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Transnational Grid Connections for Ensuring Energy Security

A Concept Paper

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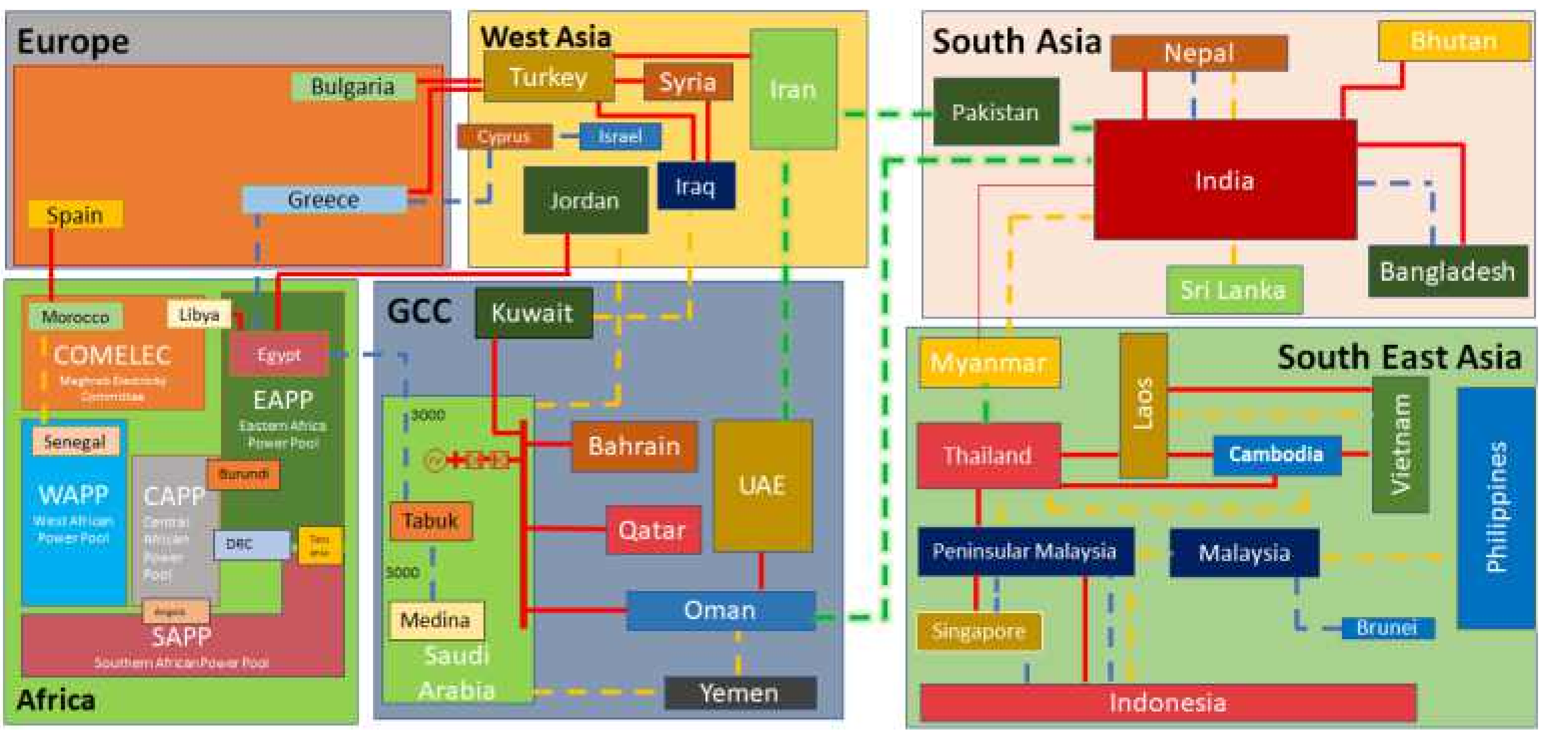

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Executive Summary

With greater emphasis on the energy transition, the interconnection of electricity grids of countries would play a pivotal role in advancing sustainable development and fostering prosperity. Many countries and regions are enhancing the integration of their power grids and engaging in bilateral as well as market-based electricity trade. The paper aims to identify coordinated actions and steps in furthering this agenda. Integration of power grids requires planning, financing, enabling regulatory provisions, harmonising grid codes etc.

The G20 leaders should emphasize the importance of cross-border power grid integration as a core pillar to advancing sustainable, affordable, and resilient energy transition at country, regional, and global levels. Cross-border power grid interconnection and power transfer would enable the integration of greater shares of Renewable Energy, while benefiting all participating countries with enhanced economic efficiency, security, clean energy transition and resilience of their power systems.

The G20 should encourage international cooperation on power grid interconnection by demonstrating to the world that it is a prioritized element of the energy transition. Promoting knowledge sharing, joint research and development and technical assistance in respect of grid interconnections are among the actions where G20 can take the lead.

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1. Introduction

Globally, energy transition and energy security, driven by renewable capacity addition are the thrust areas towards sustainability. Considering that the Sun never sets and every hour, half the planet is bathed in sunshine, harnessing energy from sun, wind and water would facilitate generation of clean energy, enough to meet the needs of everyone on the earth. However, this requires transnational exchange of electricity through grid interconnections. These efforts need to be synergized and supplemented by establishing an inter-connected global electricity grid through transnational interconnections. This is the vision for development of transnational grid connections towards ensuring energy security for a sustainable future.

Recent years have seen positive development indicating global energy transition from fossil fuel to clean fuel and investments towards renewable capacity addition have increased to new levels. The global share of renewable generation capacity by the end of 2021 is about 3064 GW. To achieve the goals set by Paris Agreement, investment in clean energy would have to be more than tripled by 2030. Further, the electricity generated from clean energy sources would have to be transmitted from the regions rich in RE to the regions deficit in RE sources through cross-border interconnections.

With **'One Earth One Family One Future'** as the theme of the current G20 presidency 2023, the concept of transnational grid connections is gaining more traction towards ensuring energy security as well as alleviating the climate crisis.

2. Drivers of Cross-Border Power Integration

Electricity infrastructure integrated across borders can foster regional cooperation and integration between neighbouring countries, leading to overall economic development. Electricity interconnections and electricity trading can create opportunities for diplomatic and economic engagement between countries, providing a platform for dialogue and cooperation on other issues of mutual interest and serve as a confidence-building measure between countries, helping to improve relations and build trust.

The economic value of power grid integration across jurisdictional borders is derived from lower overall development costs to meet electricity demand resulting from increased economies of scale and lower overall operating costs due to enhanced system efficiency, leading to more affordable electricity for consumers. The aggregation of multiple power systems with diversity in supply and demand, allows for meeting the peak electricity demand with fewer resources and lowering the total reserve requirements, thereby reducing investments and maintenance expenses in costly generating units. It also enhances the financial viability of large-scale renewable energy generation projects that may not be feasible if relying solely on the electricity demand of one country, such as large scale hydroelectric projects, wind farms and solar parks.

Global experience shows that the fundamentals driving the cross-border power grid integration have typically been the pursuit of economic efficiencies and the desire to exploit opportunities for electricity trade, either by accessing less expensive resources elsewhere for importing countries, or by earning opportunistic revenues by selling surpluses of electricity for exporting countries. Furthermore, the grid interconnections can offer energy security benefits, providing access to a more diverse and therefore more resilient mix of resources from the supply side, while also allowing a larger and more responsive load from the demand side. In recent times, when the global community is accelerating efforts to achieve the goals of the Paris Climate Agreement, responses to climate change have emerged as an increasingly important driver.

Renewable resources such as hydro, solar and wind, vary in abundance from country to country. Various renewable energy sources can be shared across different locations by integrating power grids through transnational interconnections. If there is excess solar or wind energy in one region/country, that energy can be transmitted to another region/country that may have a shortage of renewable energy, resulting in an increased overall share of renewable energy in the regional power supply mix. Even the requirement for storage facilities would reduce with the integration of electricity grids. Time Diversity in solar availability is another important factor that helps in better utilisation of Solar Energy across countries. For example, considering time diversity in solar availability (Figure 1), the requirement of transnational grid interconnection right from South East Asia (SEA) region upto Africa/European Union via South Asia (SA) and Middle East (GCC) may be explored.

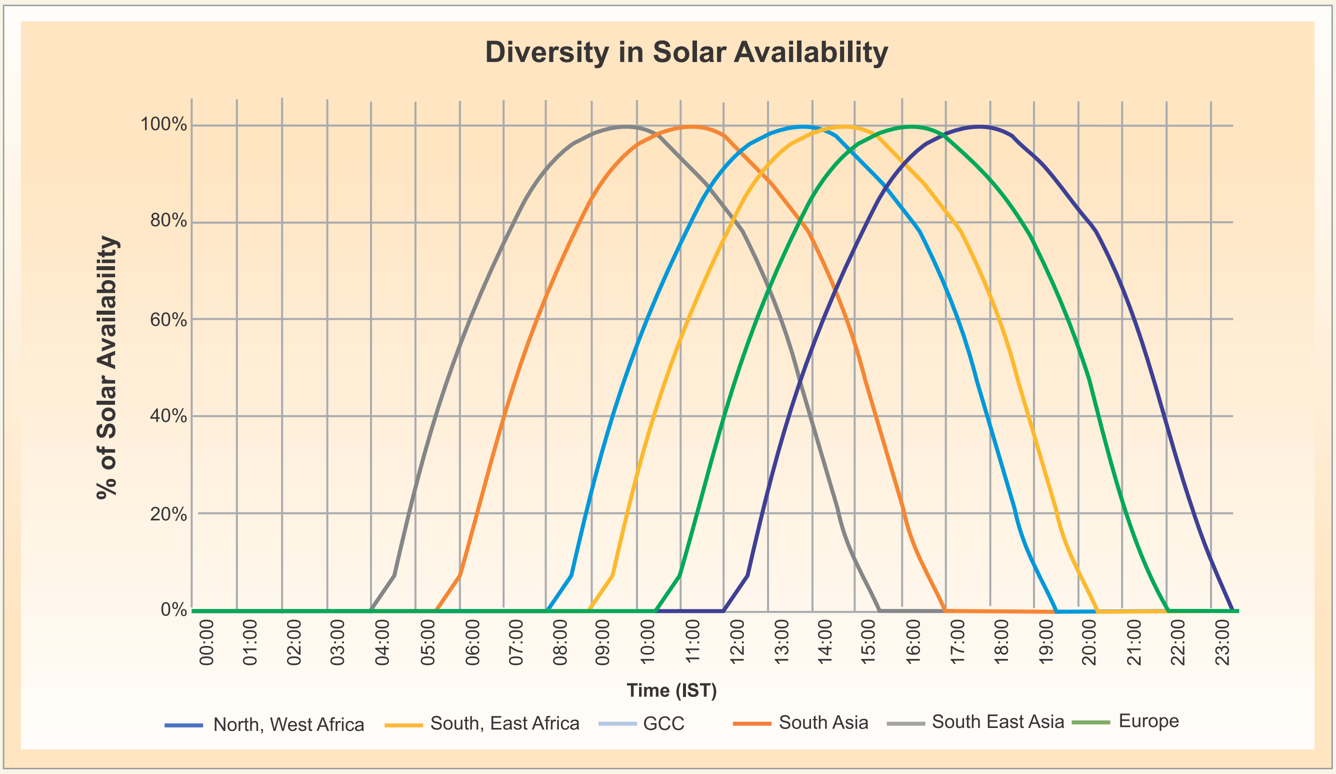

Figure 1: Diversity in solar availability

3. Benefits of Transnational Interconnections

There are several benefits of grid interconnections as given below:

i. **Facilitates Large Scale Renewable Energy (RE) Generation and Clean Energy development**

- Creates diversity of generation mix and supply, thereby ensuring energy security
- Reduction in Carbon emission, leading towards achieving clean energy targets

ii. **Optimal Utilization of Energy Resources**

- Unevenly Distributed Coal reserves, Hydro and RE Potential can be optimally utilized

iii. **Economy in Operation**

- Harnessing the time diversity in meeting the peak electricity demand
- Enlargement of balancing areas to facilitate balancing of electricity demand and supply
- Allows Sharing / pooling of reserves, thereby flexibility in optimizing the resources and deferring investment in generating capacity and energy storage

iv. **Economies of Scale**

- Setting up large sized power plants in high RE resource zone
- Economies of scale in high capacity transmission infrastructure development addressing Right of Way Issues

v. **Improvement in Grid Stability**

- Stable Frequency and Voltage Profile
- Improves flexibility, reliability and stable operation of the power system
- Provides emergency support

vi. **Regional Power Market Development**

- Normalization of electricity prices
- Access to cheaper energy

4. Cross - Border Interconnections

4.1 Major existing cross-border interconnections are given below:

- **South Asia (SA)**

  In South Asia, India shares transnational interconnections with its neighbouring countries viz. Nepal, Bhutan, Bangladesh and Myanmar through asynchronous (HVDC) as well as synchronous (AC) connections. At present, cumulative transnational transmission capacity amongst South Asian countries is about 4,100 MW. Few additional transnational transmission lines of about 4,100 MW are under construction in the region.

- **South East Asia (SEA)**

  At present, nine (9) South East Asian countries are interconnected through a combination of HVDC & AC transnational interconnections. The total transnational transmission capacity amongst SEA countries is about 8,000 MW. Further, multi-lateral interconnection link between Lao PDR-Thailand-Malaysia-Singapore (LTMS-PIP) for the transfer of 100 MW renewable hydropower from Loa PDR to Singapore via Thailand and Malaysia has commenced recently. Interconnection between Singapore and Australia through ±500 kV, 2400 MW HVDC undersea cable (3,200 km) system for the transfer of solar energy from Australia is under consideration.

- **Middle East (GCC)**

  Six (6) Gulf countries are interconnected through a combination of HVDC and AC network for reliability and sharing of reserve. The present transnational transmission capacity is about 1800 MW. Further GCC would be connected with Africa (Egypt) through ±500 kV, 3000 MW HVDC link between Medina (Saudi Arab) and Badr (Egypt), which is under construction.

Schematic of major existing transnational interconnections is shown in Figure 2.

Figure 2 : Existing transnational Interconnections in SA, SEA and GCC regions

- **Africa**

  The Northern region of Africa is connected with European power system through 400 kV, 1400 MW Morocco-Spain link. Morocco has 400 kV transnational links with Algeria and Algeria is further connected with Tunisia at 400 kV level. There is an interconnection between Tunisia and Libya which in-turn is connected to Egypt at 220 kV level. Egypt is also connected with Jordan at 400 kV level. It can be seen that there exists interconnection of Africa with both Europe and Middle East region.

- **Europe**

  The synchronous grid of Continental Europe covers territory of the ENTSO-E Continental Europe regional group and some neighboring countries not involved in the ENTSO-E. The grids of Morocco, Algeria and Tunisia are synchronised with the European grid through the Gibraltar AC link. The grid of Turkey is also synchronized with the European grid.

4.2 Planned/under construction transmission interconnection projects are given below:

A few transmission interconnection projects which have been planned/under construction to enhance power transfer between Europe and Middle East power grid are given below:

A. Europe and Middle East

i. 2000 MW, ±500 kV HVDC overhead line in Tunisia from the power plant to shoring point, submarine cables from Tunisian Northern coast to Montalto di Castro (Italy)

ii. 600 MW, HVDC ELMED (Elmed Mediterranean) interconnector through submarine cable between Italy (Sicily) and Tunisia

iii. 2000 MW, ±500 kV HVDC Bipole Tobruk (North East, Libya) - Linoperamata (Crete Island, Greece)

B. Africa and Middle East

i. 1000 MW, 500 kV HVAC Tobruk (North East Libya) - Sallum (North West Egypt) transmission line

C. Euro Asia Interconnector

i. 2000 MW, ±500 kV HVDC Hadera Site (Israel) –- Kofinou Site (Cyprus) Submarine cable

ii. 2000 MW, ±500 kV HVDC Kofinou Site (Cyprus) - Korakia (Crete, Greece) Submarine cable

D. Euro Africa Interconnector

i. 2000 MW, ±500 kV HVDC Damietta (Egypt) - Kofinou Site (Cyprus) Submarine cable

5 Key Learnings from Existing Transnational Interconnections

The rationale behind establishment of existing regional interconnections, their business model, governance structure etc. are summarized as under:

- **Purpose:** The transnational interconnections have been mainly established for power import/export to meet growing demand as well as for reliability and sharing of reserves etc in the regions.

- **Planning:** Most of the transnational interconnections have been planned by government agencies for the import or export of power through asynchronous (HVDC) or synchronous (AC) interconnections or through radial interconnections.

- **Investment:** Investment has been generally done either by the transmission utilities (own or through a Joint venture) of the respective country or government grants considering regional strategic importance. Many links were planned as a part of generation evacuation system in the exporting country and developed jointly by the respective transmission utilities of the countries.

  Several transnational transmission projects have also been funded by consortiums of utilities and multi-lateral funding agencies (ADB, The World Bank, African Development Bank, African Development Fund, Japan International Cooperation Agency, KFW, French Development Agency etc.). Few of the projects in Europe have been funded entirely by private investors with loans from commercial banks, however, ownership of such transmission assets generally remains with the Transmission System Operators (TSOs).

- **Recovery of investment:** Investment recovery is predominantly through payment of transmission charges. In Europe, there are few examples of merchant transmission projects where investment recovery is through congestion rent and auction of transmission capacity. There are few hybrid projects too where the regulators have defined the upper and lower threshold of revenues from the market. Recovery of investment is either through monthly transmission charges shared by the users or subsumed in generation tariff to be paid by the procurer in the importing country.

  In case of Gulf Cooperation Council Interconnection Authority (GCCIA), the transnational interconnections were established mainly for sharing of reserves for the security/reliability of the power system. Recovery of investment in interconnection capacity is through usage-based transmission charges determined by GCCIA.

- **Power transfer mechanism:** Cross-border power exchanges in South Asia, South East Asia, South African Power Pool (SAPP), Middle East (GCC) regions are mainly through bilateral long-term agreements. In South Asia and SAPP, there is limited energy exchange through short-term open access also. In Europe, the power markets have attained maturity and a significant quantum of power transfer takes place through power markets.

6 Opportunity for Power Transfer and Optimal Utilization of Balancing Reserves

With Transnational grid interconnection, the electricity demand of various interconnected regions can be met with less installed generating capacity as compared to the case with no interconnection. The requirement for reserves would also reduce. For example, demand diversity among SEA-SA-GCC & Africa/Europe is in the range of 1.05 to 1.10 during different seasons. There is a peak time diversity of about 6.0 hrs. among four regions i.e., about 1.5 hrs between SEA & SA and 2.5 hrs between SA & GCC and 4.5 hrs between SA and Africa. Hence, if the electricity grids of these regions are interconnected with suitable transfer capacities, peak electricity demand could be met with a less installed capacity in the region as compared to the case with no interconnection among the regions.

Transnational grid interconnection among the various regions would enlarge the balancing area and facilitate in large-scale RE integration as well as optimal utilization of balancing reserves, deferment of energy storage capacity etc.

7 Framework for Transnational Interconnections

The key drivers and enabling factors behind the transmission interconnection of regional power grids to facilitate the smooth transfer of renewable energy are political support, regional coordination mechanisms, institutional framework, commercial agreements, legal and regulatory mechanism and availability of market platforms. Considering the key learnings for existing transnational interconnections in various regions, proposed framework to facilitate establishment of regional grid interconnections is as under:

i. Inter-Governmental Cooperation

- Government-to-Government dialogue on a common vision for transnational grid interconnections to facilitate power transfer and transition towards low carbon economy and energy security
- Signing of MoUs for strategic collaboration among regions/countries
- Creating an Institutional framework for cooperation, monitoring of transnational link development etc.

ii. Technical Studies for Transnational Grids Interconnection

- Regional level coordination in planning and operation:
  - Development of planning documents, Operational Procedures and guidelines
  - Working out minimum requirements for regional grid interconnections considering existing transnational interconnections and domestic power grids
- Identification of new transnational grid interconnections:
  - Points of interconnection
  - Quantum of power transfer and its direction
- Type of interconnection Technology:
  - HVAC (radial/interconnected)
  - HVDC (Monopole/Bi-pole/Back-to-back)
  - Overhead line/underground cable/under-sea cable
- Capacity and Time frame of commissioning the links
- Identification of Communication system for real time data/voice transfer to control centres
- Techno-economic feasibility studies
- Common Technical specification and standards for regional interconnections

iii. Business model

- Identification of mode of transaction: Bilateral/ Trilateral/ Multilateral, market mechanism
- Owning and operation as well as maintenance of the link: Utility consortium / Territorial utility / Private player
- Business model for construction of links:

  Option 1: Own, Operate and Maintain by utilities of respective countries within their jurisdiction and recovery through transmission charges

  Option 2: JV by transmission utility of both the countries and recovery through transmission charges

  Option 3: DBFO (Design-Build-Finance-Operate) model i.e., Investment by one particular agency in any of the country and recovery through cost of delivered power including transmission charges

- Power Purchase Agreement / Transmission Service Agreements, as applicable
- Network Access

iv. Operational Coordination

- Real-time monitoring of grid parameters for secure grid operation
- Energy metering, accounting, scheduling, deviation settlement mechanism
- Transfer Capability Assessment
- Protection Co-ordination
- Identification of Settlement Nodal Agencies for Energy accounting
- Outage coordination
- Settlement of charges – Transmission, imbalance, Ancillary, Congestion, etc.
- Emergency Response Mechanism
- Reserve and Ancillary Services Sharing mechanism

v. **Regulatory and Legal mechanism**

- Grant of Transmission License
- Harmonizing Regulatory norms, grid code and standards for efficient operation of transnational links
- Dispute Settlement Mechanism
- Development of Power Market

vi. **Capacity Building**

- Research and development programs, knowledge sharing, seminar and workshops as well as field visits for sharing of experiences of grid interconnection, advanced technologies, best practices etc with special emphasis on sustainability and addressing the climate crisis

8 Challenges of Power Grid Integration

Despite the benefits of integration, some challenges need to be overcome to successfully integrate power grids across the borders. There is a possibility that certain countries may receive greater benefits than others, even if the overall net impact for the region is positive, making it difficult to agree on cost allocation and other key decisions to develop the requisite infrastructure. This challenge can be particularly acute in regions with limited transmission infrastructure or where there are significant differences in the levels of grid development among participating countries. There are two fundamental obstacles among others to the successful development of integrated power systems: (a) political commitment; and (b) financing.

Political commitment and coordination are the basics of foundation for successful power grid integration. Cross-border grid interconnections involve coordination and cooperation among different governments and regulatory bodies. Cooperation among countries requires strong political will and commitment to shared objectives, which can be challenging due to differences in political priorities and regulatory approaches. Political and regulatory challenges may lead to delays and uncertainty, which can affect investment decisions and hinder the development of cross-border interconnections. To effectively integrate power grids across borders, it is crucial to have political backing and robust institutions.

Power grid integration requires the development of new or strengthening existing infrastructure, such as interconnectors, transmission lines, and generation plants, which can be expensive and take a long time to build, along with appropriate institutional, operational, and commercial arrangements. However, financing cross-border transmission projects can be more challenging than financing generation projects due to long lead times associated with two or more countries involved to agree on financing modalities, ownership and operational model, addressing revenue risks, and technical/regulatory complexities. Interconnection projects might require significant upfront investments, despite the obvious economic benefits in the long run, which can deter potential investors.

9 Way Forward and G20's Role

Harnessing of clean energy resources is the need of the hour for the welfare of the global community. The availability of Renewable Energy (RE) sources along with transnational interconnections would help in reducing emissions and meeting growing electricity demand with energy security in a sustainable manner.

Addressing the challenges in grid interconnections requires a greater level of partnerships, cooperation, and coordination among governments as well as with the private sector. The G20, as a leading forum of the world's major economies, can play a crucial role in shaping the global transition to sustainable energy, while recognizing the potential of cross-border power integration in enhancing energy security, fostering economic growth, and facilitating the global transition to a low-carbon and clean energy future. It could promote the recognition of the potential that power grid integration has in achieving the global shared energy goals and commit to addressing the key challenges at the global level.

The G20 leaders may encourage international cooperation on power grid interconnection by demonstrating to the world that it is a prioritized element of the energy transition. G20 should emphasize the need for coordinated planning in transnational grid interconnections by enhancing international cooperation in information sharing, joint research and development, technical assistance and harmonization of the regulatory framework of planning and system operation. These activities will be a base for fostering political commitment and coordination among countries that are involved in intra-and/or inter-regional integration. In this context, the G20 may help develop initiatives and institutions that support intra and inter-regional grid connectivity. It is also worth considering taking advantage of the existing worldwide scale initiatives, like Green Grids Initiative — One Sun, One World, One Grid (GGI-OSOWOG) for accelerating global cooperation on cross-border power integration.

The G20 could support scaled-up investment in cross-border interconnection infrastructure by calling for increased concessional financing, including through climate funds and multilateral development financing institutions, and encouraging innovative financing mechanisms, such as green bonds and public-private partnerships. This will help overcome infrastructure challenges.

Together, the G20 leaders could pledge to work collaboratively to address the challenges in the development of integrated power systems in order to improve energy security, economic growth, and sustainable energy transitions.

10 References

- World bank, [Online]
- Net Zero by 2050: A Roadmap for the Global Energy Sector, IEA
- PWC, "Africa Energy Review 2021," PWC, November 2021.
- ENTSOE, "Statistical Factsheet 2018," ENTSOE, 2019.
- ENTSOE, "ENTSOE Powerfacts 2019," 2019.
- European Commission, "Electricity interconnections with neighbouring countries- Second report of the Commission Expert Group on electricity interconnection targets".
- https://www.pv-magazine.com/, "The weekend read: Super-grid forming in the Mediterranean".
- https://en.wikipedia.org/, "Euro-Africa Interconnector".
- Nepal Electricity Authority, "Annual Report 2020-21".
- Ministry of Finance, Nepal, "Economic Survey 2020-21".
- Bangladesh Power Development Board, "Annual Report 2020-21".
- PWC, "Africa Energy Review 2021," PWC.
- https://tyndp.entsoe.eu/tyndp2018/projects/projects/283 "EU_TYNDP 2018_Project 283"
- https://www.greenpower2020.net/project-description/ "LEG1"
- Annual Report of MoP, Annual Report of CEA (online)

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