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WORKING PAPER

POWER TRADE FOR RENEWABLE ENERGY DEVELOPMENT: Global best practices, Challenges and ways forward

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Acknowledgements:

The preparation of this working paper was led by the Energy Division, ESCAP, under the overall direction of Hongpeng Liu, Director, and the coordination of Matthew Wittenstein, Chief of Section for Energy Connectivity. The principal author of the paper was Anna Lobanova. Significant contributions were provided by Marina Gil Sevilla and Ignacio Nancupil, ECLAC; Sean Ratka, ESCWA; Anna Piwowska, UNECE; Yohannes Hailu, ECA and Yasmine Khaled Mahmoud Azmi, ESCAP. Administrative and secretariat support was provided by Prachakporn Sophon.

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Citation information:

Lobanova, Anna; Nancupil, Ignacio; Piwowska, Anna; Ratka, Sean; Gil Sevilla, Marina; Hailu, Yohannes (2025). Power Trade for Renewable Energy Development: Global Best Practices and the Role of UN Regional Economic Commissions. United Nations ESCAP, Energy Division, December 2025. Bangkok.

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Cover photo: Pok Rie (pexels.com, ID 3829454) and Kervin Edward Lara (pexels.com, ID 3976320)

Tracking number: ESCAP / 9-WP / 142

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Introduction

The global energy landscape is undergoing a fundamental transformation driven by the urgent need to decarbonize power systems and enhance energy security, and resilience. The deployment of renewable energy (RE) resources offers a pathway to achieving decarbonization goals, yet the full potential of renewables cannot be realized without robust, flexible, and interconnected, power grid infrastructure. Power sector connectivity – both physical and institutional – plays a crucial role in accelerating renewable energy deployment, reducing costs, improving reliability, and supporting energy transition.

Countries across the globe face complex challenges in securing affordable, reliable, and sustainable energy services. These challenges have been accelerated by recent geopolitical tensions, supply chain disruptions, and extreme weather events, exposing vulnerabilities in national and regional energy systems. At the same time, the uneven distribution of renewable energy resources, growing electricity demand, and decarbonization targets underscore the need for enhanced cross-border power system integration. By fostering regional cooperation and developing shared infrastructure, countries can better balance energy surpluses and deficits, leverage economies of scale for green infrastructure investments, and enhance system flexibility and resilience.

Under a UN Development Account project led by the United Nations Economic Commission for Europe (UNECE), and the United Nations Economic and Social Commission for Asia and

the Pacific (ESCAP) and jointly implemented with the Economic Commission for Latin America and the Caribbean (ECLAC), the Economic and Social Commission for West Asia (ESCWA) and the Economic Commission for Africa (ECA) have supported member States to leverage energy connectivity as a tool to enhance energy security and energy system resilience through increased capacity to design and implement policies to increase power system connectivity and cross-border power trade.

This report summarizes the main project findings and highlights how enhanced energy connectivity can accelerate energy transitions, contribute to the Sustainable Development Goals (SDGs), and strengthen long-term energy security. The report explores the role of power system connectivity in developing and integrating renewable energy resources, identifies key challenges and risks, and offers policy recommendations for building resilient, secure, and sustainable interconnected energy systems. Drawing from global experiences and focusing on five target countries - Costa Rica, Panama, Georgia, Kazakhstan, and Uzbekistan – the analysis was conducted to examine the benefits of sharing energy and resources across borders compared to operating self-sufficient domestic energy systems. Several capacity building workshops were held to identify key challenges to develop proposed connectivity initiatives in those countries and potential pathways forward.

Chapter 1. Role of Regional Commissions

Background

Energy connectivity refers to the integration of national power systems through cross-border interconnections and power trade, enabling the exchange of electricity and shared resource utilization. Well-designed energy connectivity projects enhance energy security by linking energy-deficit regions with surplus production centers, thereby diversifying supply sources and reducing reliance on imported fossil fuels. It also enables countries to explore renewable energy resources that may otherwise remain untapped due to domestic market limitations. In addition to strengthening energy resilience, enhanced connectivity can generate significant economic benefits by lowering electricity costs, improving efficiency, and unlocking access to relieved public and private funds that can be redirected toward strategic investments in infrastructure, innovation, and sustainable development.

Global experiences demonstrate the benefits of power system connectivity. For example, the European Network of Transmission System Operators for Electricity (ENTSO-E) has enabled large-scale renewable energy integration across Europe, supporting real-time balancing and reducing wholesale electricity costs¹. In Africa, the Southern African Power Pool is cooperation

of the national electricity companies under the auspices of the Southern African Development Community². Its work has improved energy access and security across multiple countries by pooling generation resources and expanding cross-border trade. In Latin America, the Electrical Interconnection System of the Countries of Central America (SIEPAC) initiative has allowed the creation of a regional electricity market stretching from Guatemala to Panama³, enhancing reliability and facilitating renewable energy integration. The Central Asia Power System (CAPS) is a regional interconnected electricity network linking together five countries in Central Asia to ensure coordinated power generation, transmission, and distribution across borders. Established during the Soviet era, CAPS remains a critical platform for balancing power surplus and deficit across Central Asian states and optimizing the use of renewable and conventional energy resources⁴.

These sub-regional initiatives highlight the opportunity for connectivity enhancement to unlock a range of potential benefits. However, many developing countries lack the infrastructure, institutional frameworks, and financial mechanisms required to realize the full potential of energy connectivity. Isolated national planning, insufficient transmission capacity, and regulatory fragmentation hinder cross-border cooperation. Furthermore, technical, financial, social, and environmental risks should be carefully managed to ensure that interconnected grids are resilient, equitable, and sustainable.

¹ <https://www.entsoe.eu/about/market/>

² <https://www.sapp.co.zw/about-sapp>

³ <https://publications.iadb.org/en/publications/english/viewer/central-american-electricity-integration.pdf>

⁴ https://unece.org/sites/default/files/2023-11/EN_Energy%20Connectivity%20in%20Central%20Asia_V2.pdf

Role of international organizations and development partners

International organizations and development partners play an indispensable role in supporting countries to overcome institutional, financial, and technical barriers that impede interconnection and regional cooperation. Their contributions span from creating platforms for dialogue, to assisting in the formulation of regional roadmaps, to mobilizing finance for large-scale transmission projects.

The comparative advantages of United Nations Regional Commissions lie in convening diverse stakeholders, facilitating dialogue across borders, producing policy frameworks, and supporting capacity development for member States. Within the framework of the UN Development Account, a joint project by UNECE and ESCAP, together with ECLAC, ESCWA and ECA, illustrates the value of such coordinated efforts. The project aims to strengthen member States' capacity to design policies that advance energy connectivity, thereby enhancing security of supply, accelerating renewable energy integration, and building more resilient energy systems.

Convening and Facilitating Policy Dialogue

One of the primary contributions of Regional Economic Commissions is their convening power. By bringing together national governments, regulators, technical experts, and development partners, they create neutral platforms for dialogue and peer-to-peer learning. The Stakeholder Engagement Workshop on Energy Connectivity and Sustainable Energy held in Georgia in April 2025 demonstrated the importance of this role. The event, co-organized by ESCAP and UNECE, gathered more than 40 participants from

governments, regulators, system operators, academia, and international agencies.

The workshop highlighted how dialogue at the regional and interregional levels enables governments to exchange practical experiences on emerging issues such as hydrogen development, cross-border interconnectors, and renewable integration. Georgia and Azerbaijan shared national perspectives on energy reforms, infrastructure projects, and development strategies, while ECLAC contributed lessons from Central America's SIEPAC interconnection project. Such exchanges demonstrated how diverse regional experiences can inform domestic policymaking and reveal opportunities for alignment with broader regional strategies.

Supporting Regional Planning

Regional Commissions also provide structured frameworks for energy connectivity planning that go beyond national borders. By developing roadmaps, methodologies, and metrics, they enable member States to assess interconnection opportunities more systematically. ESCAP's Green Power Corridor Metrics, piloted during the Georgia workshop, are a good example. These metrics allow governments to evaluate potential projects against multiple dimensions of sustainable development, including economic, environmental, and social impacts. Applied to Georgian case studies the metrics demonstrated how connectivity projects can contribute to SDGs.

Similarly, ECLAC's engagement in the workshop showcased the long-standing value of regional power pools and integration frameworks. The SIEPAC project in Central America was presented as a case study of how coordinated

planning, harmonized regulation, and joint infrastructure investments can deliver tangible benefits in terms of system reliability and renewable integration. For regions like the South Caucasus, such examples provide practical lessons on the design of governance frameworks and investment models.

Enhancing Capacity Building

Another key contribution of Regional Commissions is building the knowledge base and strengthening institutional capacity. Workshops, technical studies, and peer-learning platforms help national authorities understand both the technical complexities and regulatory dimensions of energy connectivity.

The Georgia workshop demonstrated this capacity-building dimension through interactive sessions that applied ESCAP's metrics to real projects. Participants from Georgia's regulatory commission, system operator, and ministries engaged directly with assessment tools, allowing them to reflect on benefits, risks, and implementation models.

This exercise also highlighted the importance of multi-stakeholder engagement in designing interconnection projects, ensuring that economic, social, and environmental considerations are integrated from the start.

Capacity building is also evident in the way Regional Commissions facilitate cross-regional learning. ESCWA's work on regional electricity markets in the Arab States, and ECA's engagement in initiatives like the African Continental Power System Master Plan, provide valuable parallels. By connecting these experiences, the UN system helps member States avoid duplication, adopt good practices, and anticipate challenges.

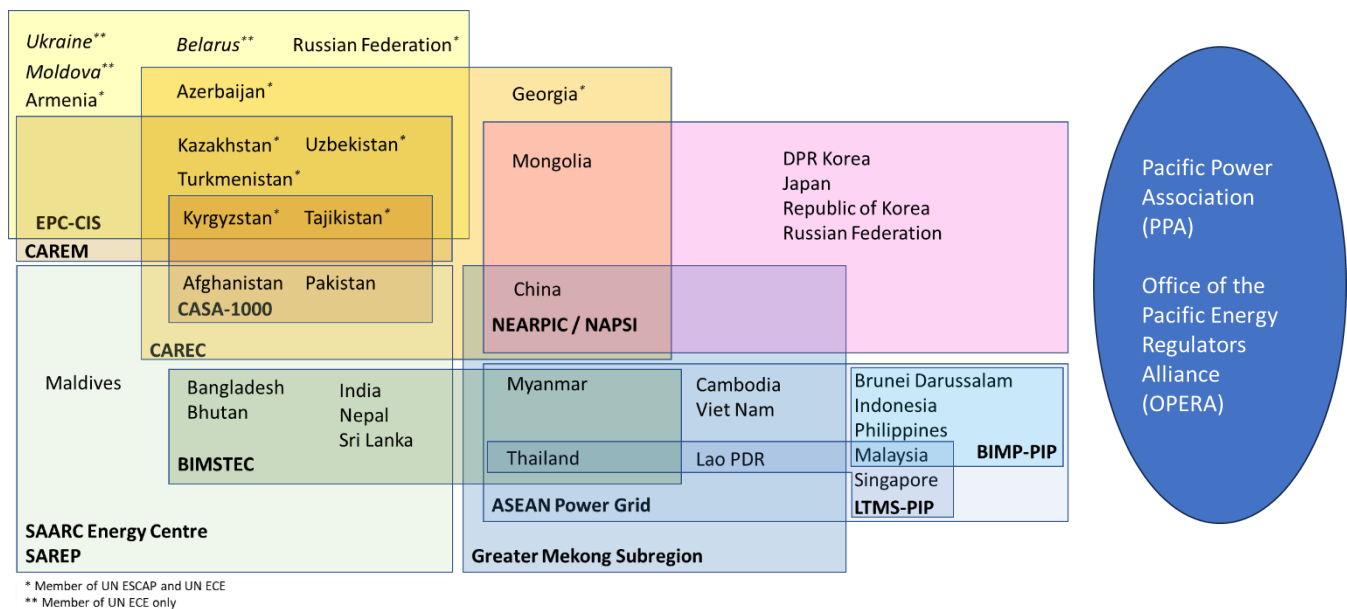
Chapter 2. Case studies

This chapter provides an overview of regional and sub-regional initiatives in the power sector. The list is not intended to be comprehensive; rather, it illustrates the diversity and complexity of power system connectivity across different parts of the world. Highlighting examples from various regions is crucial, as each operates under unique geographical, technical, regulatory, and political conditions. These differences shape both the opportunities and the barriers to developing interconnected grids, cross-border power trade, and coordinated system planning. The following chapters will explore these benefits and challenges in greater depth, providing a more detailed assessment of the technical, economic, environmental, and governance dimensions of power sector connectivity, and offering insights that can help guide policy decisions.

Asia and the Pacific

ESCAP covers 53 countries in the region, each advancing power sector connectivity at different scales and speeds. To help visualize these developments, ESCAP created a regularly updated graph that maps key connectivity initiatives across the region. Unfortunately, the graph cannot capture all the activities, reflecting how dynamic and fast-evolving the landscape has become. The initiatives presented below offer a closer look at recent progress in the Caucasus and Central Asia, illustrating how countries are translating regional ambitions into concrete projects and cooperation frameworks.

Figure 1: Connectivity initiatives in Asia-Pacific region.



Source: ESCAP

Georgia-Romania Black Sea (submarine) interconnection cable project

One of the main cross border projects in Caucasus region is the electric interconnection between Georgia and Romania (GE-RO Interconnection Project). This Interconnection Project, which was financed by World Bank, would create significant economic benefits for Southern Caucasus countries and Romania and Hungary. In particular, the electric cable would allow Caucasus

countries to benefit from expanded export opportunities to Romania and broader South-Eastern Europe considering the hourly energy market prices and import electricity during winter time periods at competitive rates thus reducing dependency on existing expensive imports and thermal generation.

The Interconnection Project would also contribute to integration of larger solar PV and wind capacity in Romania and Hungary considering the new European Green Deal by allowing to provide competitively priced reserves for those intermittent sources of electricity. The Interconnection Project would also allow Armenia to export RE based electricity coming from hydro and increasingly solar PV considering ambitious ongoing program for scaling up solar PV. Azerbaijan would be able to offer gas-based thermal electricity, which would allow to displace coal-based generation in Eastern Europe therefore contributing to decarbonization of the power sector⁵.

Figure 2: Black Sea submarine cable project



Source: Renewables.AZ⁶

Technical features:

- Structure:
 - a) 500 kV double circuit OHL SS „Jvari“ - SS „Anaklia“
 - b) 500 kV OHL SS „Tskaltubo“ - SS „Anaklia“
 - b) 2X650MW MW converter station in „Anaklia“
 - c) Submarine cable Anaklia - Constanta Sud ± 500 kV
 - d) 2X650MW MW converter station in Romania
- Voltage level of cable: 500 kV
- Capacity of cable: 1300 MW
- Length of the interconnector: 1155 km

⁵ <https://www.gse.com.ge/projects/international-projects/Black-Sea-Submarine-Cable-Project>

⁶ <https://renewables.az/en/news/joint-venture-established-to-manage-black-sea-submarine-cable-project>

Recent and planned expansions

The Italian consulting company CESI has conducted the technical-economic/feasibility study of the project (May 2022 - July 2024)⁷. The feasibility study confirmed the viability of the project, considering technical, environmental, social and other relevant factors. In addition, it revealed the possibility of large exports from the South Caucasus towards South-East Europe, predominantly consisting of renewable energy. The study shows positive economic benefits for the project participating countries. A feasibility study is also conducted to study the environmental and social aspects of the project. Based on these studies, CESI prepared the corresponding Scoping Report⁸. The document describes the main components and activities of the project and the preliminary assessment of environmental and social impacts triggered by the construction and operation. The report also reviews aspects of stakeholder engagement.

Henceforward, within the framework of the project, an Environmental and Social Impact Assessment will be carried out, as well as geophysical, geotechnical, benthic and submerged manmade objects' studies of the Black Sea seabed. These studies will determine the possibilities and best ways of practical implementation of the project.

Georgia applied to for the Project of Mutual Interest (PMI) status for the project. A Project of Mutual Interest within the context of ENTSO-E (European Network of Transmission System Operators for Electricity) is a cross-border or regional infrastructure project deemed essential for improving the functioning of Europe's internal energy market and ensuring the security of supply. PMIs focus on facilitating efficient power flows between regions, integrating renewable energy sources, and supporting the EU's energy transition goals. By applying for PMI status, TSOs align their projects with the EU's strategic priorities, gain access to financial and regulatory advantages, and contribute to a more integrated, sustainable, and secure European energy grid.

Caspian Green Energy Corridor

The Caspian Green Energy Corridor project aims to bolster regional energy cooperation and promote green energy trade among most of the Central Asia Regional Economic Cooperation Program (CAREC) member countries. The project will involve the interconnection of energy systems and the establishment of a green corridor for renewable energy transmission and trade. It envisions comprehensive transmission of green energy from the Caspian region to Europe via the Black Sea Cable.

Technical features to be defined

Recent and planned expansions

The Asian Development Bank (ADB), the Asian Infrastructure Investment Bank (AIIB), and the energy ministries of Azerbaijan, Kazakhstan, and Uzbekistan signed a Memorandum of

⁷ https://www.gse.com.ge/sw/static/file/Black_Sea_Submarine_Cable_Project_Feasibility_Study_Summary-.pdf

⁸ <https://www.gse.com.ge/sw/static/file/C3015707 - GE-RO Submarine Cable E S Scoping Report FINAL.PDF>

Understanding (MOU) to support the Feasibility Study for the Caspian Green Energy Corridor Project. The MOU establishes a high-level framework for cooperation, focusing on the development of a robust institutional and legal framework to facilitate cross-border electricity trade among Azerbaijan, Kazakhstan, and Uzbekistan⁹.

Figure 3: Caspian Green Energy Corridor



Source: Aze Media¹⁰

⁹ <https://www.adb.org/news/adb-signs-mou-aiib-azerbaijan-kazakhstan-and-uzbekistan-support-feasibility-study-caspian-green-energy>

¹⁰ <https://aze.media/uzbekistan-azerbaijan-and-kazakhstan-establish-joint-venture-to-launch-the-caspian-green-energy-corridor/>

Latin America region

Central American Electrical Interconnection System (SIEPAC)

The SIEPAC comprises 1,793 km of 230 kV transmission lines interconnecting six countries from Guatemala to Panama¹¹. It has a capacity of 300 MW and is built on towers, with provision for a second future circuit that would increase its capacity to 600 MW. It currently connects 15 substations in the region's countries through 28 access bays and includes three 20 MVar reactive compensation banks¹².

Figure 4: SIEPAC corridor



Source: ECLAC

The establishment of the Regional Electricity Market (MER), built upon the physical infrastructure, has enabled cross-border electricity trading—enhancing reliability, optimizing reserve margins, and supporting the integration of renewables. Between June 2013 and December 2015, MER delivered net economic benefits of up to USD 132 million, while integrated planning and trade scenarios have been shown to reduce total system costs by up to 16 %¹³ under high-integration with renewables scenarios

¹¹ <https://crie.org.gt/mer/>

¹² <https://www.cree.gob.hn/sistema-de-interconexion-electrico-de-los-paises-de-america-central/>

¹³ https://www.iadb.org/en/news/energy-transition-latin-america-and-caribbean?utm_source=chatgpt.com

Recent and planned expansions

- Installation of the second circuit of the 301.8km SIEPAC ~300MW line between the Agua Caliente substation in Honduras and the Sandino substation in Nicaragua, and the installation of the second circuit between the La Virgen substation in Nicaragua and the Fortuna substation in Costa Rica¹⁴¹⁵.
- Colombia-Panama extra-regional interconnection developed using 300 kV HVDC, with an approximate length of 500 km and a capacity of 400 MW. It consists of three segments: two land sections (150 km in Colombia and 220 km in Panama) and one marine section (130 km) connecting the land segments¹⁶¹⁷.

Technical features

- Institutional Model: Independent regional entity with public and private participation (EPR).
- Interconnection Type: Synchronous, AC 230 kV, 300 MW, ~1,800 km
- Preparation for expansion: Design for a second circuit that would double capacity to 600 MW
- Market Evolution: From exchange for reliability to structured MER with rules, regulator (CRIE) and operator (EOR)

Key takeaway: Management by a specialized regional entity, combined with phased technical expansion and a rules-based commercial framework, has bolstered system resilience while paving the way for significantly greater integration of renewable energy.

Andean Electrical Interconnections (Colombia–Ecuador–Peru)

Overview

Since the 1990s, Colombia and Ecuador have maintained electricity exchanges through 230 kV interconnections, with bidirectional flows that have reached more than 1,000 GWh per year in periods of drought or water abundance. In 2007, the transmission capacity was expanded with the Pasto-Quito line (500 MW). Peru joined the scheme through the Zorritos–Machala link (138 kV), allowing modest exchanges (up to 80 MW), with studies underway to expand to 500 kV.

Technical features

- Interconnection Type: AC 230 kV (Colombia–Ecuador), 138 kV (Ecuador–Peru)
- Capacity: ~500 MW (Col–Ecu), ~80 MW (Ecuador–Peru)¹⁸¹⁹
- Institutional Model: cooperative mechanisms between governments and agencies of the Andean Community (CAN)²⁰

¹⁴ <https://www.eprsiepac.com/comunicado-de-prensa-obras-ii-circuito/>

¹⁵ <https://www.bcie.org/en/news-and-media/news/article/for-the-benefit-of-more-than-49-million-central-americans-cabei-strengthens-regional-energy-integration-with-the-financing-of-the-second-siepac-circuit>

¹⁶ <https://www.eprsiepac.com/linea-siepac/proyectos/>

¹⁷ <https://www.interconexioncp.com/descripcion-tecnica/>

¹⁸ <https://www.iadb.org/en/project/RG-T4612>

¹⁹ <https://knowledge.energyinst.org/new-energy-world/article?id=139744>

²⁰ <https://eulacfoundation.org/en/strengthen-regional-energy-integration-andean-electricity-interconnection-system>

Figure 5: Andean Electrical Interconnection System (SINEA) Corridor



Source: ECLAC

Recent and planned expansions

- Project for a new 500 kV interconnection between Ecuador and Peru (Zorritos–Guayaquil, ~1,000 MW)²¹
- Studies to interconnect Peru and Chile through the Arica-Tacna node (~220 kV initially)²².

Key takeaway: The Andean interconnection has proven to be an effective mechanism for managing droughts and variable hydrologies, reducing costs and strengthening energy security, although challenges remain in regulatory harmonization and expansion towards an integrated Andean market.

Southern Cone Interconnections (Brazil–Argentina–Uruguay–Paraguay)

Overview

The Southern Cone has one of the most interconnected hydroelectricity systems in the world. Itaipu (Brazil–Paraguay, 14 GW), Yacyretá (Argentina–Paraguay, 3.2 GW) and Salto Grande (Argentina–Uruguay, 1.9 GW) form the backbone of regional electricity integration. These binational plants supply more than 60% of Paraguay's consumption and provide flexibility and key exports to Brazil and Argentina.

Technical features

- Institutional Model: Binational companies (Itaipu Binacional, Yacyretá, CTM Salto Grande)
- Interconnection Type: AC 220–500 kV, including Itaipu HVDC converters (50/60 Hz)
- Installed Capacity: >20 GW in generation and multiple international exchanges

²¹ <https://www.bnamericas.com/en/news/procurement-being-structured-for-ecuador-peru-power-link>

²² <https://knowledge.energyinst.org/new-energy-world/article?id=139744>

Figure 6: Southern Cone Interconnections (SIESUR) Corridor



Source: ECLAC

Recent and planned expansions

- Transmission reinforcements in Argentina (500 kV NEA-Litoral) to evacuate energy from Yacyretá.
- Feasibility study of a 500 kV (~2,000 MW) direct Uruguay-Brazil interconnection complementing the Rivera-Livramento link.

Key takeaway: Binational hydroelectricity has been a pillar of energy integration and security in the Southern Cone, demonstrating how large shared projects can generate long-term benefits in cost, reliability, and stability.

Arab region

The Arab region has a long history of regional grid interconnections aimed at improving adequacy, lowering reserve requirements, and enabling more cost-effective integration of renewable energy. These efforts range from the mature GCC Interconnection Authority (GCCIA) system in the Gulf to the Egypt–Levant–Iraq corridor and the expanding North Africa–Europe linkages. A growing policy push under the Pan-Arab Electricity Market (PAEM) framework complements these physical infrastructures with a vision for regional market integration. Collectively, these cases highlight scalable institutional models, financing arrangements, and technical approaches that ESCWA member States can adapt to strengthen cross-border renewable integration and resilience.

GCC Interconnection Authority (GCCIA)

Overview

GCCIA operates a 400 kV regional backbone interconnecting the six Gulf states via a common bus and HVDC components that bridge Saudi Arabia's 60 Hz system with its 50 Hz neighbors. The network spans ~913 km of double circuit overhead lines with associated substations.²³

By sharing reserves and providing emergency support, the system has yielded cumulative economic savings exceeding US\$3 billion by end-2023, including fuel savings, deferred capacity, and avoided outages. The interconnection continues to generate annual benefits as structured trade mechanisms expand.²⁴²⁵

Recent and planned expansions

- Kuwait–Saudi upgrade toward ~3,000 MW via new Al Wafrah substation
- UAE–Oman 400 kV Baynunah–Ibri direct link (~530 km)
- GCC–Iraq 400 kV interconnection to Al Faw (~295 km, 600 MW first phase)²⁶²⁷²⁸

Technical features

- Institutional model: Independent regional entity with clear roles vis-à-vis national TSOs
- Asynchronous bridging: HVDC elements allow 50/60 Hz interconnection
- Market evolution: Shift from reliability-focused exchange to structured trade and auctions²⁹³⁰³¹

²³ <https://gccia.com.sa/gccia-grid/our-existing-network/>

²⁴ https://gccia.com.sa/wp-content/uploads/2024/08/2022-FILE_28.pdf

²⁵ <https://www.fitchratings.com/research/international-public-finance/fitch-affirms-gulf-cooperation-council-interconnection-authority-a-outlook-stable-06-08-2025>

²⁶ <https://gccia.com.sa/gccia-grid/projects-under-construction-2/>

²⁷ <https://www.nbmcw.com/news/gccia-qdf-sign-agreement-for-oman-direct-interconnection-project.html>

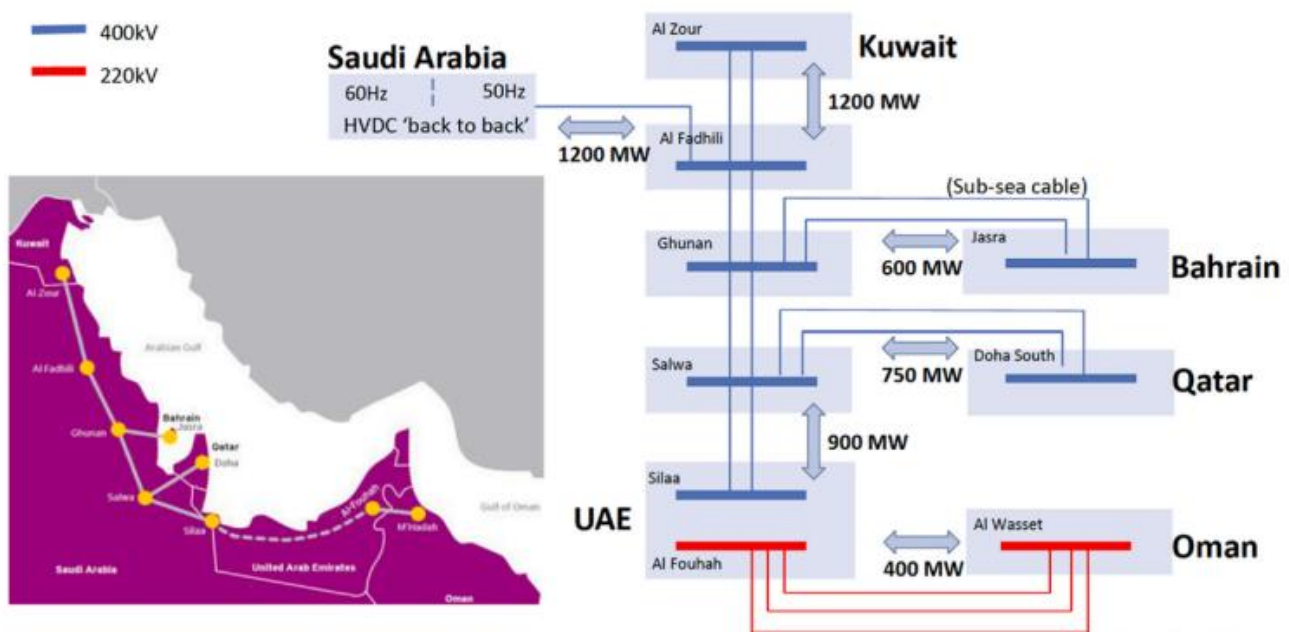
²⁸ https://www.miga.org/sites/default/files/2024-04/GCCIA%20IRAQ%20Interconnection%20Project_ESIA.pdf

²⁹ <https://documents1.worldbank.org/curated/en/099072124082035121/pdf/P1745041896f3b0261ba5c134ea628f9140.pdf>

³⁰ <https://www.gevernova.com/grid-solutions/sites/default/files/resources/products/applications/hvdc/gccia-interconnection-brochure-en-2018-05-grid-pea-0570.pdf>

³¹ <https://documents1.worldbank.org/curated/en/099072124082035121/pdf/P1745041896f3b0261ba5c134ea628f9140.pdf>

Figure 7: Network typology of GCC interconnections



Source: ResearchGate³²

Key takeaway: A dedicated regional operator, phased technical expansion, and rules-based trade have delivered significant savings and resilience—while preparing the grid for high renewable energy penetration.³³

Egypt-Levant-Iraq interconnections

Egypt–Jordan

Egypt and Jordan have been interconnected since 1998/1999 via a 400 kV, ~13 km AC submarine cable across the Gulf of Aqaba, with an exchange capability around 500–550 MW. The parties renewed exchange arrangements in 2025 and are studying capacity upgrades (targeting ~1,100 MW via a second link).³⁴

Jordan–Syria–Lebanon

Jordan and Syria are linked by a 400 kV overhead line (147 km; 300–800 MW nominal range), and Syria is connected to Lebanon at 400 kV/230 kV/66 kV. While the physical assets exist, cross-border flows have been intermittent (or halted altogether) due to conflict-related outages and technical/operational constraints. Reactivation depends on rehabilitation and institutional alignment.^{35,36}

³² https://www.researchgate.net/publication/392463567_Grid-Forming_GFM_Converters_in_Modern_Power_Systems_A_Review_of_Control_Methods_Pilot_Projects_and_Strategic_Roles_in_Renewable_Energy_Integration

³³ https://gccia.com.sa/wp-content/uploads/2024/08/2022-FILE_28.pdf

³⁴ https://med-tso.org/wp-content/uploads/2022/02/EG-JO_project_sheet.pdf

³⁵ <https://nepco.com.jo/en/Interconnection.aspx>

³⁶ <https://www.atlanticcouncil.org/in-depth-research-reports/report/great-sea-connections-financing-the-eastern-mediterraneans-energy-transition/>

Jordan–Iraq (emerging)

A phased interconnection is under construction, with initial capacity of 150–200 MW and planned reinforcements to Jordan’s eastern network. Commissioning is targeted for 2025.³⁷

Key takeaway: Even modest cross-border links can support meaningful bilateral trade and grid stability, but sustained flows require political alignment, system readiness, and reinvestment in dormant infrastructure. The phased Egypt–Levant–Iraq system offers a model for layered connectivity amid regional fragility.

North Africa–Europe linkages

Morocco–Spain (in operation)

Morocco and Spain operate two 400 kV AC submarine circuits across the Strait of Gibraltar (commissioned 1997 and 2006), jointly providing ~1,400 MW of technical capacity. Red Eléctrica in Spain and its Moroccan counterpart, L'Office National d'Electricité et de l'Eau Potable, have agreed to develop a third 400 kV link to further increase exchange capability.³⁸

Tunisia–Italy “ELMED” (under implementation)

The 600 MW, 200–224 km HVDC ELMED interconnector (Partanna–Mlaabi) is progressing with EU/IFI financing. Commissioning is expected later this decade. The project enables bidirectional trade and supports Tunisia’s renewable energy integration.^{39,40,41}

Key takeaway: Cross-Mediterranean capacity, combined with domestic grid upgrades and market access, can turn North Africa’s solar and wind resources into dependable exports—while maintaining flexibility for variable flows.

Maghreb subsystem – Algeria–Tunisia–Libya

Algeria, Morocco, and Tunisia form the COMELEC synchronized block, with multiple 220/400 kV interconnections (e.g., Morocco–Algeria with two 400 kV and two 220 kV lines). Reinforcements are planned along:

- The Algeria–Tunisia corridor
- A new 400 kV double circuit Tunisia–Libya line (~1,250 MW additional capacity)⁴²

Key takeaway: Joint planning under COMELEC and MED-TSO enables low-cost reinforcements,

³⁷ <https://www.fananews.com/language/en/nepco-director-reviews-progress-on-jordan-iraq-power-interconnection-project>

³⁸ <https://www.ree.es/en/sala-de-prensa/actualidad/nota-de-prensa/2022/11/Red-Elctrica-and-its-Moroccan-counterpart-carry-out-maintenance-work-on-the-reserve-cable-of-the-submarine-electricity-link-between-Spain-Morocco>

³⁹ <https://www.terna.it/en/projects/projects-common-interest/italy-tunisia-interconnection>

⁴⁰ <https://www.eib.org/en/projects/pipelines/all/20170028>

⁴¹ <https://www.ebrd.com/home/news-and-events/news/2024/ebd-finances-tunisiaitaly-600-mw-elled-electricity-interconnector.html>

⁴² https://med-tso.org/wp-content/uploads/2022/02/DZ-TN-LY_project_sheet.pdf

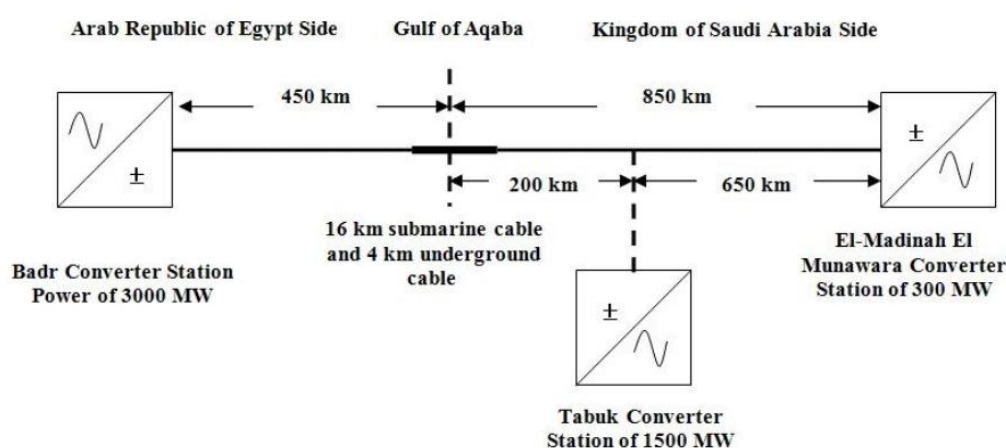
operational harmonization, and future linkage to European capacity markets—unlocking North Africa’s flexibility for regional and international trade.

Egypt-Saudi Arabia HVDC Interconnection

This is the first large-scale HVDC project in the MENA region (3,000 MW, ~1,350 km at 500 kV), linking Badr (Egypt) and Medina/Tabuk (Saudi Arabia), including a submarine Red Sea crossing. Commissioning is phased: 1.5 GW is expected first, with full capacity targeted by mid/late 2025, pending construction. Specifications have been published by Hitachi Energy and IEA.⁴³⁴⁴

Key takeaway: This landmark project enables time-zone-based energy exchange—transmitting Egypt’s midday solar surplus to meet Saudi Arabia’s evening peaks—and establishes a vital backbone for future PAEM-aligned trade between North Africa and the Gulf.

Figure 8: Schematic design of the Egypt-Saudi Arabic HVDC Interconnection



Source: ResearchGate⁴⁵

Policy architecture – PanArab Electricity Market (PAEM)

The Pan-Arab Electricity Market (PAEM) is a flagship initiative spearheaded by the League of Arab States with technical support from ESCWA and others. It seeks to harmonize regulatory frameworks and facilitate multilateral electricity trade across the Arab region. Its phased roadmap envisions moving from bilateral exchanges to a fully integrated regional power market.

Strategic interconnections—such as Egypt–Saudi Arabia HVDC, GCCIA expansions, and Maghreb–Europe links—are critical enablers of PAEM’s long-term vision of a resilient, flexible, and unified Arab electricity market. In 2024, the World Bank/ESMAP published methodologies for cross-border transmission pricing and congestion rent allocation—cornerstone elements to operationalize fair and bankable regional renewable energy trade.⁴⁶⁴⁷

⁴³ <https://www.hitachienergy.com/us/en/news-and-events/customer-stories/saudi-arabia-egypt>

⁴⁴ <https://www.iea.org/policies/14291-egypt-saudi-electricity-interconnection-project>

⁴⁵ https://www.researchgate.net/publication/350504493_Feasibility_study_of_an_Offshore_Wind_Farm_with_the_Egyptian-Saudi_Arabia_HVDC_link

⁴⁶ <https://paem.org/>

⁴⁷ <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099072124082035121/p1745041896f3b0261ba5c134ea628f9140>

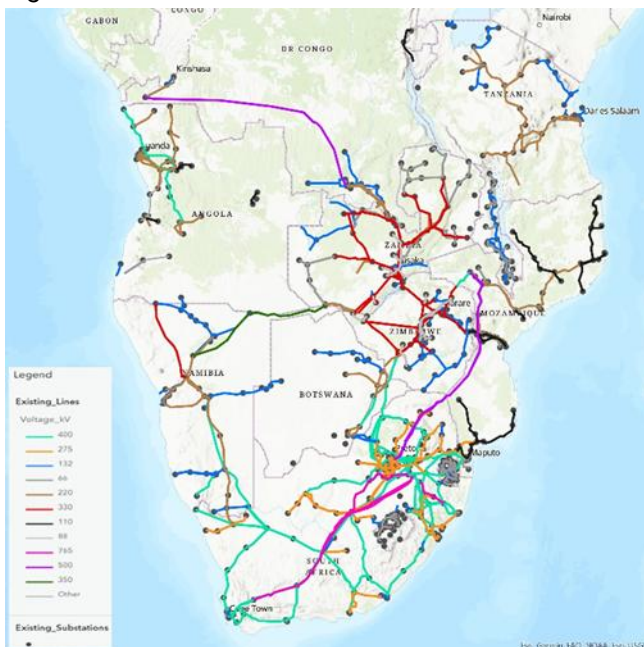
Africa region

The Africa region has a history of energy-based regional integration facilitated through the establishment of regional power pools and development of regional interconnections. With the establishment of the Southern African Power Pool (SAPP) in 1995, West African Power Pool (2000), Central African Power Pool (2003) and Eastern Africa Power Pool (EAPP) (2005), the region fostered institutions to interconnect across countries. With the establishment of the North African Power Pool, or COMELEC, in 2018, all sub-regions of the continent embedded institutional frameworks for regional interconnection. To implement the vision of the African Single Electricity Market operationalization by 2040, a Continental Power System Master Plan for integrating Africa's regional electricity markets and grid infrastructure is developed with a goal to increase regional electricity trade, put the foundation to an integrated continental electricity market, increase renewable energy development, and enhance collective energy security.

Southern African Electrical Interconnection System within SAPP

The SAPP region consists of 12 countries, with 400 million people, 52 GW available capacity and a peak demand of 57 GW, with at least 5 GW of regional power deficit (SAPP, 2024)⁴⁸, with a regional ambition to increase the share of renewables above 30% by 2040. Four countries in the pool generate excess electricity: Angola; Mozambique; South Africa and Tanzania. Current interconnections rely on 533 kV DC, 400 kV, 330 kV, 275 kV, 220 kV and smaller capacity lines.

Figure 9: South African Power Pool interconnections



Source: South African Power Pool

The SAPP has a regional competitive electricity market enabled through regional interconnection system and a designed market framework that allows electricity trade under day ahead market (DAM), intra-day market (IDAM) and a futures power market (FPM) trading regime. In September 2025, 87.4 GWh of electricity was traded in the DAM, 10.1 GWh in FPM weekly traded volumes, and

⁴⁸ Eng. Alison Chikova, Southern African Power Pool. "Developing Energy Connectivity for a Secure power Systems: SAPP Perspective." Presented on 2 December 2024, 13th International Forum of Energy for Sustainable Development, Bangkok, Thailand.

4.3 GWh in IDM.⁴⁹ Regional interconnection and trading systems in the region enable lowering electricity costs, increasing energy security, and accessing clean energy sources. The benefits to countries in the SAPP power system are substantial. For example, the World Bank (2019) assesses that a full interconnection of SAPP would result in over US\$42 billion in investment and operation cost savings by 2040, with benefits increasing from about \$100 million/year in 1999 to nearly \$2 billion/year in the 2017–2040 period⁵⁰, as regional interconnection deepens. However, current transmission infrastructure capacity places a constraint in advancing electricity trade as reflected in the September 2025 SAPP Market Performance Report, which noted “the 76.6 GWh of potentially tradable power was not traded due to transmission constraints in September 2025. In August 2025, 72% of the energy matched in all markets was traded.”

Recent and planned expansions

- Within the SAPP electricity system, several projects are under feasibility study such as the Mozambique-Tanzania transmission line, Malawi-Zambia line, and the Mozambique-Zimbabwe line.
- Construction is underway for two interconnectors: the Mozambique-Malawi line and the Namibia-South Africa line.
- Eight interconnectors are currently under a feasibility study, including the Mozambique-Tanzania line, the Malawi-Zambia line and the Mozambique-Zimbabwe line.
- The Southern Africa Development Community, with countries within the SAPP, has similarly identified three priority transmission corridors with eight priority interconnectors (SADC).

Technical features

Institutional framework: under a power pool approach, the Southern Africa region has advanced transmission system integration under the coordination of the SAPP, which enables participating utilities and private generators to participate in the market.

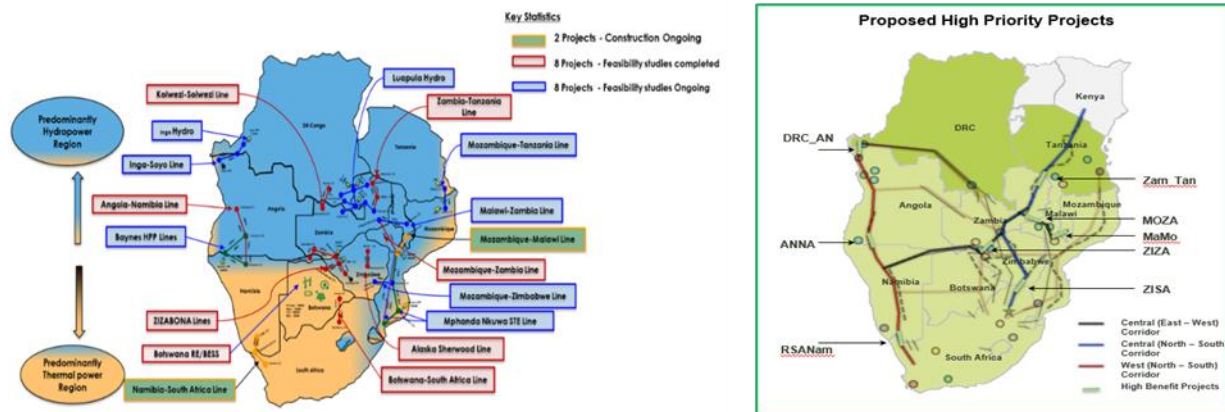
Interconnection type: currently rely on 533 kV DC, 400 kV, 330 kV, 275 kV, 220 kV and smaller capacity lines.

Market development: SAPP advanced day-ahead market since 2009, established post day ahead market in 2013 and a futures and intra-day market since 2016. Though not currently in operation, a balancing market has been designed since 2022. Evolution of the regional market anticipates ancillary services market and potential renewable energy market.

⁴⁹ SAPP Market Performance Report, September 2025. <https://www.sapp.co.zw/sites/default/files/SAPP%20Market%20Performance%20Report%20-%20September%202025.pdf>

⁵⁰ Tom Remy and Debebrata Chattopadhyay, *Energy for Sustainable Development* Vol. 57, pp. 81-97; available here: <https://www.sciencedirect.com/science/article/abs/pii/S097308262030243X>

Figure 10: South African interconnections development



Source: SAPP (image 1) and the South African Development Community (image 2).

Key takeaway: regional power pooling, supported by a regional institution managing system operation, accompanied with regional electricity market development enabling increasing trade under different regimes, with a robust target to integrate renewable energy enhance regional energy security help reduce investment and operational costs and offer greater opportunity for energy transition.

The Ethiopia-Kenya Interconnection

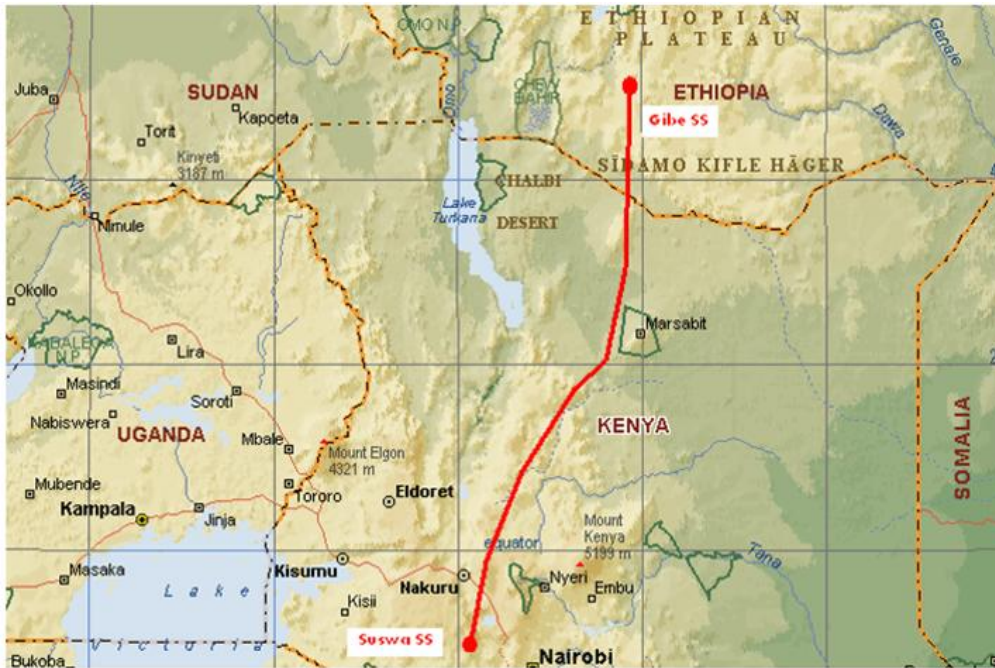
The Ethiopia-Kenya electrical interconnection was intended to leverage the sizeable low-cost renewable energy potential of Ethiopia (45,000 MW from hydro alone) to supply the growing electricity needs of Kenya, and further enable interconnection with Tanzania, with the eventual goal of interlinking the Eastern and Southern Africa power pools. The interconnection has a capacity to export renewable energy from Ethiopia to Kenya of up to 2000 MW[4], through transmission infrastructure spanning 1,045 km.⁵¹ The transmission network became operational since 2022, supplying 200 MW of electricity capacity, with demand to double the capacity exchanged to 400 MW.

This power interconnection agreement supported by the African Development Bank, the French Development Agency and the World Bank, will provide reliable and affordable energy to an estimated 870,000 to 1.4 million Kenyan households of which 18% will be in rural areas.⁵² The power purchase agreement (PPA) concluded between Kenya and Ethiopia is expected to further benefit a broader region in the long-term through spill-over benefits to Eastern, Northern and Southern Africa regions through interconnections to their respective power pools. The PPA is part of the Eastern Electricity Highway Project which is expected to increase the supply of low-cost electricity to Kenya and provide export earnings to Ethiopia and energy cost savings in Kenya.

⁵¹ Dr. Popescu, 2009. "HVDC Converter Station and Facilities and Basic design on transmission lines report." Final feasibility report on Ethiopia-Kenya Power Systems interconnection project, vol. 2, 2009

⁵² Horn of Africa Initiative, 2022. "Kenya and Ethiopia Signed Power Purchase Agreement (PPA)." <https://www.hoainitiative.org/news/kenya-and-ethiopia-signed-power-purchase-agreement-ppa#:~:text=Kenya%20and%20Ethiopia%20have%20signed,State%20Minister%20of%20Finance%2C%20Dr.>

Figure 11: East African Power Pool interconnections



Source: East African Power Pool.

Technical features:

Institutional framework: under a joint project coordination mechanism, within the broader framework of the EAPP, Ethiopia and Kenya advanced interconnection.

Interconnection type: a 500 kV high-voltage direct current (HVDC) transmission line with a total length of 1,045 km with a transmission capacity of 2,000 MW.

System performance: robust system performance, low overall losses, with 400 kV AC system to comply with the EAPP Grid Code, and the Kenyan grid constituting the construction of 400/220 kV substation and 16.5 km 132 kV underground cable to connect two substations.⁵³

Recent and planned expansions:

- A major development is the further interconnection into the United Republic of Tanzania enabling to export renewable energy from Ethiopia via the Kenyan grid.
- According to the Stockholm Environment Institute – Africa, the trial energization in June 2025 of the interconnection with the United Republic of Tanzania was “the first of its kind under the Eastern Africa Power Pool (EAPP) framework.”
- Furthermore, the Kenya Electricity Transmission Company Limited (KETRACO) expects to earn \$6.3 million/year in transit fees⁵⁴ while through export to Kenya alone, Ethiopia earns an estimated \$100 million/year⁵⁵ https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-US&wopisrc=https%3A%2F%2FUnitednations.sharepoint.com%2Fsites%2FEscap-OD_SMP%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F7e4bcc7914734e76ac829b94f5597b65&wdlor=cED

⁵³ ADB, 2024. Project Completion Report for Public Sector Operators.

⁵⁴ Stockholm Environment Institute – Africa: <https://www.esi-africa.com/industry-sectors/smart-technologies/smart-grids/kenya-energy-wheeling-trial-ethiopia-tanzania/>

⁵⁵ Ethiopian Electric Power. “Ethio-Kenya electric system interconnection economic inputs.” <https://www.eep.com.et/wp-content/uploads/2024/02/2-December-9-2022.pdf>

606E36-A036-4BBD-8020-4331E803F55F&wdenableroaming=1&mscc=1&hid=39D2E7AA-D756-41FE-AF83-CDB792C10927.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=827e5dcc-bf3d-2a02-83d2-175f49f8171c&usid=827e5dcc-bf3d-2a02-83d2-175f49f8171c&newsession=1&sftc=1&uihit=docaspx&muv=1&ats=PairwiseBroker&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Funitnations.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&wdorigin=Outlook-Body.Sharing.ServerTransfer.LOF&wdhostclicktime=1761548316015&afdfight=59&csi=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush_-_ftn9

- AUDA-NEPAD further stipulates that the Ethiopia-Kenya-Tanzania interconnection could synchronize with Uganda, Rwanda, Burundi and D.R. Congo systems pointing in the direction of a potential wider regional interconnection.
- In the Kenya-Tanzania segment alone, 510 km of interconnection with HVAC transmission line with transfer capacity of 1,600 MW is constructed.⁵⁶

Key takeaways: joint project implementation mechanisms, high efficiency transmission technology, supported by power purchase agreements (PPAs), complying with regional transmission standards guided by a regional Grid Code and leveraging cross-border transmission investments into a much wider regional interconnection and power exchange strengthen the value addition of transmission infrastructure to participating countries.

⁵⁶ AUDA-NEPAD. “Kenya-Tanzania Power Interconnection Line Energized - A Milestone in Regional Energy Integration.” <https://www.nepad.org/news/kenya-tanzania-power-interconnection-line-energized-milestone-regional-energy>

Chapter 3. Benefits and opportunities

Cross-border power connectivity is an important tool for integrating renewable energy by balancing supply and demand across borders, improving system efficiency, and reducing curtailment. It enables economies of scale, helps to attract investment, and enhances system reliability and resilience—especially important as countries transition away from power systems that rely primarily on fossil fuel to ones based on high shares of RE resources. Connectivity also supports the achievement of multiple SDGs by promoting access to modern energy resources, economic growth and job creation, social inclusion, and regional cooperation. Many countries have recognized the potential role of power system connectivity as a tool for sustainable development, as well as the role of the UN Regional Economic Commissions as platforms to enable and support collaboration and capacity development. For example, the ESCAP member States have endorsed the Regional Road Map for Cross-Border Power System Connectivity as a strategic framework to strengthen cooperation, harmonize regulations, and accelerate sustainable energy transitions across the Asia-Pacific region⁵⁷.

Balancing power system surplus and deficits across borders

Variability of renewable energy generation often creates surpluses in some areas while others face shortages. Power connectivity helps balance these mismatches by enabling efficient electricity exchanges and better use of renewable resources. Many regions with strong RE potential are far from demand centers or lack sufficient system flexibility, while neighboring areas may face deficits due to limited generation, high fossil-fuel costs, or unfavorable weather. By linking power systems, countries can benefit from diversity in supply and demand, for example, exporting surplus midday solar power to a nearby time zone experiencing evening peak demand.

In Central Asia, for instance, Kyrgyzstan and Tajikistan have significant hydropower surpluses during summer months, while Kazakhstan, Turkmenistan and Uzbekistan rely on fossil fuel-fired generation to meet peak electricity demand needs⁵⁸. The CAPS was established to integrate and optimize the power systems of these countries through coordinated generation and transmission planning, allowing dynamic energy balancing between countries. Following the dissolution of the Soviet Union, however, the system became fragmented, and regional electricity exchanges are now largely governed by bilateral or trilateral agreements, which constrain the use of real-time commercial trade and technical balancing mechanisms that could enhance efficiency and reduce costs.

⁵⁷ <https://www.unescap.org/our-work/energy/energy-connectivity/roadmap>

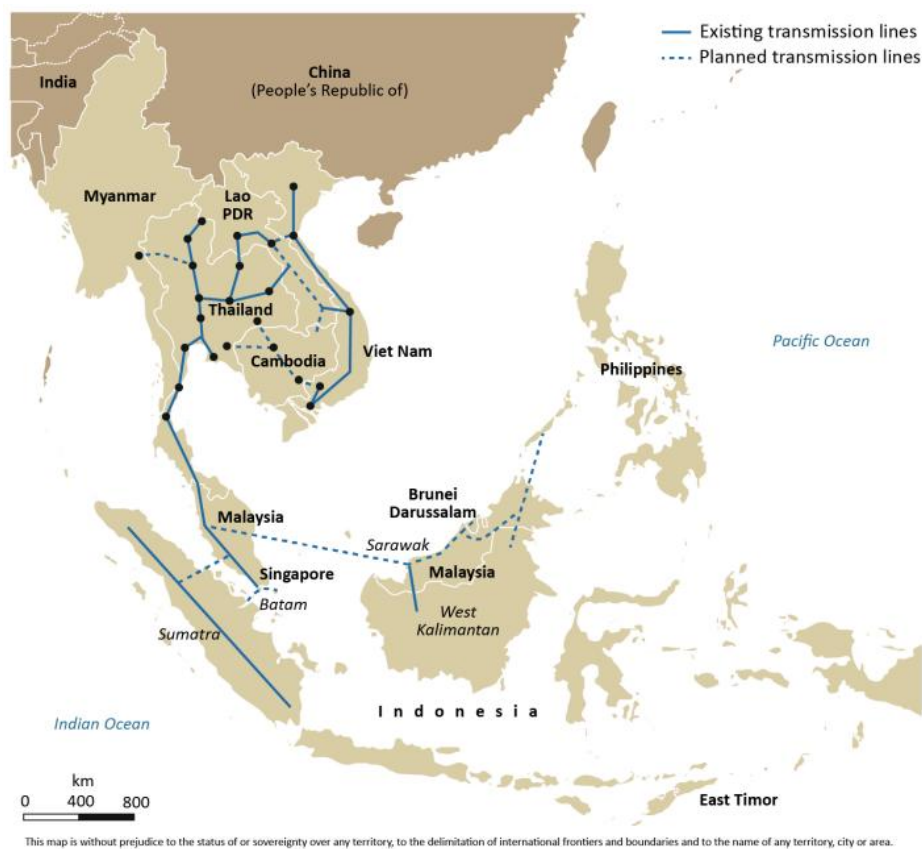
⁵⁸ <https://www.iea.org/reports/cross-border-electricity-trading-for-tajikistan-a-roadmap/opportunities-for-electricity-trade>

Economic benefits

Building large-scale renewable energy projects often requires investment that may exceed the financial and demand capacities of developing countries. Beyond financing, regional connectivity improves the utilization rate of renewable assets. Large-scale projects often produce significant surpluses during peak generation hours. Interconnected power systems solve this challenge by expanding the market size, allowing surplus electricity to flow to neighboring regions where demand is higher. For example, in Southeast Asia, the Lao People's Democratic Republic (Lao PDR) has leveraged its hydropower surplus through a multilateral power trade agreement with Thailand, Malaysia and Singapore (the Lao PDR, Thailand, Malaysia, Singapore Power Integration Project, or LTMS-PIP; see Figure 12), earning revenues from the cross-border trade of electricity while at the same time supporting regional diversification and decarbonization goals.

Connectivity also enables economies of scale in infrastructure development. Coordinated planning for regional renewable energy corridors and shared transmission networks reduces duplication of investments, lowering the overall cost of electricity generation and delivery. Analysis by UNECE found that greater integration of energy systems among countries would save the region at least USD 1.4 billion in electricity production costs each year by 2050⁵⁹.

Figure 12: Regional Transmission Links in Southeast Asia – ASEAN Power Grid



Source: International Energy Agency (IEA)⁶⁰

⁵⁹ <https://unece.org/sed/documents/2025/03/modelling-resilient-and-integrated-energy-system-central-asia>

⁶⁰ https://iea.blob.core.windows.net/assets/37a2b2f0-bab0-47e0-a618-1a0259926b26/Establishing_Multilateral_Power_Trade_in_ASEAN.pdf

Increasing system reliability and decarbonization potential

Regional cooperation strengthens energy security and resilience by diversifying supply and enabling countries to share resources—especially valuable during low renewable output or unexpected outages. It also reduces the need for each country to maintain costly backup capacity, as cross-border trade allows electricity imports during demand spikes or shortfalls, supporting a smoother transition away from fossil-fuel-based plants. Interconnected grids further enhance resilience by providing redundancy: if a plant or line fails, power can be rerouted through other links. This stability is vital for investors, creating predictable long-term demand, improving project bankability, and lowering the cost of capital for large renewable projects.

Contribution to SDGs and energy transition

Cross-border connectivity supports achievement of multiple SDGs. By linking national power systems through shared infrastructure and coordinated markets, countries unlock not only environmental benefits but also wider social and economic gains that touch multiple aspects of sustainable development.

Apart from supporting SDG7 (Affordable and Clean Energy), connectivity also plays a critical role in SDG 13 (Climate Action), as it enables large-scale integration of renewable energy across borders and therefore supports power system decarbonization. Countries rich in solar, wind, or hydro resources can export surplus clean power to neighbors reliant on fossil fuels, reducing regional carbon emissions and supporting collective decarbonization targets.

Cross-border connectivity also fosters economic growth and industrial development (SDG 8 and SDG 9). Reliable and competitively priced electricity is a cornerstone for attracting investments, supporting manufacturing, and developing new industries such as electric mobility, hydrogen production, and green data centers. Regional interconnections reduce power costs by creating larger, more efficient markets and enabling economies of scale in infrastructure investments. This not only benefits national economies but also promotes regional economic integration, trade, and cooperation.

Energy connectivity contributes to social inclusion and poverty reduction (SDG 1 and SDG 10) by expanding access to electricity in rural or marginalized communities near borders. Enhanced power availability supports essential services such as schools, hospitals, and water supply systems, improving living standards and reducing inequalities between urban and rural populations or between energy-rich and energy-deficient countries. In areas affected by conflict or fragility, shared energy infrastructure can also become a tool for peacebuilding and cooperation, strengthening regional ties and fostering mutual dependency that reduces geopolitical tensions.

SDG 5 (Gender Equality) benefits indirectly from energy connectivity. Access to modern energy services often releases household burdens traditionally carried by women, such as time spent on gathering fuel or performing manual tasks. Cross-border electricity trade that enhances energy access can enable women's participation in education, economic activities, and entrepreneurship,

fostering gender empowerment.

Electricity connectivity supports SDG 6 (clean water and sanitation) by allowing to use more renewables in powering essential water infrastructure (pumping stations, treatment plants, and sanitation systems, which are energy-intensive and critical for clean water access). Integrating renewable energy reduces water consumption significantly—wind and solar can cut lifecycle water use by up to 99% compared to fossil fuel power plants, which rely heavily on water for cooling and fuel processing. Enhanced interconnection enables reliable energy supply to remote areas, facilitating climate-resilient water services and smart management systems that improve efficiency and reduce resource waste.

Connectivity supports SDG 11 (Sustainable Cities and Communities) by ensuring resilient and flexible electricity supply for growing urban centers. Interconnected grids reduce blackout risks, stabilize power quality, and facilitate the integration of clean transport systems, making cities more sustainable and livable.

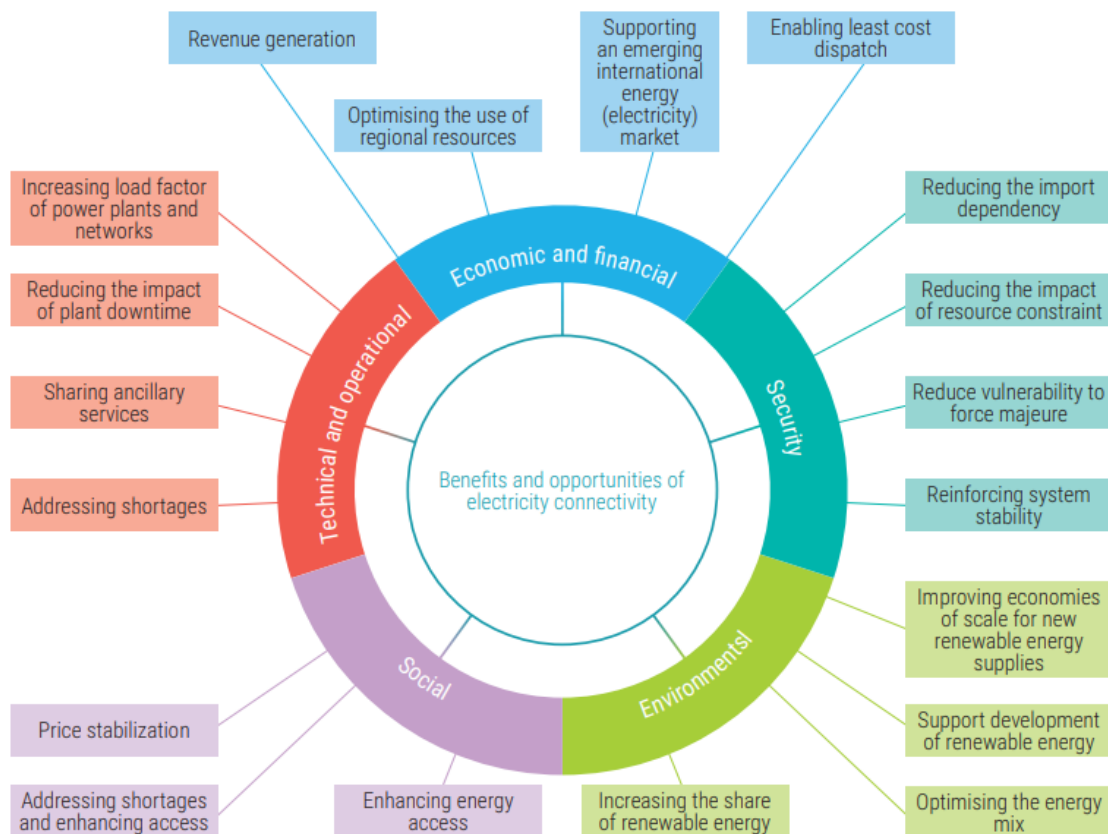
Lastly, SDG 17 (Partnerships for the Goals) is inherently strengthened by cross-border energy initiatives. Successful interconnections require long-term regional cooperation, harmonized regulations, and shared investments among governments, utilities, development banks, and private sector actors. These partnerships build institutional capacity, encourage technology transfer, and establish a foundation for broader cooperation on climate change, trade, and infrastructure development.

Cross-border connectivity is much more than a technical solution for energy access and decarbonization. It is a catalyst for inclusive, sustainable development, driving progress across a wide range of SDGs by creating affordable, clean, and reliable energy systems that foster economic growth, social well-being, gender equality, and regional cooperation.

Chapter 4. Challenges and risks

Despite significant benefits, power system connectivity development presents significant technical challenges. These challenges include grid infrastructure limitations, managing variability of renewable energy sources, financial challenges, institutional and regulatory barriers, as well as social and environmental risks.

Figure 13: Challenges and barriers to connectivity



Source: ESCAP⁶¹

Technical challenges

One of the most pressing challenges is the physical limitations of existing transmission infrastructure. Many developing countries lack adequate high-voltage transmission lines that can carry large quantities of electricity across long distances. Even where interconnections exist, they may be aging, under-maintained, or technically incompatible with neighboring systems. Grid bottlenecks can lead to congestion, increased transmission losses, and constraints on the volume and direction of power flows, ultimately reducing the efficiency and reliability of cross-border electricity trade. In addition, differing technical standards and grid codes, such as voltage levels, frequency control mechanisms, and protection schemes can make synchronization of national grids difficult or even unfeasible. A recent ESCAP report⁶² underscores the urgency of aligning grid development with generation goals, particularly in light of COP29 pledges to expand energy storage

⁶¹ <https://repository.unescap.org/server/api/core/bitstreams/4c5626cb-ce05-4e54-8780-8094c232849a/content>

⁶² <https://www.unescap.org/kp/2025/role-grids-energy-transitions>

and transmission infrastructure. The report urges integrated planning, enhanced data transparency, robust financial mechanisms, regulatory reform, and stronger regional cooperation. As countries integrate increasing shares of variable renewable energy, interconnected grids must accommodate new patterns of intermittency and unpredictability. Renewable generation can fluctuate rapidly due to changes in sunlight or wind speed. When such variability occurs across multiple interconnected countries, it can strain grid stability and complicate power flow coordination. Maintaining system balance is more complex in an interconnected, multi-country grid. Each country may have different demand profiles, generation mixes, and market structures. Balancing supply and demand require real-time data exchange, coordinated dispatch, and shared reserves.

Frequency and voltage stability become harder to manage in larger networks, especially when power flows are dynamic and unpredictable. The lack of a central dispatch authority in many regional systems can lead to coordination failures, inefficient dispatch, or duplication of reserves. Inadequate planning and management can lead to dramatic consequences, thus massive blackout that struck Spain and Portugal in April 2025, was triggered by a voltage surge worsened by conventional power plants failing to stabilize voltage levels during an electricity spike⁶³.

Financial challenges

The development of cross-border power system connectivity is capital-intensive and requires long-term, stable financing. Large-scale investments are needed not only for generation projects, but also for high-voltage transmission infrastructure, interconnection facilities, system balancing tools, and grid modernization. However, many regions face serious financial challenges that limit the pace and scale of connectivity efforts. There is also regional imbalance. Europe, the United States, China, India, and parts of Latin America are leading the way, global investment in power transmission grew by 10% in 2023 to reach USD 140 billion. Advanced economies and China accounting for about 80% of the global total⁶⁴.

Despite growing recognition of the benefits of regional power trade, actual investments into cross-border electricity infrastructure remain relatively limited. Private sector investors and commercial banks are often reluctant to finance cross-border infrastructure due to long project horizons, high upfront capital costs, and the complex coordination required between multiple governments and utilities. Transmission projects in particular lack clear revenue models, as they do not generate direct cash flows. Cost recovery often depends on regulated tariffs or intergovernmental agreements, which may be subject to change or delay, further undermining investor confidence. Many regional interconnection projects lack bankable project structures. Project preparation and feasibility studies may be incomplete or outdated, and there is often no lead agency responsible for coordinating financial structuring, risk allocation, or stakeholder engagement.

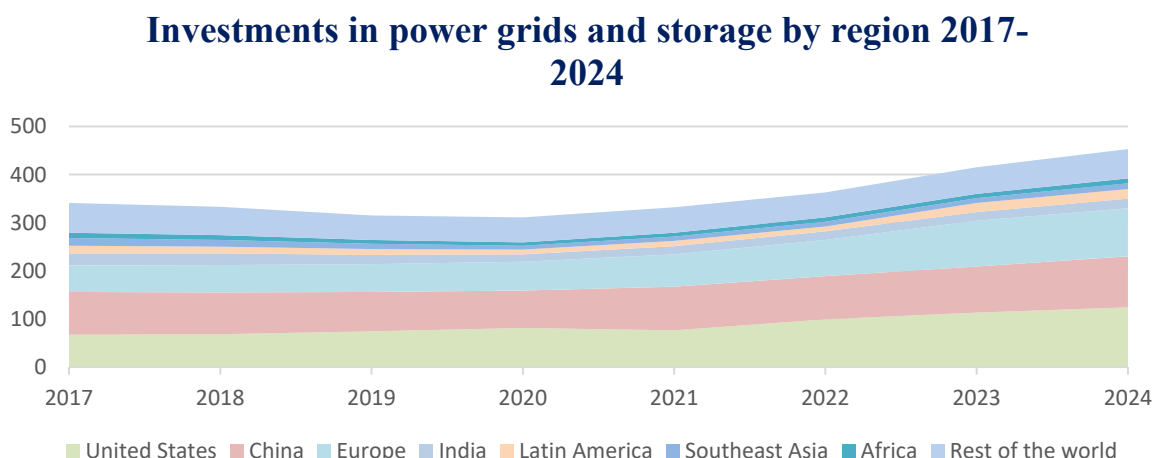
Cross-border electricity projects are often viewed as high-risk investments due to a range of political, financial, and operational uncertainties. These include political instability, regulatory changes, and disputes between countries that can undermine long-term agreements; currency and payment risks linked to exchange rate volatility and financially weak utilities; and low sovereign credit ratings that limit access to affordable financing. Additionally, operational challenges such as poor coordination between national grids and technical failures further increase investor concerns. These risks raise the cost of capital, discourage private sector participation, and often

⁶³ <https://www.reuters.com/business/energy/what-caused-iberian-power-outage-what-happens-next-2025-06-18/>

⁶⁴ <https://www.iea.org/reports/building-the-future-transmission-grid>

shift the financing burden to public institutions or development banks, delaying project implementation and diminishing returns.

Figure 14: Investment in power grids and storage by region 2017-2024



Source: IEA data⁶⁵

Institutional and regulatory barriers

Institutional and regulatory frameworks are the foundation upon which successful cross-border electricity connectivity is built. Even when technical and financial conditions are favorable, institutional misalignment and fragmented regulatory approaches can significantly hinder the development and operation of interconnected power systems. Lack of regulatory harmonization and isolated national energy planning restrict the efficiency and scalability of regional power trade. Power system connectivity requires seamless coordination between national electricity markets, transmission system operators, and regulatory agencies. However, in many regions, regulatory frameworks differ widely across borders, reflecting national priorities, market designs, and levels of institutional maturity. These differences create legal and procedural incompatibilities that complicate power trade.

For instance, countries may have different tariff structures, grid codes, licensing procedures, and rules for third-party access to transmission infrastructure. One country may have an unbundled electricity sector with independent regulators and competitive wholesale markets, while its neighbor operates under a vertically integrated utility model with state-determined prices. In such cases, cross-border power transactions face legal uncertainty, commercial risk, and limited transparency, deterring private sector participation and long-term investment. The absence of standardized contracts and dispute resolution mechanisms also creates uncertainty. Moreover, regulatory authorities often lack formal mandates or mechanisms for cross-border cooperation, and regional institutions tasked with coordination may have limited enforcement power.

Countries tend to conduct energy and infrastructure planning in isolation, without accounting for regional opportunities or synergies. National energy strategies, investment plans, and grid expansion roadmaps are typically designed to meet domestic supply and demand projections, often overlooking the potential benefits of regional cooperation. This insular approach leads to inadequate investment decisions, such as redundant power plants or transmission lines that could

⁶⁵ <https://www.iea.org/data-and-statistics/charts/investment-in-power-grids-and-storage-by-region-2017-2024>

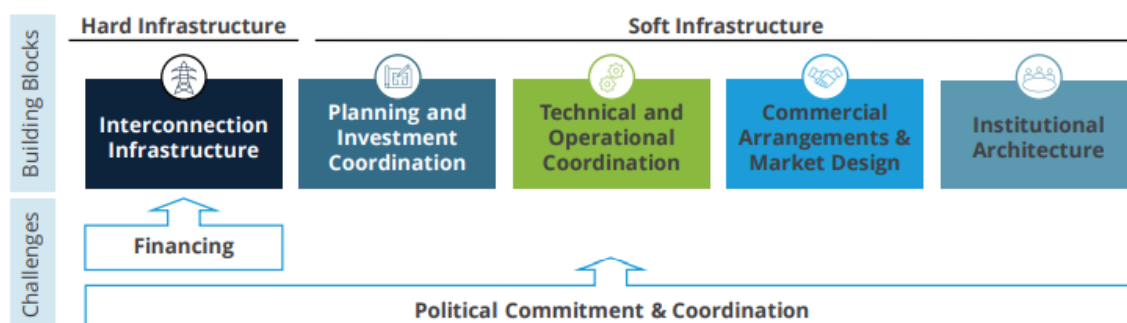
have been avoided through regional coordination. It also means that large-scale renewable projects with cross-border relevance may not be prioritized or included in national planning processes. As a result, many high-potential clean energy projects remain stranded due to lack of coordinated support from neighboring countries. When planning is conducted nationally, countries tend to overbuild capacity as a hedge against uncertainty, increasing system costs and environmental impacts. A regional planning approach, in contrast, would allow for resource coordination, shared reserves, and joint investments, optimizing costs and improving system resilience.

Social and environmental risks

While cross-border power sector connectivity can drive economic growth, energy security, and renewable energy integration, it also carries significant social and environmental risks that should be carefully managed to ensure sustainable and inclusive development. Large-scale electricity transmission projects often require extensive land use, which can lead to deforestation, habitat fragmentation, and biodiversity loss. The construction of high-voltage transmission lines across borders may cut through protected forests, wetlands, or wildlife corridors, threatening endangered species and ecosystems. In mountainous or coastal regions, transmission corridors can also exacerbate soil erosion and increase the risk of landslides or flooding. Additionally, while renewable energy sources like hydropower are low in carbon emissions, the development of large dams can affect river flows, disrupt aquatic ecosystems, and degrade water quality.

Moreover, power connectivity projects often affect local and indigenous communities, particularly those living near generation sites or along transmission corridors. These communities may face land acquisition or loss of access to natural resources without adequate compensation or consent. Projects that proceed without meaningful stakeholder can increase existing inequalities, generate resistance, and trigger legal disputes. Another key concern is the lack of transparency and participation in decision-making processes. In many countries, affected communities have limited avenues to express concerns or influence project design, particularly when development is driven by regional agreements or foreign investments. Weak environmental and social safeguards can lead to rushed environmental impact assessments or inadequate resettlement plans. Proactively addressing social and environmental risks important for long-term community acceptance, and the resilience of energy transition.

Figure 15: Building Blocks of Power System Integration and Key Challenges



Source: World Bank⁶⁶

⁶⁶ <https://documents1.worldbank.org/curated/en/099011525114533597/pdf/P174081-aaf9e616-6af1-46a7-b568-0daaf585daad.pdf>

Chapter 5. Policy recommendations

Lessons learned on aligning power trade and renewable deployment

The experience of different regions highlights several important lessons on how cross-border electricity trade can be aligned with the accelerated deployment of renewable energy. One of the clearest lessons is the importance of regulatory harmonization. When countries operate under divergent tariff schemes, licensing procedures, or grid codes, cross-border transactions are limited, and investors face legal and commercial uncertainty. Where regulatory frameworks have been harmonized, as in the case of the Central American Regional Electric Market (MER) under SIEPAC, regional trade has expanded and created space for greater renewable integration. This underscores the need for stronger regional institutions and mechanisms that can provide clear, transparent, and enforceable rules.

Another key lesson is the role of bankable project structures in attracting investment. Transmission projects and renewable generation with cross-border relevance often fail to move forward due to incomplete feasibility studies or unclear cost-recovery mechanisms. Investors are reluctant to commit capital in the absence of stable revenue models. To address this, governments and regional bodies must ensure that tariffs, bilateral contracts, or revenue-sharing mechanisms are reliable and long-term. Development banks and regional financial institutions can also play a critical role in reducing risk perception and providing guarantees.

It is also demonstrated that foreign direct investment (FDI) can play a catalytic role in advancing both renewable deployment and power connectivity. However, to mobilize this capital effectively, stable regulatory frameworks, predictable policy signals, and adequate risk allocation mechanisms are required. The region's recent experience shows that the availability of capital is not the main barrier; rather, institutional capacity, regulatory certainty, and cross-border coordination are the enabling conditions that determine success.

A further lesson concerns the strategic value of regional interconnections as a tool for resilience and renewable integration. By linking diverse energy systems, countries can mitigate the variability of renewable resources, optimize reserve margins, and reduce system costs. Large binational hydropower projects in the Southern Cone, the Andean interconnections, and emerging initiatives in the Caribbean demonstrate that interconnection enhances both flexibility and energy security. Regional planning approaches that incorporate these synergies allow for more efficient and sustainable investment pathways.

Finally, institutional capacity and stakeholder dialogue are as important as technical and financial solutions. Where specialized regional entities exist—such as the Network's Enterprise Owner (EPR) in Central America—the integration process has been more effective. Strengthening regional cooperation mechanisms, fostering public-private partnerships, and ensuring meaningful participation of affected communities are therefore essential to building trust and advancing integration in a socially inclusive manner.

Development of national frameworks

The development of robust national frameworks is the foundation for advancing power system connectivity and enabling regional energy cooperation. This chapter highlights three essential pillars of national frameworks that underpin cross-border connectivity projects: transmission infrastructure and interconnection readiness, grid flexibility measures, and enabling policies for renewable integration and power trade.

Enhancing transmission infrastructure and interconnection readiness

The physical backbone of power system connectivity lies in well-developed national transmission networks. Many countries across Asia and the Pacific still face significant bottlenecks, including aging infrastructure, insufficient high-voltage transmission capacity, and limited redundancy to handle cross-border flows. Preparing national grids for interconnection requires targeted investments in:

- **Transmission expansion and modernization:** Upgrading lines to higher voltages and introducing high-voltage direct current (HVDC) technology can increase transfer capacity and minimize losses.
- **Grid reinforcement at border points:** Strengthening substations and ensuring compatibility of frequency and voltage control mechanisms are prerequisites for reliable interconnection.
- **Resilience and redundancy:** Designing networks with sufficient spare capacity and climate-resilient infrastructure reduces risks of cascading outages and supports secure regional trade.

Grid Flexibility Measures

Beyond physical expansion, connectivity requires national frameworks that foster system flexibility. As renewable penetration increases, countries need tools to balance variability, optimize resources, and ensure stable operation across interconnected systems. Key measures include:

- **Energy storage systems:** Utility-scale batteries, pumped hydro storage, and emerging technologies provide balancing services, absorb surplus renewable generation, and release power during peak demand.
- **Smart grids and digitalization:** Deploying advanced metering, supervisory control and data acquisition (SCADA) systems, and real-time monitoring improves situational awareness and operational coordination across borders.
- **Demand-side management and response:** Enabling consumers to shift or reduce consumption in response to price signals or grid needs enhances system efficiency and reduces stress on transmission lines.

Enabling Policies for Renewable Integration and Cross-Border Trade

Finally, national frameworks must include coherent policies and regulatory measures that align renewable energy expansion with interconnection opportunities. Priority areas include renewable energy targets linked with grid planning with integrating national renewable commitments into transmission development plans to ensure that cross-border infrastructure is built to unlock resource potential. IEA World Energy Investment 2025 Report shows that about 2.2 trillion USD is expected to be invested into renewables, storage, grids and electrification, compared to 1.1 trillion USD into fossil fuels. But the future growth depends on regulatory frameworks that enable efficient interconnection, permitting, and cross-border coordination⁶⁷. That is why policies that reduce investment risk, including guarantees and cost-sharing mechanisms are critical for attracting private sector participation. In this regard regulatory harmonization is essential to establishing common grid codes, technical standards, and market rules facilitate synchronization and minimizes barriers to trade. Where bilateral or regional agreements on power exchanges, congestion management, and cost recovery create institutional environment for sustainable trade.

Strengthening and regional cooperation frameworks

The experience in several regions has shown that regional cooperation is indispensable to advance power system integration and maximize the benefits of renewable energy deployment. While national efforts remain essential, they are not sufficient to address the technical, regulatory, and financial challenges that accompany cross-border electricity trade. When countries commit to shared institutions and common rules, the benefits extend well beyond energy security to include greater resilience, cost reductions, and increased capacity to integrate renewable resources effectively.

Harmonizing regulations and grid codes

One of the priorities is harmonizing regulations and grid codes. Divergent standards on voltage, frequency, protection schemes, licensing, and tariff structures continue to limit the scale of cross-border transactions. Establishing regional platforms for regulatory convergence can reduce uncertainty, enable interoperability, and lower transaction costs. ECLAC has consistently highlighted the importance of strengthening regional regulatory bodies, providing them with adequate mandates and resources to coordinate planning, enforcement, and dispute resolution mechanisms.

Data sharing

Another essential area is data sharing and transparency. Integrated operation of interconnected grids requires real-time information on demand, generation, reserves, and transmission capacity. However, data availability remains uneven across the region. Establishing regional observatories and digital platforms for data exchange would facilitate coordinated dispatch, improve system

⁶⁷ <https://www.iea.org/reports/world-energy-investment-2025>

reliability, and enable more accurate planning for renewable integration. Such efforts must also be underpinned by clear governance arrangements to ensure confidentiality, data integrity, and equal access among participating countries.

Market design

Advancing towards more integrated market design is key to unlocking the full benefits of power trade. While bilateral exchanges remain the most common practice, they provide limited efficiency gains compared to structured regional markets with transparent rules, open access, and non-discriminatory participation. Lessons from the MER in Central America and emerging experiences in other regions show that structured markets enable more efficient allocation of resources, reduce reserve margins, and create price signals that support renewable energy investment. Strengthening the mandate of regional operators and regulators is therefore critical to transition from opportunistic trade to a rules-based regional electricity market.

Conclusion and way forward

Cross-border energy connectivity has proven its value in unlocking renewable resources, lowering system costs through economy of scale, and strengthening resilience by sharing reserves and balancing variability across borders. The experience from Europe, Africa, Latin America, Central Asia and the Arab region points to a common lesson: when physical interconnections are paired with adequate regulations, transparent data, and capable institutions, countries move from isolated, higher-cost systems to reliable, decarbonizing power markets. The remaining obstacles including transmission bottlenecks, fragmented regulations, uneven project preparation, and inconsistent social and environmental practices slow down the development, but can be manageable.

The way forward should include coordinated actions at national and regional levels. Nationally, governments should align renewable targets with transmission and interconnection plans, ensure grid flexibility through storage, demand response and digital control, and streamline permitting and land acquisition with stakeholder engagement. Regionally, regulators and system operators should prioritize harmonization of rules while institutionalizing data sharing for forecasts, cross-border capacity and reserves.

International organizations, especially the UN Regional Commissions (ESCAP, UNECE, ECLAC, ESCWA, ECA) play pivotal role in this process. Their neutral convening power, policy toolkits and peer-to-peer learning platforms help translate political commitment into bankable projects. In partnership with development banks and technical agencies, they can help to coordinate national and regional plans for development of connectivity projects.

With focused national preparation, pragmatic regional harmonization, high-quality project structuring, and sustained multilateral support, countries can move from fragmented initiatives to a scalable pipeline of interconnections that deliver measurable gains in providing secure, affordable, low-carbon energy supply.



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