furthermore, in some instances, interconnection provides the least-cost option for countries with limited energy resources and power deficits, as has been the case in West Africa. System integration may therefore be beneficial, even if active trade is unlikely or limited in scope.*

The motives for trading – and hence developing the regional interconnected system – come from the need to reduce high costs of electricity supply to the consumers, increase the low-capacity factors of power plants, and enhance the efficiency of the generation subsectors by increasing competition based on regional complementary resourcing.

The situation in WAPP is quite different. The regional electricity mix is dominated by fossil fuels (75%) and in power plants located in the region's three largest economies, Nigeria, Ghana, and Côte d'Ivoire. Therefore, export from these three countries to their neighbours constitutes the vast majority of international trading in the region. Nigeria's export to Togo/Benin, via a 330 kV interconnector, alone represented 39% of the WAPP total transmission in 2018 (WAPP, 2019).

Trading within the WAPP region is currently characterised by factors such as: necessities determined by power deficits in various parts of the system; constraints due to lack of transmission connections; and governance by utility-to-utility PPAs and TSAs. Only Ghana and Nigeria have unbundled their electricity sectors (DBSA, 2019).

The motives and structures for trade here are significantly different from those of the more completely established SIEPAC. The WAPP project is still a work in progress and therefore does not demonstrate the targeted situation, which would complete a unified network across the region, eliminate transmission constraints, and establish a competitive, day-ahead electricity market following the SIEPAC example.

Development of Nord Pool represents a case where the physical transmission infrastructure of the region existed at the time the market was established. Therefore, the focus of integrated power system development was not on infrastructure, but on markets. The Nord Pool day-ahead trading platform offers an efficient and competitive marketplace for its participating countries' generation sector (as sellers) and distributors and large consumers (as buyers). Spread across Europe, 360 companies from 20 countries trade in the Nord Pool markets. In 2019, Nord Pool traded a total of 494 TWh of power, which is more than the total domestic supply of the founding four countries, which stands at 409 TWh.

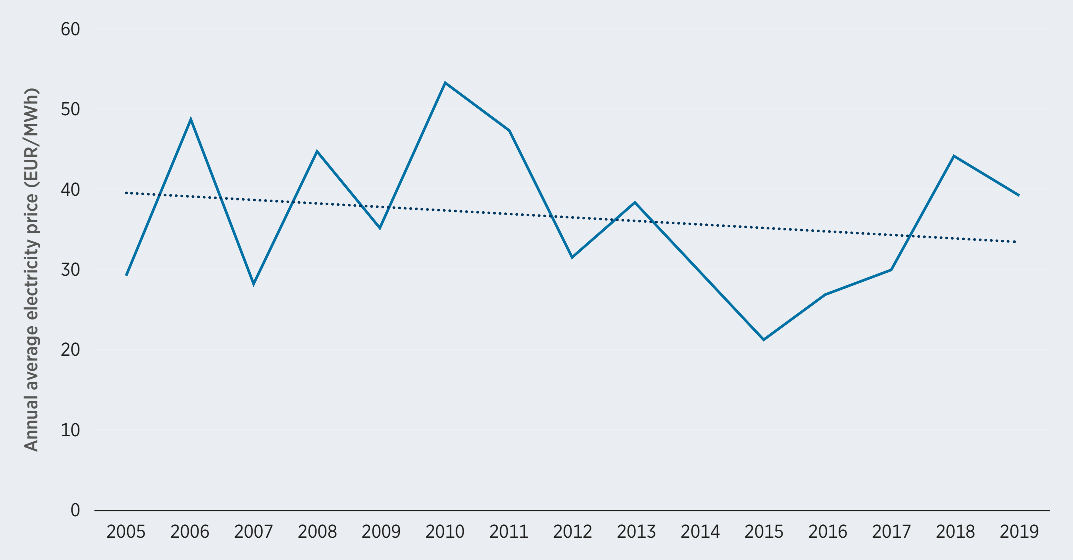
The Nord Pool case demonstrates that developing regional power system integration does not serve only the sector operators, such as power generation companies. Creating efficient sector operations leads to a lower cost of electricity, driving the countries' productive sectors and producing energy services for their citizenry. Integration is thus ultimately for the public good of the region. In the Nord Pool area, this is understood as a target that has largely been achieved. The average system price has been on a declining trend and has reached a level that is already challenging for natural gas fired power plants, for example, to achieve. Figure 23 below demonstrates this, with the trend price of EUR 32/MWh in 2019 equalling USD 36/MWh.

Deep integration with a genuinely competitive regional marketplace provides no safe havens for the market participants, unlike the realm of vertically integrated utilities, or of a single buyer system with regulated bid prices. Generation companies may suffer losses, and their assets become stranded due to market transformation, changing fuel prices and innovation. Furthermore, there is no protection for domestic generation assets in competition with foreign generating companies.

The economic and financial drivers of the three case studies can be summarised as follows:

- SIEPAC is a comprehensive project, concurrently developing both the underlying transmission infrastructure and the electricity trading platform. Besides the political push, the project is driven by a careful analysis of the business case, made by identifying differences in production costs that lead to opportunities for trade. The original feasibility study estimated economic and financial costs and benefits for the region and for each participating country separately. The materialised trade patterns show that the cost differentials support increasing trade and consequent efficiency across the region.

Figure 23 Nord Pool system price, 2005 to 2019



Source: Nord Pool

- WAPP is a project in progress and whilst the same long-term objectives for trading are similar to SIEPAC, WAPP still needs to develop the enabling environment for trading to happen in an integrated regional power system. The highest priority for the region is to mobilise financing and implement the generation and transmission infrastructure needed for increased access to electricity in accordance with SDG 7. Most of the utilities of the WAPP member countries are still vertically integrated. Integrated transmission grids will enable economies of scale for large hydropower and thermal projects, as well as integrating large, utility-scale solar PV and wind power capacities into the system.
- Nord Pool was developed on a platform of existing transmission infrastructure. The expected benefits were based on improved market performance, lower prices, greater productivity and competitiveness leading to economic growth and job creation.

► Implications for NEA interconnection

"There must be a cost differential between trading partners for trading to happen." A key lesson learnt is that the benefits of regional interconnection should be clear and transparent, and analysed not only economically, but also financially, for every participant separately and for the total of the regional integrated system. Unlike the situation with SIEPAC and WAPP, the national generation systems of the NEA region are relatively advanced, and an introduction of a regional marketplace is not expected to spur substantially greater efficiencies. Therefore, the first task of the planners of NEA interconnection should be to focus on understanding in detail the price differentials across borders. That is, the financial costs and benefits related to interconnectors between the pairs of NEA countries e.g. the Republic of Korea and Japan and China and the Republic of Korea, as well as trading with renewable energy between Mongolia and China, the Russian Federation and Mongolia, the Russian Federation and China and the Russian Federation and Japan.

Many of the cost-benefit analyses carried out on NEA power system integration have been based on idealised circumstances, including a web of nodes connected by strong transmission links enabling bi-directional trade between the nodes. Development of the required infrastructure is a huge task, however. The NEA region is large, the interconnector lengths between some nodes exceed 1000 km, and regionally meaningful capacity additions of renewable energy must be in several GWs. Such a grid can only be developed gradually and over a long period of time – and by a multitude of investors. Therefore, it is essential for the scheme that renewable power generation investments and cross-border connections, which are feasible already today or in the near future, are identified as the first priority and the parties proceed to conceptual designs of the business cases of cross-border trade.

The base premise for many studies about interconnecting the NEA region has been the concept of developing renewable energy resources in China's North and Northeast regions (bioenergy, solar and wind), the Russian Federation's Siberia and Far East (hydropower and wind), and Mongolia (solar and wind). This is underpinned by the observation that the cost and availability of land stand as barriers to developing the same kinds of large-scale renewable resources in Japan and the Republic of Korea.

The renewable energy resources in Mongolia have been confirmed to be of high quality, but there are quality resources also in China's Inner Mongolia Autonomous Region (IMAR) and Gansu Province, where part of the Gobi Desert is located. At about 1000 km, the distance from, for example, Dalanzadgad in South Mongolia to Beijing is shorter, however, than, for example, from the Jiuguan 8 GW Wind Power Base in Gansu to Beijing, which is about 1500 km.

More detailed studies are now needed to establish conceptual cost estimates tailored to specific sites for renewable electricity generation in China, Mongolia, and the Russian Federation. These estimations should consider that a programmatic development of the resources on the scale of GWs can result in economies of scale leading to costs converging with the lowest range of installed costs that are currently achieved by many technologies in China.

The quality of resources available at potential sites for renewable generation in different countries within the region should also be a key part of any discussion. The cost differential of developing the resources in Mongolia and the Russian Federation – as opposed to developing them in China, Japan, or the Republic of Korea – is based primarily on the properties of the resources, such as higher solar irradiation, a higher capacity factor for wind, and excellent conditions for hydropower. The differential must be large enough to cover the additional cost of interconnection needed to transmit electricity from the production bases to China (or later to Japan and the Republic of Korea) so that the landing cost of electricity in China remains competitive in the country's respective provincial power market.

If properly organised during development, the renewable resources of the region can be used to balance one another to produce a more reliable system. The ability to balance the variability of wind and solar power generation with the Russian Federation's hydropower should be considered, which leads to the concept of synchronised development of sets of resources across the region. For instance, wind and solar farms, possibly in Mongolia, could be twinned with hydropower in the Russian Federation and associated transmission to China.

Further studies need to consider the local circumstances in Mongolia and the Russian Federation more deeply. Research needs to report the market conditions in the Russian Federation and compare domestic hydro and wind power generation opportunities to the alternative of export-oriented business with long transmission interconnectors. As a part of this, the conditions arising from the operations of the energy and capacity market of the Siberian grid should be better understood.

Another energy resource abundantly available in Mongolia and the Russian Federation is coal. China's coal resources are also substantial, however, and Japan and the Republic of Korea have for decades imported coal from international markets. If new coal resources were developed for new power generation in Mongolia, or the Russian Federation, in the context of the NEA electricity interconnection, it is not evident that there would be a significant cost differential between a new coal-fired, mine-mouth power plant in China and an equivalent facility built to similar efficiency and environmental standards, say, in the Russian Federation or Mongolia, to the disadvantage of the plant in China. Furthermore, most countries are in the process of revising their power expansion strategies to halt further development of coal for electricity and to start a gradual fossil fuels phase-out from power generation. In this context, expanding coal should not play a role in justifying NEA electricity interconnection, whereas interconnections can support phasing out coal.

Emphasis on renewable energy exports notwithstanding, the complementarities in the national energy mixes, time zone differences, and demand patterns will also create cost differentials that enable regional trade. These are of particular importance for interconnectors between markets which are sensitive to hourly price differences and might benefit from bi-directional dynamic trading. Examples of this would include interconnectors between the Republic of Korea and Japan, as well as China and the Republic of Korea.

Finally, cross-boundary interconnections are available to contribute to grid stability on many levels. They can provide additional reserves in the event of emergencies, helping address the variability issue in renewable generation by leading variable generation to large load centres and by utilising wide-area geographical diversity. They can also reduce dependency on high-cost generation sources in load centres by alleviating transmission congestion.

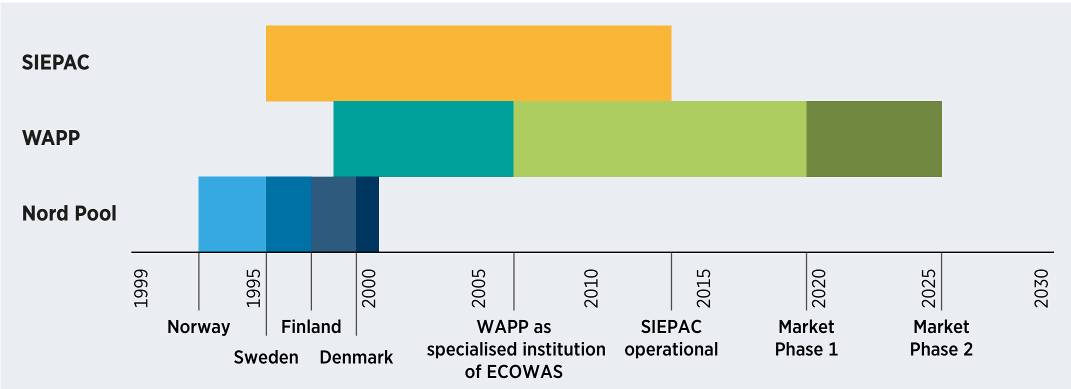
Infrastructure and time needed to complete an interconnected system

The three case studies differ significantly in their development histories. What is common for all of them, however, is that each system had some key infrastructure already in place as a platform on which to start developing regional interconnectivity and a regional electricity market.

This aspect was notable with SIEPAC, where, prior to 1996 – the date of the political and practical agreement for launching the project – Costa Rica had already developed interconnectors with Panama and Nicaragua. In addition, Nicaragua was connected with Honduras, and Guatemala with El Salvador. SIEPAC infrastructure was largely built utilising these existing lines. The idea of Central American interconnectivity had also existed since the 1970s, with the initial feasibility study carried out as early as 1987. As REM started in 2013, it took 26 years from the feasibility study to reach that point, including 17 years to implement the project.

WAPP, established in 1999, probably has a broader scope for West Africa than SIEPAC for Central America, or Nord Pool for Nordic countries. As a specialised energy agency of ECOWAS, it has the role of overseeing and co-ordinating regional power sector development. This includes both generation and transmission investments, aiming at a regionally interconnected system that can support large-scale power plants operating regionally and trading electricity in a competitive marketplace.

Figure 24 Schedules of SIEPAC, WAPP and Nord Pool



Source: Authors

Note: The three systems continue to evolve and grow, so the end point of a bar does not reflect the final constellation of the integrated system, but just the end of the initial build-up stage. The shades of colours for WAPP and Nord Pool highlight some institutional milestones and new member countries joining in the initial Nordic constellation, as described in the text. Nord Pool extended first to cover seven members, including three Baltic States. Today, Nord Pool is part of the pan-European market coupling mechanism, covering 31 European TSOs.

Some transmission connections had been built from Nigeria, Ghana, and Côte d'Ivoire to their neighbouring countries prior to WAPP's 're-launch' as an ECOWAS agency in 2006, but the transmission infrastructure was mostly rather underdeveloped. The Stage 1 market started operations in 2019, after a basic set of trading rules had been established. Two key interconnection projects, the CLSG and OMVG loops, will finally connect all the member countries with high voltage power lines by the end of 2022. WAPP aims to launch the second stage of the electricity market soon thereafter, when the necessary market rules have been finalised and the ICC has developed sufficiently to act as a market operator. This will allow bilateral trading with transit through third-party countries, based on standard commercial contracts and a day-ahead market for short-term exchanges. If ready in 2024, it will have taken 25 years from the establishment of WAPP to develop the supporting infrastructure connecting all member countries and creating the regional marketplace.

Despite these long gestation and implementation periods, both SIEPAC and WAPP have worked systematically towards time-bound goals. In achieving these goals, both SIEPAC and WAPP have found the value of partnerships with multinational development banks (MDBs). These have been the IADB for SIEPAC and the African Development Bank for WAPP, as well as the World Bank for both. These MDBs have participated in the financing of priority projects and facilitated other institutions' co-financing, as well as provided technical assistance throughout the development history of these schemes.

Nord Pool differs from SIEPAC and WAPP by having already had sufficient cross-border transmission infrastructure in place in the early 1990s, when competitive day-ahead trading started. The process of establishing Nord Pool can be seen as having been initiated in 1990, when the Norwegian parliament approved legislation for the restructuring of the power industry, including the unbundling of vertically integrated utilities. The Nord Pool marketplace was then established in 1993, marking the commencement of trading in Norway. Following their respective sector restructurings, Sweden joined the market in 1996, Finland in 1998, and Denmark in 2000.

The Nordic experience shows that, under liberal policies dedicated to free trade and conditions of uncomplicated foreign policy relations among neighbours, utilities can also work together to develop cross-border transmission infrastructure organically, without a grand plan or leadership from the national governments of the trading partners. The cross-border lines initially served multiple purposes, and their value as a source of system reserves was even greater than the opportunities they provided for commercial electricity exchanges.

► Implications for NEA interconnection

In all three reference cases the participating countries had developed bilateral interconnectors prior to any institutionalised regional electricity integration organisation, which then helped form one. In the Nordic countries, interconnectivity had developed to a degree that made a unified electricity marketplace possible as a stand-alone project. In WAPP, all participating countries are not yet connected to the regional transmission grid, which is still under construction. In NEA, the existing cross-border electricity transmission infrastructure is notably bilateral. The capacities and locations of interconnectors have been designed with the intention of meeting localised electricity demands. The region's transmission utilities and research institutions have proposed various grid development alternatives for future regional interconnection, based on entirely new transmission lines. The plans rely on HVDC technologies, which have been proven for long-distance power transmission in numerous projects worldwide, but especially in China. In addition, the strengthening of certain sections of national lines may be needed in Mongolia and the Russian Federation. None of the comprehensive plans for region-wide interconnection have been adopted as a shared view by the key stakeholders for the future regional grid configuration, however.

In the NEA region, the former Soviet Union was the first to build a 1150 kV, ultra-high voltage (UHV) transmission line, which was laid in Kazakhstan in 1985 over some 500 km. Since then, China has become the world's leading country in the application of UHV DC technology to transmit electricity from remote regions with excess supply to areas of higher demand. The excesses in China are often associated with solar PV and wind power development in the country's western and north-western provinces. A recent project commissioned in 2019 from Xinjiang to Anhui, about 3 300 km, applied HVDC technology at 1100 kV and has a capacity of 12 GW. The project was completed just four years after its approval.

China has already fully commercialised and applied HVDC technology – be it 500 kV, 800 kV, or more – to transmit variable renewable energy to large load centres. The concept of large hydropower, wind, and solar PV bases with HVDC technology transmission over long distances to load centres is therefore available, with most recent studies on NEA interconnectivity relying on it. An important consequent detail is that – unlike SIEPAC, Nord Pool, and the future of WAPP, which form wide area synchronous grids – the future regional integration of the NEA countries does not need nor benefit from national systems synchronising with each other.

NEA interconnection will primarily rely on new lines, but there are still weaknesses to be solved in the internal grids. This was also the case when the SIEPAC line was built, and is linked to regional grid development within the NEA countries. The Russian Federation's grid between the Siberian and Far East grids is congested and undersized. The Mongolian grid is designed for domestic demand and would not be able to contribute to the transmission of GW-range VRE. In China, the connections between IMAR and the East China load centres in Beijing, Tianjin, Hebei, and Shandong are congested, leading to high levels of renewable electricity curtailment in IMAR. Therefore, any renewable energy development for export markets in Mongolia's South Gobi would need to consider solving the congestion issue or having the landing point of the interconnector designed to transmit directly to East China.

Electricity markets

Both the regional electricity market of SIEPAC and the trading in WAPP have been developed as projects closely interlinked with the development of regional transmission infrastructures. In both Central America and the future plans for West Africa, the national markets and the regional market are kept separate. Following the founding principles, the regional market is allowed to develop gradually. SIEPAC's stated progressive evolution concerns issues such as accepting new market participants, increasing operational co-ordination, developing the interconnected grid, and strengthening the institutional set-up.

In the Nordic countries, there are no longer specific national markets, but the Nord Pool trading platform dominates electricity trading in the region. Operating through PPAs in Nordic countries is still completely possible, however. Arrangements where renewable electricity plants sell a part of their output to the Nord Pool spot market with renewable certificates – and the rest to a dedicated client under long-term corporate PPA – for example, are becoming increasingly popular, as businesses wish to decarbonise their own operations. Furthermore, competing power pools are also allowed to operate in the Nord Pool countries – and in the EU area in general – and some have already established their operations there.

Implications for NEA interconnection

The SIEPAC and WAPP electricity markets are based on the principle of keeping national markets separate from regional electricity markets. This principle is partly attributable to the limited capacity of the regional interconnection, but more importantly to the desire of the member countries to develop their own power systems and market structures in a gradual manner. Developing electricity co-operation in the NEA region also does not necessitate the ideal of a unified market and harmonised rules. The NEA market is more than 170 times the size of SIEPAC. The Russian system alone is divided to three market zones and spans nearly 7 000 km. In China, the markets operate on provincial levels. The Japanese market is fragmented with two zones using different frequencies and several price zones in the power exchange. Most NEA countries have introduced competitive generation-side markets with advanced features. Rather than aiming at harmonisation across the region, the regional integration project should seek realistic solutions that permit different NEA markets to work together. Co-operation could, for example, start if the importers and exporters of electricity were allowed to act as market participants in each other's power exchanges. There are several possible methods for the TSOs in the participating countries to recover the costs of establishing lines.

Markets in the realm of economic benefit studies

The economic benefit analysis of regional interconnectivity is typically based on a comparison of two factors: first, the total cost of the power supply of an aggregate of regional countries operating separately as national systems; and second, the cost of the electricity supply in the region when the national systems are operating as one, linked by interconnectors, with electricity transfers between the countries only constrained by the capacities of the interconnecting lines.

In both cases the capital costs are calculated based on an optimised, least-cost expansion plan over the selected time horizon, with the operating costs based on optimised generation dispatch over 8 760 hours for every year.

An underlying assumption of this modelling work is free trade with electricity throughout the region, under some technical or policy constraints. This methodological assumption, however, should not be misinterpreted as a practical recommendation for the region to pursue 'Deep Integration', as defined in the integration stage models above.

► New market mechanisms of the region

As indicated earlier, cross-border price differentials in the NEA region can support trading in multiple forms between the countries. One form of trade may include long-term PPAs and TSAs for unidirectional exports of renewable energy. These may come from large wind and solar energy production bases or hydropower plants in Mongolia and the Russian Federation and go to load centres in China, Japan and the Republic of Korea.

The other form of trading supported by regional interconnections can take place through participation in the intra-day, day-ahead or mid-to-long-term markets across borders. These markets enable a more nuanced trading than fixed PPAs, as they facilitate seizing opportunities based, for example, on time zone differences and different demand patterns.

KPX, in operation since 2001, is a compulsory exchange where electricity is traded through hourly supply-side bids coming from more than 900 generation companies – including six major ones. The market price consists of the system marginal price (SMP) and capacity payment (CP). When a power production unit has declared its availability, a CP is paid to a generating unit, regardless of actual generation (KPX, 2020).

JEPX is a voluntary, day-ahead market where power generation companies and retail companies buy and sell electricity through half-an-hour bids (JPEX, 2020). JEPX is rapidly increasing its share in the Japanese market (Zissler and Cross, 2020).

China has set up pilot electricity exchanges, most of which started operations in 2020, in eight provinces. The exchanges trade with products falling under three principal categories:

- a mid-to-long-term market from multiple days to annual
- an energy spot market, day-ahead in one hour bids
- ancillary services, including a variety of flexibility products and frequency control. In some cases, interprovincial bidding is also possible (RMI, 2019).

Mongolia operates a single-buyer system under the auspices of its national dispatch centre. For the state-owned power plants, generation prices are regulated by the Energy Regulatory Commission. IPPs and renewable energy producers have PPAs and feed-in-tariffs.

The Russian Federation's grid is divided into three zones. Of these, Zones 2 (Siberia) and Zone 3 (Far East – Kaliningrad Oblast, Far East, Arkhangelsk Oblast, and the Komi Republic) are pertinent to NEA interconnectivity. Zone 3 is based on regulated power and energy delivery agreements, whereas Zone 2 is managed through market mechanisms that also include a spot, day-ahead platform and capacity market (Inter RAO, 2020).

The existence of competitive electricity markets in the NEA countries and their operational rules have not been reflected in many past studies and plans for the NEA region's electricity interconnection. Those will, however, be of vital importance for regional interconnectivity development. For example, when considering prospective electricity transmission from the proposed renewable energy base in Mongolia's South Gobi to China, the nearest landing point for an interconnector is in West IMAR. IMAR is one of the pilots for the proposed new provincial electricity market in China. Furthermore, West IMAR TSO has a degree of autonomy in its operations that is different from other provincial branches of the SGCC.

In this context, a project pursuing NEA power system integration should not aim at creating a harmonised market across the region, at this stage. The regional integration project should rather seek realistic solutions that allow different NEA markets to work together. Co-operation can be started organically, if importers and exporters of electricity can act as market participants in each other's power exchanges.

Institutions

The case studies reveal several similarities in their institutional composition. One is the vital role utilities have played in regional institutions. Secondly, the regional institutional structure includes the same elements as the national structures: an infrastructure company, an entity for the market operation, a regulatory agency, and high-level oversight.

On the surface, SIEPAC and WAPP may appear to be top-down, government-led projects because their creations were so intricately linked to the political and economic integration processes managed by SICA and ECOWAS, respectively. Since these projects were conceptualised and launched, however, it has been the region's utilities that have owned and managed the actual implementing agencies – EPR of SIEPAC and WAPP itself. The development of Nord Pool is also a product of the proactive work of the Nordic countries' large, state-owned utilities. Nord Pool was established and owned by the national transmission system operators (TSOs) that were produced from the unbundling of utilities during the power sector restructuring process.

WAPP and EPR can be seen as having similar functions to those of the Nordic TSOs, as they have the task of developing and maintaining the transmission systems – albeit only the regional element of those systems. A further difference is that WAPP does not own and operate the regional interconnectors – they belong to the national utilities – but WAPP prepares plans, mobilises resources for the necessary investments, and helps in the implementation of cross-border transmission.

Both SIEPAC and WAPP have regional level regulatory agencies, CRIE for SIEPAC and ERERA for WAPP. Their regulatory authority is strictly limited to the regional activities of the systems. In Nord Pool, the regional market is not separate from the national markets, as the commercial electricity market is unified. Therefore, the Nordic countries, or the enlarged Nord Pool area, do not have such an entity, but all regulatory control is held by the national regulatory agencies. According to the EU's principle of subsidiarity, if there is no need for EU intervention, the member states keep their decision-making authority. Therefore, the role of ACER as a regional agency for the co-operation of regulators also remains limited.

The operation of the trading platform is dedicated to independent entities – EOR for SIEPAC, ICC for WAPP, and Nord Pool (and today other NEMOs too) for the Nordic region. Again, the principal difference is that the scopes of EOR and ICC are limited to only regional cross-border trading, whereas Nord Pool comprehensively covers all kinds of trading of electricity and related products within the region.

► **Implications for NEA interconnection**

Regional electricity integration usually starts with the creation of new regional institutions, with this clearly the case with SIEPAC and WAPP, but not with Nord Pool. Institutional structures developed to support SIEPAC, WAPP and Nord Pool may not, however, serve as relevant references for institutions now needed for NEA electricity integration. Institutions should be aligned with the vision for interconnectivity development. The NEA interconnection plans thus far do not aim to set up a regional market separate from national markets (SIEPAC), nor is the feasibility of a region-wide unified market (Nord Pool) proven to be a realistic goal worth pursuing in NEA. Therefore, there is no need at this stage for a regional regulator, or a committee contemplating harmonised regulation throughout the region, for example. NEA might benefit, however, from such institutional development as would provide better co-ordination of plans and studies, identification of priority investments, a capacity to develop business cases and engineering concepts for key investments, and maintain a dialogue that seeks to form a more unified view of the desired future regional grid and underlying investments in renewable energy generation.

The co-existence of a regional market with national markets may result in a greater need for political co-ordination, both nationally and regionally. SIEPAC established CDMER as a high-level body to develop the REM and facilitate compliance with the commitments established in the Second Protocol to the

REM Framework Treaty. WAPP, as a specialised agency of ECOWAS, has access to political decision making through the governing bodies of ECOWAS. For Nord Pool, however, there is no institutionalised guidance from governments. Considering, however, that many of Nord Pool's participating utilities are state-owned – and in all the TSOs governments hold a prominent position – there is always recourse to bring matters to the sector ministries when needed.

As noted earlier, there is no lack of high-level political will to develop cross-border energy co-operation between the NEA countries. Five foreign policy drivers were mentioned above in support of NEA interconnectivity development. The need to institutionalise the process leading to the realisation of the NEA interconnection is often mentioned in the context of discussions of the many studies and interconnectivity plans for NEA, as well as at stakeholder gatherings, such as at the NEARPIC forums.[14] At its latest of those, there has been an increasingly emphasis on the necessity of shifting from analysis to implementation. Participants have recommended that the various initiatives, plans and studies made be more closely linked to a political process that should aim at creating a co-ordinated, multilateral approach to interconnectivity development and associated investment projects in NEA countries.

The same call has been heard from high-level decision makers. In 2018, the Mongolian president proposed establishing an organisation to formulate a comprehensive policy and prepare relevant agreements and negotiations on the NEA Super Grid project. This would take place with the appropriate involvement of Mongolia, the Russian Federation, the Peoples Republic of China, Japan, the Republic of Korea and the Democratic People's Republic of Korea.

The *Regional Road Map on Power System Connectivity: Promoting Cross-border Electricity Connectivity for Sustainable Development* – a high-level draft strategy formulated by the Energy Working Group on Energy Connectivity (EWG-EC) at the request of the member countries of ESCAP – also presents a target of establishing a sub-regional body for NEA connectivity by 2022 (ESCAP, 2019). This is due to be presented for approval at the 77th Session of the Energy Committee of ESCAP in May 2021.

While there is general agreement that interconnectivity plans should move toward implementation, the proponents of the NEA interconnection plans and national policy makers are today somewhat disconnected. The sphere of stakeholders active with the plans does not fully cover the line ministries of all NEA countries. Furthermore, there is not yet an expressed consensus about choosing to promote renewable energy as the primary objective for interconnectivity. As a result, efforts to advance the interconnection idea are

[14] *See NAPSI Authority (EDF, 2019b; Podkovalnikov, 2018b)*

not programmatic and systematic. An institution might be useful in serving as a bridge between national and regional interests, while at the same time bringing coherence to interconnection plans by reconciling the contradictory elements in various initiatives and proposals.

The institution could therefore start with modest responsibilities for:

- creating business models for cross-border electricity trading under NEA market conditions
- planning, scheduling and implementing studies and roadmaps for individual interconnection projects
- initiating and co-ordinating discussion and analytic work needed to develop cross-border renewable energy investments in Mongolia and the Russian Federation
- helping to align bilateral interconnection plans with the multilateral interest and common regional power interconnectivity strategy
- deepening multilateral co-ordination and its institutionalisation, as necessary
- providing a multilateral platform for continuing dialogue.

The experience of WAPP, SIEPAC, and Nord Pool identifies TSOs as holding a key role in interconnectivity development. On the other hand, interconnectivity is more than just electricity transmission – the primary domain of TSOs – as its underlying motive is to enable and promote trading with clean electricity.

In order to gather together both TSOs and governments, the institution suggested here should therefore have two layers. One would be a permanent co-ordination unit, a small secretariat, to carry out the planning, co-ordination, and promotion activities outlined above. The key officials should be nominated by the TSOs or equivalent organisations that are integrally involved in the electricity cross-border operations of the NEA countries. All member countries should pledge to support the operations of the unit with funds, co-operation and access to information. The second would be a steering committee in the spirit of SIEPAC's CDMER. This would be composed of representatives of the countries' ministries of energy, or equivalent bodies, and have the authority to co-ordinate national policies and measures associated with the NEA interconnection, as well as to oversee and guide the operation of the co-ordination unit.

Concluding recommendations

Political support for NEA electricity interconnection

A key fact and premise for future work is that there is no regional economic co-operation organisation that could act as the wellspring for electricity interconnectivity and associated institutional development for the NEA region that is comparable to SICA, ECOWAS, or the EU. The development of cross-border co-operation in the electricity sector must therefore rely on entirely different kinds of political and economic partnerships. Each NEA country has a platform initiative for regional multilateral economic co-operation, including the cross-border electricity trade. The high political capital that the leaders have placed on their specific national initiatives for the region may guide the countries to competitive profiling for the leadership position in that development. This may risk slowing down efforts to find a practical – yet multilateral and gradual – way forward.

Renewable electricity development as the centrepiece of the political agenda for NEA interconnectivity development

The economic motives for trade in SIEPAC, WAPP, and Nord Pool can be clearly identified. When SIEPAC and WAPP were launched, their motivation could be attributed to supply deficits, capacity surpluses and complementarities in their generation fuel mixes. Yet, trade motives have not been specified very explicitly for NEA interconnection and for each of the five NEA countries. Desire for renewable energy development forms a common denominator for China, Japan, and the Republic of Korea, while Mongolia and the Russian Federation are endowed with large renewable energy resources. This mutual interest in renewable energy can help reduce the political barriers to interconnection arising from concerns over energy security and the geopolitical aspects of electricity interconnection.

The NEA countries have complementarities not only in renewable energy resource endowments, but also in capacities for innovation, technology, EPC, asset operation, and financing. The region's countries should assume a collaborative approach to implementing renewables-based interconnections with the aim of investments being open to companies and technologies across borders.

As the NEA countries have pledged ambitious net-zero carbon plans by or near the middle of this century, the development, life extension and increased use of coal-fired power generation should not be among the options for cross-border trading. If efficiency and environmental requirements are equalised across the region, the cost differential of fossil-fuelled power production between countries is likely to become much smaller. The cornerstone of NEA interconnection is the desire for trading in renewable energy, as opposed to the desire for simple trading in energy.

The nature of interconnection within the NEA region will require purpose-built infrastructure using the latest technologies.

A common feature in the three case studies is their development from pre-existing technical and policy infrastructure. The existing infrastructure within the NEA region does not currently meet the needs of regional interconnection, while the existing bilateral agreements do not provide a regulatory foundation for building further interconnection. The geography of the region and the great distances involved, however, would necessitate the deployment of the latest technology in any case, so this current lack of infrastructure should not be seen as a significant draw back. Similarly, regulatory and institutional development within the region can take place with careful consideration given to the specific goals of interconnection.

Evolving markets bring about new business opportunities for trading

Developing electricity co-operation in the NEA region does not necessitate an ideal of a unified market and harmonised rules. The NEA market is more than 170 times the size of SIEPAC. The Russian Federation system alone is divided into three market zones and spans nearly 7 000 km. In China, markets operate on provincial levels. The Japanese market is fragmented, with two zones with different frequencies and several price zones in the power exchange. Most NEA countries have introduced competitive, generation-side markets with advanced features.

Rather than aiming at harmonisation across the region, the regional integration project should seek realistic solutions that align with the markets of the participating countries. The ideal of a unified market could be rejected and focus placed on identifying opportunities and business cases from the existing, increasingly competitive and dynamic national and provincial electricity markets.

Cross-border co-operation can be started organically, if the importers and exporters of electricity are allowed to act as market participants in each other's power exchanges. There are several possible methods – discussed in the section "Review of selected studies: The Asian Super Grid and REI" –

for the TSOs in participating countries to recover the costs of establishing lines. Future studies should identify the most productive methods for ensuring stable lines are established to support efficient trading.

Plans for new institutions to match the specific needs of the region

Regional institutions reflect what is set as an ideal for national sector institutions, which include in the liberalised market model a regulator, a TSO, a market operator, and political oversight.

Regional electricity integration starts with the creation of new regional institutions, as was clearly the case with SIEPAC and WAPP. The specific examples of the institutions established in the case studies, however, are not directly applicable to the case of NEA. Institutions developed at this stage should be aligned with the vision for interconnectivity development, and this vision has not yet been clearly established.

NEA might, however, benefit from the development of an institution that would foster the co-ordination of plans and studies, the identification of priority investments, and the development of business cases and engineering concepts for key investments. Such an institution might also maintain a dialogue that seeks to form a more unified view of the desired future regional grid and of underlying investments in renewable energy generation.

The institution suggested here should therefore have two bodies in order to gather together both TSOs and governments. One body would be a permanent co-ordination unit – a small secretariat – to carry out the planning, co-ordination, and promotion activities outlined above. The key officials should be nominated by the TSOs or equivalent organisations that are integrally involved in electricity cross-border operations in the five NEA countries. All member countries should pledge to support the operations of the unit with funds, co-operation, and access to information. The second body would be a steering committee in the spirit of CDMER of SIEPAC. This would be composed of representatives of the countries' ministries of energy or equivalent bodies, having authority to co-ordinate national policies and measures associated with the NEA interconnection, as well as to oversee and guide the operation of the co-ordination unit.

References

ACER (2020), *Mission*, European Union Agency for the Cooperation of Energy Regulators, https://acer.europa.eu/en/The_agency/Mission_and_Objectives.

Amundsen, E. and L. Bergman (2005), *Why has the Nordic electricity market worked so well?* Working Papers in Economics, Vol. 18/05, University of Bergen, Department of Economics, https://ideas.repec.org/p/hhs/bergec/2005_018.html.

APERC (2015), *Electric power grid interconnections in Northeast Asia: A quantitative analysis of economic and environmental benefits,* Asia Pacific Energy Research Centre, Tokyo, https://aperc.or.jp/search_results.php.

ATS (n.d.), website, ATS (Administrator of Trade System), www.atsenergo.ru (accessed 20 March 2021).

BP (2020), *BP statistical review of world energy,* BP, www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

BP (2019), *Russian Federation's energy market in 2018, Statistical Review 1,* BP www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-russia-insights.pdf.

Belikova, K.M., N.V. Badaeva and M.A. Akhmadova (2019), "Cooperation of China and Russia in the framework of the Asian Super Grid: Political and legal aspects", *International Journal of Economics and Business Administration*, Vol. 7, No. 1, pp. 215-226.

BNAmericas (2020), *At a Glance: Central America power market challenges,* www.bnamericas.com/en/news/at-a-glance-central-america-power-market-challenges.

Castro, M.E.C, J.E.F. Pineda and R.A.G. Santamaria (2017), *Diversificación de la Matriz Energética de El Salvador Mediante la Promoción de Fuentes de Energías Renovables; Análisis y Propuestas Bajo Una Perspectiva de Sustentabilidad, 2007 a 2015* (Diversification of the energy matrix of El Salvador through the promotion of renewable energy sources; Analysis and proposals under a sustainability Perspective, 2007 to 2015), Unversidad Centroamericana "José Simeón Cañas", Antiguo Cuscatlán, www.uca.edu.sv/economia/wp-content/uploads/018-Diversificaci%C3%B3n-de-la-matriz-energ%C3%A9tica-de-El-Salvador-mediante-la-promoci%C3%B3n-de-fuentes.pdf.

CDMER (2019), *Propuesta Ajustada del Tercer Protocolo al Tratado Marco del Mercado Eléctrico de América Central* (An adjusted proposal for the third protocol to the Central American framework treaty on electricity market), Consejo Director del Mercado Eléctrico Regional de América Central, www.amm.org.gt/portal/?wpfb_dl=578PROPUESTA%20AJUSTADA%20DEL%20TERCER%20PROTOCOLO%20AL%20TRATADO%20MARCO%20-%20Noviembre%202019%20Vf2(2).pdf.

Chudinova, L., S. Podkovalnikov and I. Trofimo (2019), *Prospective cooperation between Unified Power System of Russia and Asian Supergrid,* International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), Vladivostok, Russia, 2019, pp. 1-5, https://dx.doi.org/10.1109/FarEastCon.2019.8934226.

Chung, K.-H. and B.-H.H. Kim (2007), "Economic feasibility on the interconnected electric power systems in North-East Asia," *Journal of Electrical Engineering and Technology*, Vol. 2/4, pp. 452-460, https://dx.doi.org/10.5370/jeet.2007.2.4.452.

ClientEarth (2010), *The impact of the Lisbon Treaty on climate and energy policy – an environmental perspective*, ClientEarth legal briefing, www.documents.clientearth.org/wp-content/uploads/library/2010-01-01-the-lisbon-treaty039s-impact-on-climate-change-and-energy-policy-ce-en.pdf (accessed 21 October 2020).

CRIE (2020), La Comisión Regional de Interconexión Eléctrica website, https://crie.org.gt/.

DBSA (2019), *Briefing note: Unbundling practices and opportunities for private sector engagement in energy transmission in Africa*, Development Bank of South Africa, www.dbsa.org/sites/default/files/media/documents/2021-03/Briefing%20note%20Unbundling%20in%20the%20Energy%20Sector%20in%20Africa%20-%20July%202019.pdf.

EC (2007), Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC.

EDF (2019a), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 6: Power Trade and Regulation, Consultant's report*, Électricité de France, Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-4.

EDF (2019b), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Draft final report, Consultant's report,* Électricité de France, Paris (TA 9001-MON). www.adb.org/sites/default/files/project-documents/48030/48030-001-tacr-en.pdf

EDF (2018a), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 2: Market and power trade assessment, Final version, Consultant's report,* Électricité de France, Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-0.

EDF (2018b), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 4: Mongolia energy sector profile and projections – Conventional generation and renewable energy capacity expansion plan, Consultant's report,* Électricité de France, Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-2.

EDF (2018c), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 5: Mongolia and North East Asia power grid development, Consultant's report,* Électricité de France, Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-3.

EDF (2017a), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 1: Inception report, Consultant's report*, Électricité de France Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-6.

EDF (2017b), *Strategy for NAPSI: Northeast Asia Power System Interconnection - Technical Assistance for Mongolia, Module 3: Planning & evaluation criteria – Assumptions for the studies,* Consultant's report, Électricité de France, Paris (TA 9001-MON), www.adb.org/projects/documents/mon-48030-001-tacr-1.

Encyclopedia.com (2020), Organization of Central American States (ODECA), www.encyclopedia.com/humanities/encyclopedias-almanacs-transcripts-and-maps/organization-central-american-states-odeca.

Energinet (2020), Organisation, https://en.energinet.dk/About-us/Organisation (accessed 21 October 2020).

Energy Charter (2014), *Gobitec and the Asian Super Grid for renewable energy sources in Northeast Asia*, Energy Charter Secretariat, Energy Economics Institute of the Republic of Korea, Energy Systems Institute of the Russian Federation, Ministry of Energy of Mongolia, and Japan Renewable Energy Foundation, www.energycharter.org/fileadmin/DocumentsMedia/Thematic/Gobitec_and_the_Asian_Supergrid_2014_en.pdf.

ENTSO-E (2020), News, European Network of Transmission System Operators for Electricity, www.entsoe.eu/ (accessed 21 October 2020).

EOR (n.d.), *Flujos de Potencia en Tiempo Real* (real time power flow) Website, Ente Operador Regional (Regional Operator Entity), www.enteoperador.org/ (accessed 20 October 2020)

EPR-SIEPAC (2020), *Empresa Propietaria de la Red* (Network owner company (SIEPAC-EPR)) Website, www.eprsiepac.com/contenido/.

ERERA (2015a), Resolution No. 006/ERERA/15, Adoption of the Tariff Methodology for Regional Transmission Cost and Tariff, Adopted by the Regulatory Council in Ghana, 18 August 2015.

ERERA (2015b), Resolution No. 005/ERERA/15, Approval of the Regional Market Rules for the West African Power Pool, Approved by the Regulatory Council in Ghana, 18 August 2015.

ESCAP (2020), *Regional power grid connectivity for sustainable development in North-East Asia, Policies and strategies*, United Nations Economic and Social Commission for the Asia and the Pacific, Bangkok.

ESCAP (2019), *Electricity connectivity roadmap for Asia and the Pacific: Strategies towards interconnecting the region's grids,* United Nations Economic and Social Commission for the Asia and the Pacific, Bangkok.

Fingrid (2020), Website, Fingrid,www.fingrid.fi/en/ (accessed 26 October 2020).

Fortum (2019), *From national to regional grid planning - Differences and harmonisation opportunities in the operations of the Nordic TSOs*, Fortum Energy Review, November 2019, www.fortum.com/sites/default/files/documents/fortum-energy-review-grid-planning-11-2019.pdf (accessed 23 October 2020).

GEIDCO (2018), *Recent research achievements of Northeast Asia Energy Interconnection,* Global Energy Interconnection Development and Cooperation Organization, Conference reports, www.gei-journal.com/en/contents/102/337.html.

GIH (2019), *Côte d'Ivoire-Liberia-Sierra Leone-Guinea (CLSG) Interconnector Project: A G20 Showcase Project*, Global Infrastructure Hub, www.gihub.org/resources/showcase-projects/c%C3%B4te-d-ivoire-liberia-sierra-leone-guinea-clsg-interconnector-project/.

Gobitec Initiative (n.d), *History Gobitec*, Gobitec Initiative, https://gobitecdotorg.wordpress.com/history/ (accessed 19 October 2020).

ICC (2020), WAPP Information and Coordination Centre, data dashboard, http://icc.ecowapp.org/.

IDB (2014), *Sustainable infrastructure for competitiveness and inclusive growth – IDB infrastructure strategy*, Inter-American Development Bank, Washington, DC, https://publications.iadb.org/en/sustainable-infrastructure-competitiveness-and-inclusive-growth.

IEA (2020), Data and statistics, International Energy Agency, www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource.

IEA (2019), *Integrating power systems across borders*, International Energy Agency, www.iea.org/reports/integrating-power-systems-across-borders

Inter RAO (2020), *Electricity trading in Russia*, www.interrao.ru/en/activity/traiding/tradesb.php.

IRENA (2020a), *Renewable capacity statistics 2020*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2020b), *Global renewables outlook, 2020 edition*, International Renewable Energy Agency, Abu Dhabi.

ITC (n.d.), International trade statistics 2001-2020, International Trade Centre, www.intracen.org/itc/market-info-tools/trade-statistics (accessed 12 November 2020).

JEPX (n.d.), Website, Japan Electric Power Exchange (JEPX), www.jepx.org/english/index.html. (accessed 20 March 2021).

Khamisov, O. and S. Podkovalnikov (2018), Shadow Price Analysis of Potential Northeast Asia Power System Interconnection, IEEE Asia-Pacific Power and energy engineering conference.

Kim, N.I., and S.K. Lee (2018), 유럽 전력망 연계의 확대과정과 장애요인: 동북아 전력계통 연계에 대한 시사점(*The process for grid expansion with emerging challenges in Europe: Implications for power grid interconnection project in North-East Asia region)*, Korea Energy Economics Institute.

Kimura, S. and S. Ichimura (2019), "Cost-profit analysis for Japan-Russia and Japan-South Korea interconnectors", *Global Energy Interconnection*, Vol. 2, No. 2, pp. 114-121, https://dx.doi.org/10.1016/j.gloei.2019.07.002.

KPX (n.d.), *Electricity market trading process*, Korea Power Exchange (KPX), www.kpx.or.kr/eng/contents.do?key=299. (accessed 20 March 2021).

Lee, S.K. and K.J. Jeong (2017), 동북아 슈퍼그리드 구축사업 관련 해외 사례분석과 시사점 (*An analysis for overseas cases and implications for power grid interconnection project in North-East Asia Region)*, Korea Energy Economics Institute.

Lo, B. (2006), *China and Russia: Common interests, contrasting perceptions*, CLSA Asian Geopolitics, Special report, www.chathamhouse.org/sites/default/files/public/Research/Russia%20and%20Eurasia/russiachinamay06.pdf.

Meeus, L. et al. (2020), *The Evolution of Electricity Markets in Europe*, Loyola De Palacio Series on European Energy Policy, Edward Elgar Publishing Ltd., Cheltenham, UK and Northampton, MA, USA.

METI (2020), *Energy White Paper 2020*, Japanese Ministry of Economy, Trade and Industry. www.enecho.meti.go.jp/about/whitepaper/2020html/2-1-1.html.

Ministry of Energy (2018), Доклад по реализации «Энергетической стратегии России на период до 2030 года» (Report on implementation of energy strategy of Russian Federation for the period up to 2030), Ministry of Energy of the Russian Federation, Moscow.

MOTIE (2019), *Third Energy Master Plan*, Ministry of Trade, Industry and Energy of ROK, Sejong, www.etrans.or.kr/ebook/05/files/assets/common/downloads/Third%20Energy%20Master%20Plan.pdf.

Nord Pool (2020), Website, www.nordpoolgroup.com/ (accessed 21 October 2020).

Nord Pool (2009), *Welcome to Nord Pool Spot, Det Energipolitiske Udvalg* (The Energy Policy Committee) *2009-10*, Nord Pool Spot AS, https://www.ft.dk/samling/20091/almdel/EPU/bilag/354/882165.pdf.

Nordel (2007), Nordic Grid Code 2007, 15 January, https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/nordic/planning/070115_entsoe_nordic_NordicGridCode.pdf, (accessed 26 October 2020).

Nordic Energy Research (2020), *Tracking Nordic clean energy progress 2020*, Nordic Energy Research, www.nordicenergy.org/publications/tracking-nordic-clean-energy-progress-2020/ (accessed 21 October 2020).

Otsuki, T., A.B.M. Isa and R.D. Samuelson (2016), "Electric power grid interconnections in Northeast Asia: A quantitative analysis of opportunities and challenges", *Energy Policy*, No. 89, pp. 311-329.

Pastukhova, M. (2019), *Power grid connectivity in Northeast Asia: Towards a more sustainable energy system?* Presentation on behalf of ESCAP at Korea International Renewable Energy Conference, Seoul, https://unescap.org/events/north-east-asia-regional-power-interconnection-and-cooperation-forum-2019.

Podkovalnikov, S. (2018), *Multilateral arrangements for power interconnection in Northeast Asia: Recent developments*, Presentation at NEARPIC Forum in Ulaanbaatar, October 2018, www.unescap.org/events/north-east-asia-regional-power-interconnection-and-cooperation-forum-2018.

Podkovalnikov, S. et al. (2018), "Justification of effectiveness of international power interconnections with separation of effects between participants", *Automation and Remote Control,* Vol. 79, No. 10, pp. 1756-1766, https://dx.doi.org/10.1134/S0005117918100028.

Podkovalnikov, S., V.A. Savel'ev and L. Yu Chudinova (2015), "Prospects of electric-energy cooperation between Russia and northeast Asian countries", *Studies on Russian Economic Development,* Vol. 26, No. 4, pp. 403-412, https://dx.doi.org/10.1134/S1075700715040085.

Renewable Energy Institute (2019), *Asia International Grid Connection Study Group third report*, Renewable Energy Institute, Tokyo, www.renewable-ei.org/en/activities/reports/20191023.php.

Renewable Energy Institute (2018), *Asia International Grid Connection Study Group second report,* Renewable Energy Institute, Tokyo, www.renewable-ei.org/pdfdownload/activities/REI_ASG_SecondReport_EN.pdf.

Renewable Energy Institute (2017), *Asia International Grid Connection Study Group interim report,* Renewable Energy Institute, Tokyo.

Rivas, S.E. (2019), *Developing the Regional Electricity Market (REM) of the Electrical Interconnection System of the Countries of Central America (SIEPAC Project)*, Presentation at Asia Clean Energy Forum 2019, ADB, Manila, Philippines, www.asiacleanenergyforum.org/presentations/.

RMI (2019), *Tracking China's provincial spot market designs: 2019,* Rocky Mountain Institute, www.rmi-china.com/static/upfile/news/nfiles/202003271741106938.pdf.

Shah, D. and S. Chatterjee (2020), "A comprehensive review on day-ahead electricity market and important features of world's major electric power exchanges", *International Transactions on Electrical Energy Systems*, https://doi.org/10.1002/2050-7038.12360.

SICA (2020), Juridical Framework of SICA, Central American Integration System, www.sica.int/sica/marco_j_en.aspx.

Statnett (2020), Website, www.statnett.no/ (accessed 26 October 2020).

Statnett, Energinet, Svenska kraftnät and Fingrid (2019), *Nordic Grid Development Plan 2019,* www.fingrid.fi/globalassets/dokumentit/fi/tiedotteet/lehdistotiedotteet/stet0126_nordic_grid_dp_2019.pdf, (accessed 23 October 2020).

Statnett, Energinet, Svenska kraftnät and Fingrid (2018), *The way forward – Solutions for a changing Nordic power system*, www.svk.se/siteassets/om-oss/rapporter/2018/the-way-forward---solutions-for-a-changing-nordic-power-system_with-appendices.pdf (accessed 21 October 2020).

Supponen, M. (2011), *Influence of national and company interests on European electricity transmission investments,* Doctoral dissertation, Aalto University publication series DOCTORAL DISSERTATIONS 77/2011.

Svenska kraftnät (Swedish power grid) (2020), Transmissionsnätskarta (Transmission network map), www.svk.se/om-kraftsystemet/om-transmissionsnatet/transmissionsnatskarta/ (accessed 26 October 2020).

Trujillo, M.A.H. (2019), *Integrating the power sector in Central America: Myths and realities,* Commentary, Italian Institute for International Political Studies, www.ispionline.it/en/pubblicazione/integrating-power-sector-central-america-myths-and-realities-24234.

Urízar, C.H. (2019), *Experiences/lessons learned with Cross Border Energy Market,* Presentation at Asia Clean Energy Forum 2019, ADB, Manila, Philippines, www.asiacleanenergyforum.org/presentations/.

Voropai, N. et al. (2019), "Development of electric power cooperation in Northeast Asia", *Global Energy Interconnection,* Vol. 2, No. 1, pp. 1-6, https://dx.doi.org/10.1016/j.gloei.2019.06.001.

WAPP (2020), Website, West Africa Power Pool Organization, www.ecowapp.org/en/.

WAPP (2019), *WAPP Business Plan 2020-2023*, West Africa Power Pool General Secretariat, www.ecowapp.org/en/documentation.

WAPP (2018), Ecowas Master Plan for the Development of Regional Power Generation and Transmission Infrastructure, Final report, Vol. 0, synthesis by Tractebel, Engie, West Africa Power Pool Organization.

World Bank (2020a), Open Data, World Bank, https://data.worldbank.org/.

World Bank (2020b), *Programme Document for West Africa Regional Trade Development Policy Financing Program*, Report No. PGD121, World Bank.

World Bank (2017), *Project paper for West African Power Pool (WAPP) – Côte D'Ivoire, Liberia, Sierra Leone, and Guinea (CLSG) Power Interconnection Project*, Report No. PAD 2375, World Bank.

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, *Global Energy Interconnection,* Vol. 3, No. 3, pp. 292-302, https://dx.doi.org/10.14171/j.2096-5117.gei.2020.03.010.

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