Role of regional interconnection in fostering RE Integration in Eastern Africa Power Pool

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Abstract

The Eastern Africa Power Pool (EAPP) was established in 2005 in order to exploit the benefits of regional cooperation regarding the development of power systems of Eastern African countries. Strengthening the grids, extending cross-border interconnections and increasing electricity trade flows between neighbouring countries could have significant positive effects on the overall welfare of power systems but so far the results still lag behind ambition in the EAPP region. This paper shows possible pathways for the EAPP electricity system until 2030 and illustrates the benefits of regional integration of EAPP members’ power systems in the light of economic efficiency, system welfare and new ambitions about the development of RES to reduce the carbon footprint of power systems. The fostering of regional interconnections will allow to maximize national potentials of RES and to integrate larger RES capacity into the systems, while ensuring its robustness and an efficient management of intermittency.
Introduction

Established in 2005, the Eastern Africa Power Pool (EAPP) is the specialised electric power institution of the Common Market for Eastern and Southern Africa (COMESA). The two institutions work to foster regional economic integration of African countries, also through the integration of national power systems. Twelve countries are actually members of the EAPP: Burundi, DRC, Egypt, Ethiopia, Kenya, Libya, Rwanda, Sudan, Tanzania, Uganda, Djibouti and South-Sudan.

EAPP’s mission is to create a “unified regional electricity market [...] to secure power and optimize the usage of energy resources in the region”.

Its main objectives could be resumed as follow:
- To promote regional planning of investments in generation, transmission and distribution assets within the region;
- To increase interconnections and power exchanges between member countries;
- To create a supportive environment for financing of power energy investments in the region.

The EAPP energy landscape

Despite the fact that EAPP governance framework is in place since 2005, electricity systems in Eastern Africa remain largely underdeveloped. Most of the EAPP members face the challenge of relatively low electrification rates, i.e. according to IEA around 80% of East African population lives with no access to electricity. Electrification rates at national level are rarely above 40% and there is a significant discrepancy between urban and rural areas (see Table 1).

In 5 out of 10 EAPP countries, only 10% or less of the rural population has the privilege of access to power. This circumstance is typically compensated by a strong use of solid biomass for cooking and heating: in 2015, biomass contributed with 110 Mtoe to total final consumption in the EAPP region representing a 59% share, while electricity only contributed with 17 Mtoe, covering 9% of total final consumption. In rural areas, biomass use is even higher, especially woody biomass. As population levels rise, the region’s biomass consumption could double every 20-25 years, according to REN 21.

Fig. 1 – The EAPP area
<table>
<thead>
<tr>
<th>Country</th>
<th>Population without electricity (M of people)</th>
<th>National electrification rate</th>
<th>Urban electrification rate</th>
<th>Rural electrification rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burundi</td>
<td>10</td>
<td>5%</td>
<td>28%</td>
<td>2%</td>
</tr>
<tr>
<td>DRC</td>
<td>62</td>
<td>18%</td>
<td>42%</td>
<td>0%</td>
</tr>
<tr>
<td>Egypt</td>
<td>1</td>
<td>99%</td>
<td>100%</td>
<td>99%</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>73</td>
<td>25%</td>
<td>85%</td>
<td>10%</td>
</tr>
<tr>
<td>Kenya</td>
<td>36</td>
<td>20%</td>
<td>60%</td>
<td>7%</td>
</tr>
<tr>
<td>Libya</td>
<td>0</td>
<td>100%</td>
<td>100%</td>
<td>99%</td>
</tr>
<tr>
<td>Rwanda</td>
<td>8</td>
<td>27%</td>
<td>72%</td>
<td>9%</td>
</tr>
<tr>
<td>Sudan</td>
<td>24</td>
<td>40%</td>
<td>67%</td>
<td>26%</td>
</tr>
<tr>
<td>Tanzania</td>
<td>36</td>
<td>30%</td>
<td>57%</td>
<td>18%</td>
</tr>
<tr>
<td>Uganda</td>
<td>31</td>
<td>19%</td>
<td>52%</td>
<td>12%</td>
</tr>
</tbody>
</table>

**Tab. 1 – Electricity access in EAPP countries in 2014 (Source: IEA, World Energy Outlook, 2016)**

Power generation is inadequate to satisfy the current power demand in the region. As a result, shortages and load shedding are frequent and affect the economic activity and the global social welfare of the EAPP countries. The power demand of the EAPP region has increased on average by 7.5% per year between 2000 and 2016. For forthcoming years, there is an expectation of a strongly growing electricity demand, driven by the widespread of electricity access, urbanization, population growth and GDP increase. Satisfying such a massive demand increase will require large investments in new generation capacities, including the deployment of renewables, and in the development of electricity grid infrastructures. The power generation mixes of EAPP members are not diversified, relying very often on one or two technologies for more than 90% of the installed capacity (see Figure 3). Nevertheless, EAPP members can rely on abundant local energy sources to expand electricity generation in a competitive way. While fossil energy sources are available only in few countries (i.e. oil and natural gas in Egypt and Sudan, coal in Tanzania), the renewable energy potential is particularly abundant within the all-region.

![Electricity demand in 2016](image)

**Fig. 2 – The EAPP members’ power demands, 2016 (Sources: see Methodological note)**
Fig. 3 – The EAPP members’ installed capacity in 2016, MW total and by fuels (%)  (Source: see Methodological note)

The hydropower potential is around 45 GW in Ethiopia as well as in DRC and up to 3 GW in Uganda. Kenyan geothermal potential is estimated between 8-12 GW and all the Rift Valley, which includes also Ethiopia and Tanzania, is rich in geothermal resources. Biomass potential is also very strong, from peat to agriculture residues and waste, and widespread in all the countries and it represents a valuable solution for power generation. Finally, all EAPP members present perfect conditions for the development of wind energy and solar energy, notably PV. Solar Europe estimates a solar potential of 1.1 TW in the EAPP region. Egypt, DRC, Tanzania, Ethiopia and Sudan also feature a significant wind power generation potential.

While hydropower, geothermal and biomass power plants are common in the region, and might be considered as mature technologies, grid-connected wind and solar power are still not very common. Maximisation of intermittent renewable energy resources will require proper integration strategies, as the implementation of innovative technologies and market reforms as well as the
enhancement of power networks and interconnections. Increasing power systems integration and trade, through the creation of a regional power market, can enhance energy security, bring economies of scale in investment, facilitate financing, enable greater renewable energy penetration and allow synergistic sharing of complementary resources.

The observation of EAPP countries’ power sectors shows that National Governments have preferred stand-alone approaches in order to ensure the security of power systems until today. Despite the existence of the EAPP framework, only few countries are effectively interconnected and the existing interconnectors have very limited transmission capacity. As a result, market integration and power exchanges remain very low within all the EAPP region. Changing this approach will have significant positive impacts in the light of the future energy systems evolution.

Tab. 2 – Existing Interconnector and main committed new projects, MW (Source: EAPP Master Plan 2014)

<table>
<thead>
<tr>
<th>Region to/from</th>
<th>Region from/to</th>
<th>Existing</th>
<th>Committed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drc</td>
<td>Burundi</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Drc</td>
<td>Rwanda</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>Sudan</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Kenya</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>Tanzania</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Rwanda</td>
<td>Burundi</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Rwanda</td>
<td>Tanzania</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Sudan</td>
<td>Ethiopia</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>Burundi</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>Kenya</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>Rwanda</td>
<td>5</td>
<td>250</td>
</tr>
<tr>
<td>Uganda</td>
<td>Tanzania</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Regional system planning as solution for optimal integration of renewables in electricity systems

The vast potential of renewable energy in the EAPP countries represents a key opportunity for the future development of power systems within the region. However, proper integration strategies are required to make efficient use of these valuable renewable energy resources. Examples of such strategies are (1) the implementation of innovative technological solutions such as storage, demand response and micro-grids, (2) an appropriate market design (RES market integration, ancillary services), and (3) an upgrade of the physical infrastructure (grid enhancement, interconnections). The enhancement of cross-border interconnections is an efficient option for a more organic development of RES and it would allow the countries to maximise their potential and to reduce RES related risks, such as intermittency. Regional integration would then coexist with other solutions, contributing to create the “hybrid power system” necessary to efficiently address the power system development challenge in the region.

Grid development as technical solution for the efficient integration of RES into power systems

Bulk deployment of wind and solar PV requires redesigning the grid rules in order to accommodate and integrate the energy produced without constraints. The intermittency of wind and solar generation could endanger the stability of small electricity systems where online flexible generation is missing. Therefore, biomass and other technologies could be relevant in order to support the system, compensating the
intermittent nature of wind and solar PV and increasing the ability to dispatch energy.

Some of this renewable energy potential could first be exploited at local level in the form of micro grids. In fact, this is already happening in some EAPP countries thanks to government policies, rapidly declining global prices for solar PV and innovative business models. One example is the Powercorner initiative, launched in 2016 by the French multi-national energy company ENGIE in Tanzania. Their first project involved electrifying a rural village of 800 inhabitants by deploying a hybrid containerised mini-grid consisting of 16 kW of PV panels, 45 kWh of Lithium-ion batteries and a back-up genset. The technical solution includes a low-voltage AC distribution network and access to energy efficient appliances (TVs, fridges, freezers etc.). Clients pay a deposit upfront (connection fee) and ENGIE installs a smart meter for charging the consumption on a pre-paid basis. Payments are handled via mobile money, i.e. cell phones. By the end of 2017, eight Powercorner projects will be deployed in Tanzania alone, each ranging between 20 and 40 kW of PV capacity. By 2018, the initiative will be launched in two more EAPP countries.

Such initiatives help to kick-start the electrification process but they do not generally eliminate the need for larger electricity grids. This is because the most cost-effective RES potential is not always located near consumption centres, especially when it comes to wind and hydro, as can for instance also be observed in Ethiopia. In fact, the experience in Europe shows that investments in new RES capacity are accompanied by investments in new grid infrastructure that is used to connect power plants and for integrate markets. As required by the European Commission, the European Network of Transmission System Operators for Electricity (ENTSO-E) publish a Ten Years Network Development Plan (TYNDP), every two years, with a focus on the future scenarios (demand + generation) and providing a list of infrastructure needs. The TYNDP 2016 scenarios include a relevant growth of renewable electricity sources, supplying 45% to 60% of the total annual demand. As reported in the last plan, most transmission investment needs (€150 billion investments of pan-European significance) are linked to RES-integration developments, planned in order to connect RES to the grid or to relieve network congestion.

The TYNDP example demonstrates that grid development is necessary to enable RES deployment and could solve several further issues related to electricity supply and quality of the service. New grid reinforcements are planned in order to answer to different purposes, typically for mutual support in case of scarcity situations, thereby ensuring the reliability of electricity supply. Their role in improving social welfare has received growing attention due to several black out registered over the last 20 years. As illustrated in the TYNDP 2016 report, market integration also fostered by grid reinforcements reduces bulk power prices by 1.5 to 5 €/MWh (depending on fuel and CO2 cost assumptions per scenario).

To solve investment needs, TSOs have proposed tailor-made grid reinforcement solutions adapted to every specific situation. As a result, a large range of available technologies has been implemented. For 15% of the cases, the upgrade of existing overhead lines can prove sufficient to achieve the required capacity increase with a limited impact on the related areas. Increased grid transfer capability does not always match with increased network length thanks to
restructuring; and when the network length increases, it is by 40% underground or subsea.

This experience indicates that in order to fully exploit the benefits of RES in the EAPP region, a thorough grid planning at national and transnational level would be beneficial.

**Regulatory aspects for successful regional integration**

Electricity systems are radically changing, thanks to the new rising technologies from the production sector through to consumption. The cost reduction of solar and wind power facilities is shifting the trajectories of the forecast towards an even more distributed generation. The EU is leading the international communities in the aim to pursue diversification of the supply of services in the coming years by increasing user numbers with direct involvement of all parties. The new regulatory proposals (introduced by the 2014 Climate and Energy Policy Framework, by the 2016 “Clean Energy For All Europeans” policy package) will create business opportunities for innovative companies able to diversify and offer consumers even more services.

According to the EC proposals, in future energy markets should reward flexible generation, demand and storage at equal footprint. Additionally, market rules must be adapted in order to make renewable producers participate both in the energy and services markets (procured from primary, secondary, tertiary and balancing reserve). This will facilitate innovation and digitalisation and will make European businesses responsible for providing greater energy efficiency and low-emission technologies. The increasing complexity of networks implies a higher need of coordination among different grid users to better identify threats to secure system operations and to adjust measures to mitigate these risks. The European Commission is supporting initiatives organised by transmission system operators at regional level, with the scope of strengthening their cooperation in assisting their task of maintaining the operational security of the electricity system. The areas of collaboration cover several initiatives: sharing existing tools, methods, and procedures, operating services alternately or cooperatively and jointly optimising services and tools for TSOs as well as developing new ones.

To enable the full integration of new distributed users in the market, the 2016 “Clean Energy For All Europeans” legislative package indicates that countries and network operators must make an effort to develop robust transmission and distribution infrastructures and a well-interconnected European network. The Commissioners state that whilst Europe has the most secure electricity network in the world, significant investments will be required up to 2030 to strengthen transmission and distribution.

A strong coordination between TSO and DSO is necessary, with reference to the planning of grid development, in order to face local congestion on the medium and low voltage grids, as well as to face the need of voltage control. Thus, they should contribute to the formation of an integrated European energy market. They enable the energy transition and empower prosumers’ contribution by ensuring transparency, confidentiality and neutrality in data management, no matter which data governance is established. TSOs and DSOs should contribute to the social welfare maximisation with a fair cost and benefit allocation.
<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>PUBLIC SECTOR</th>
<th>PRIVATE INVESTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility</td>
<td>Assess revenues, operating costs and investments and compare different project implementation scenarios and schemes</td>
<td>Assess revenues, operating costs and investments and decide whether and how to implement the project</td>
</tr>
<tr>
<td>Financial viability</td>
<td>Assess financial performance of the project over its life and calculate whether and to what extent the project needs public support</td>
<td>Assess whether dividends paid over project’s life are in line with own hurdle rate of return for investment</td>
</tr>
<tr>
<td>Bankability</td>
<td>Assess if the projected cash flows are adequate to finance the projected debt services and calculate whether and to what extent the project needs public support in order to be bankable</td>
<td>Assess if the projected cash flows are adequate to cover the projected debt services and the project is bankable</td>
</tr>
</tbody>
</table>

Tab. 3 – Public and private investors financial approaches to infrastructure investments

**Financial aspects of cross-border interconnections projects**

The financial viability and bankability of the interconnection projects are based on different principles depending on the investor characteristics: public sector versus private investors (see Table 3).

Sometimes a project may appear economically feasible to a company but not be structured or scheduled optimally for bank financing. Indeed, banks are most interested in cash flow during loan repayment period not overall project economics and their main interest is to ensure that the project offers:

- sufficient collateral
- predictable and adequate future project cash-flows, i.e.:
  - enough revenue to pay off loans
  - enough financial benefits to attract private finance
- high probability of success within given market

In general, “bankability” reflects constraints/opportunities of both the project scope and the environment in which it is implemented. In this context the Free Cash Flow on Operation is the key indicator for lenders.

More specifically, to finance transmission infrastructures two models are available:

- **Project financing**, where financing is made by an independent company (either owned by the utilities or participated by third parties)
  - When adopting “project financing”, the main issue to be addressed is the relative cost of capital and the likelihood of raising funds for the project
  - This financing scheme would impact the cross-border energy transactions through a specific tariff for the use of the interconnector (entry-exit system).

- **Split investment**, where each company would finance its own part of the network.
  Under this scheme each company would include its own part of the investment in the network tariff. Key issues to be addressed are:
  - How to allocate the investment?
  - How to split congestion revenues?

In the Split Investment approach usually the recommended choice is to determine the revenue stream for each party with a cost-plus approach, known also as a “rate-of-return (RoR)” regulation.
RoR is used to determine a stream of revenues that allows recovering the investment. Each year the utility is allowed to recover part of its capital expenditures (CAPEX) and its operating expenditures (OPEX). Revenues are then defined as the sum of OPEX, charges, amortization and capital remuneration. Capital remuneration (gross of its yearly amortization) is obtained by multiplying the asset value by a defined interest rate.

Independently from the financing scheme, another key issue is the optimal definition of the Project Gearing (Debt/Equity Ratio). In general for the Project Gearing the remarks summarised in the Figure 4 apply.

![Figure 4 - Project gearing best practice for infrastructure investments](image)

**The benefit of an integrated EAPP**

To illustrate the potential benefits of enhancing regional integration between the EAPP members, we have developed a high-level quantitative analysis based on an electricity market model aimed at simulating the behaviour of the EAPP system in the year 2030 (more details in the Methodological note). Three scenarios have been developed in order to illustrate different possible paths for EAPP members to satisfy the future demand increase. The scenarios aim at showing the potential benefit of interconnections in the integration of intermittent renewable sources within the EAPP area:

- The “Grey scenario” illustrates a case in which future demand will be satisfied primarily through to investments in thermal generation capacity (with a 6% penetration of intermittent renewables over regional demand), and only already committed interconnectors will be built in the region;
- The “Green scenario” considers the same interconnection capacity of the Grey scenario, but envisages more investments in intermittent renewables (18% wind and solar in 2030); and
- The “Green Integration scenario” includes additional interconnection investments (plus 5.3 GW with respect to Grey and Green scenario).

Key characteristics of the scenarios are summarized in **Table 4** while details on generation mix are shown in **Figure 5**.

<table>
<thead>
<tr>
<th></th>
<th>Grey</th>
<th>Green</th>
<th>Green Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Demand in 2030</td>
<td>525 TWh</td>
<td>525 TWh</td>
<td>525 TWh</td>
</tr>
<tr>
<td>185 TWh (w/o Egypt)</td>
<td></td>
<td>185 TWh</td>
<td>185 TWh (w/o Egypt)</td>
</tr>
<tr>
<td>Intermittent RES penetration (% on demand)</td>
<td>~6%</td>
<td>~18%</td>
<td>~19%</td>
</tr>
<tr>
<td>Interconnection capacity</td>
<td>3.4 GW</td>
<td>3.4 GW</td>
<td>8.7 GW</td>
</tr>
</tbody>
</table>

**Table 4 – Key scenario characteristics**
Fig. 5 – Installed capacity and generation mixes in the three scenario

**Go green.** Our analysis shows that in green scenarios the levelized cost of energy is lower due to the long term cost advantage of wind and solar generation. In the Green scenario this allows for an advantage of about 0.3 B$/year, which reduces the cost of meeting the increasing demand by a range of around 4-5 B$ in the Green in the long term.

**Use interconnections.** The advantages of the going green are amplified by interconnections. In the Green Integration scenario, the presence of interconnection on one hand reduces the need for more expansive thermal generation (which is necessary in the Green scenario to ensure system security), and, on the other hand, allows to transfer across countries excess renewable generation fully exploiting their potentials (with a significant reduction of curtailments). The reduction in the levelized cost of energy rises to 0.8 B$/year, providing a potential cumulative long term saving (for consumers) ranging from 12 to 17 B$.
Despite overall energy costs decrease, upfront investment costs (2017-2030, see Figure 7) increase by 7 B$ because the development of additional intermittent renewable capacity only partially replaces thermal capacity which remains compulsory to ensure enough flexibility in the system. This negative impact can be alleviated substantially if an increased development of interconnection is pursued as this solution provides lower energy costs without additional investment costs. In fact, the additional investments for the interconnections are compensated by the possibility to reduce investments in thermal generation as the system is able to better exploit the complementarity of the generation mix of the different countries through import/export of energy and flexibility.

Successful examples of cross-border integration

As mentioned above, the geographical area covered by the EAPP is endowed with outstanding renewable energy sources. One of the most promising and largely still unspoiled form of renewable energy is represented by the hydro resources, namely associated to the Nile river. The hydropower potential of the Nile Basin is estimated to be 145,000 MW. This potential for hydropower would allow providing 65 percent of the region’s electricity demand. The remaining demand could be supplied exploiting the availability of a wide range of renewable energy resources including solar, wind and geothermal.

In this context, Ethiopia is already playing a key role to boost hydropower generation not only to supply the steadily growing internal demand, but also to trade reliable renewable power with the neighbouring systems, particularly Kenya and Sudan. Some successful stories are recalled here below.

Ethiopia-Kenya integration
Between Ethiopia and Kenya a 2,000 MW 500 kV HVDC link is currently in an advanced stage of construction and its commissioning is foreseen by 2019 (see Figure 9). The total value of the project is approximately $1,260 million, mainly financed by the World Bank, the African Development Bank and the French Development Agency. A long-term (25 years) power purchase agreement (PPA) of 400 MW with Kenya has already been signed with capacity factor of 85% corresponding to about 3,000 GWh/yr. In general, this interconnector will allow covering possible shortfalls of energy supply in Kenya, a power system which is largely based on RES generation. Indeed, despite a wide availability of local RES, the power system of Kenya may be at risk of inadequate power supply due to a combination of geothermal inflexibility, intermittency of wind and PV generation and occurrence of very dry years in the country. Hence, the HVDC link with Ethiopia will help solve these constraints.

About 30 MW of this NTC is in PPA for export toward Rwanda;
- 132 kV line Kenya-Tanzania with NTC equal to 220 MW in both directions.

- Planned interconnections:
  - 2x400 kV lines Tanzania-Kenya with NTC equal to 1,300 MW in both directions;
  - 2x400 kV lines Uganda-Kenya with NTC equal to 300 MW in both directions.

Thus, the Sodo (Ethiopia) - Suswa (Kenya) interconnector will represent an electric highway fostering the creation of a regional electricity market from Ethiopia southwards.

### Ethiopia-Sudan integration

A successful example of integrated generation-interconnection projects is represented by the interconnections between Ethiopia and Sudan.

In this case a stepwise approach has been undertaken consisting of the construction firstly of a small size interconnection (100 MW), and later on a large size interconnection (3,000 MW). The construction and operation of the first interconnection line allowed to address and solve the whole spectrum of problems, technical, environmental, economic and financial, though at a small scale. Further, it allowed appraising the real benefits arisen from the exploitation of this first interconnector. The main characteristics of this first Ethiopia-Sudan interconnector are depicted in Figure 10.

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**Fig. 9 – Routing and main characteristics of the Ethiopia-Kenya HVDC Interconnector**

In general, this interconnection can be used in the coming years to trade power further southward with Uganda and Tanzania through the following interconnecting lines:

- Existing:
  - 2x132 kV lines Kenya-Uganda with NTC equal to 145 MW in both directions.
Fig. 10 – Routing and main characteristics of the first Ethiopia-Sudan Interconnector

Since the commissioning of this interconnector in December 2013 a number of tangible benefits can be highlighted, namely:

- **Enhanced access to electricity.** Approximately a total of 1.4 million households in Ethiopia and Sudan have been able to have access to electricity at an affordable price.

- **Better integration of reserve capacity.** Ethiopia could export its surplus of hydro generation and Sudan could spare fossil fuels importing carbon free energy, hence reducing the GHG emissions of the country.

- **Improvements in reliability and security of supply in both countries.** The improvement of security of supply has consequently given benefits at social level particularly for the local small-medium enterprises.

- **Generation of economic benefits from energy trading.** Ethiopia has raised its capacity to generate revenue from exporting power, to about $ 8.8 million annually. In turn Sudan has gained from lower tariffs of $ 0.05/kWh for imported electricity as compared to $ 0.096/kWh from power generated domestically.

- **Complementarity between the predominantly hydropower in Ethiopia and the thermal based generation in Sudan.** Though the energy is mainly flowing from Ethiopia to Sudan, this latter ensures security of supply in Ethiopia in periods of low rainfalls.

- **Environmental benefits** associated to lower GHG emissions thanks to hydropower in Ethiopia.

In addition to the above benefits, this first cross-border infrastructure allowed to enhance collaboration between Ethiopian and Sudanese technical specialists in the respective governments and utilities.

Finally, the investment cost of this interconnection has been $ 55.8 million. The relatively small scale of this project allowed to solve quite easily the financing issues. The funding of the project has been almost equally shared between the two parties and the World Bank has been the main lender.

This “small case” project represented the basis for the development of a wider regional power market and related transmission infrastructures.

In the wake of the success of the first Ethiopia-Sudan interconnector, in 2015 the governments of the two countries decided to move forward to examining a much bigger interconnection (3,000 MW) boosting substantially the energy interchanges between the two countries. The feasibility study was awarded to CESI, who completed the activities in January 2017. The new interconnector is called “Blue Nile Energy Corridor” and its main characteristics are summarised in **Figure 11.** The drivers towards an enhanced integration between Sudan and Ethiopia are manifold, in summary:

**Ethiopia**

- Enormous hydro potential available
- Large power generation increase foreseen in the mid-term:
• 6 GW new installed hydro power in Grand Renaissance Dam

Sudan

• High demand growth foreseen in Sudan: mainly due to the improvement of electrification of several isolated areas (+13.7% average annual growth in 2020-2030)

The main objective is to increase the reliability of power supply in the two Countries by taking advantage of the hydro-thermal complementarity of the two systems, and the variability of the peak demand.

The “Blue Nile Energy Corridor” represents an outstanding example of combined generation and interconnection project, since the economic justification of the project is closely related to the construction of the Grand Renaissance Dam.

Main characteristics of the Blue Nile Energy Corridor

- Technology: AC - Overhead transmission line – double circuit with intermediate substation in Sudan – line series compensated
- Length: 590 km
- Size: 3,000 MW
- Voltage level: 500 kV
- Substations:
  - Grand Renaissance (Ethiopia)
  - New Jebel Aulia (Sudan)
- Intermediate substation:
  - New Rabak (Sudan)

Fig. 11 – Routing and main characteristics of the Blue Nile energy corridor

Though a number of issues have already been addressed and solved when building and operating the first Ethiopia-Sudan interconnector, the implementation of a much bigger project calls for the overcome of daunting challenges, particularly related to:

• Economic justifications of the project, the estimated investment cost of which is $450 million
• Environmental and social impact on the territory

• Solutions to finance the project.

As for the economic justifications of the project, an accurate simulation of the expected power and energy exchanges between the two countries and related benefits were assessed applying different market models, such as:

• Coordinated thermal generation only
• Integrated hydro-thermal generation (coordinate scenario)
• Market coordination based on bilateral agreements
• Regional coordination considering neighbouring countries (possibility of wheeling part of the Ethiopian hydropower to Egypt).

Considering that the lifetime of the new infrastructure is at least 40 years, the analyses had to cover a sufficiently wide time period. The economic analysis has been carried out considering a time period until 2055. As an example, Figure 12 shows the expected energy exchanges in both directions until the year 2035 in the so called coordinated scenario. It can be seen that, whereas in the first period of operation until 2030 the energy exchanges are predominantly towards Sudan, later on a bidirectional exchange is expected since Sudan would develop internally a mix of wind and PV generation combined with natural gas fired power plants. In parallel, the internal demand growth in Ethiopia would reduce the power surplus for export. By quantifying the benefits arising from a bilateral and regional market integration and monetising other benefit indicators associated to security of supply and integration of RES generation, a cost-benefit analysis has been carried out showing the full economic viability of this project.
As for the environmental and social impact, since the Blue Nile Energy Corridor is stretched over about 600 km, in parallel to the technical and economic analysis, it turned out to be of utmost importance to define in detail the routing by minimising the interference with other infrastructures and activities, particularly the agricultural areas. Further, direct contacts with the local authorities and municipalities have been undertaken so to find preliminary agreements since the beginning of the project design. This action turned out to be key to avoid delays in the permitting process.

Finally, as soon as the two parties have approved the project based on the positive technical and environmental outcomes and the appealing economic indicators, immediately a new process was started to find how to finance the project. Indeed, in many situations, especially in case of countries with poor affordability and low financial rating, transmission projects, though economically justified, were delayed or even cancelled due to the lack of a solid financial model, which is essential to get the required capital.

In the case of the Blue Nile Energy Corridor, the Split Investment has been selected and for the two parties the best financing model in terms of project leverage (debt/equity ratio) has been computed together with the two key financial indicators: Free Cash Flow on Operation and Free Cash Flow on Equity. Currently the two parties are in negotiation with potential lenders to start the project implementation once the share of equity capital and bank debt has been secured.

**Fig. 12 – Routing and main characteristics of the first Ethiopia-Sudan Interconnector**

**Best Practices from the rest of the world (Central America- SIEPAC)**

A successful example of the role of interconnection to create a regional electricity market is represented by the SIEPAC (Sistema de Interconexión Eléctrica de los Países de América Central - Central American Electrical Interconnection System). The idea of interconnecting the six countries of Central America (Panama, Costa Rica, Honduras, Nicaragua, El Salvador, and Guatemala) dates back to 1987. After a long process the SIEPAC interconnection is now in operation. It consists of a 1,788 km long corridor with a capacity of 300 MW. The transmission lines are at 230 kV double circuit (see Figure 13) connecting 16 substations, enabling the power exchanges with the domestic grids. The upfront investment costs attained approximately $506 million.

The SIEPAC represents an electricity highway overlapped to the national systems enabling bidirectional power exchanges between all interconnected countries. The basic idea for its construction was the possibility of exploiting the complementarity of already
existing and planned generation resources in the various countries with related price differentials. Hence, differently from many EAPP interconnection projects, the construction of the various SIEPAC building blocks was not associated to the construction of specific power plants. Indeed, each country retained its own autonomy in the generation expansion project, more or less as it happens in Europe.

Thus, two important lessons can be drawn from SIEPAC:
- Engagement of political authorities
- Adoption of gradualness in the integration process.

This two basic conditions have been the basis for the creation of regional markets also in other areas of the world, such as SAPP (the Southern African Power Pool) and, more recently, the ArcoNorte Project aiming at interconnecting Guyana, Suriname and French Guiana with the Brazilian States of Roraima and Amapá. The stepwise integration of Ethiopia and Sudan power systems and markets represents an example coherent with the process followed in Central America.

In particular, the development of the market mechanisms for cross-border energy transactions followed a smooth and gradual process. In the SIEPAC case the first energy exchanges were based on short term transactions arising from regional optimal dispatch. These short term exchanges (spot market) were later integrated by medium and long term contracts. In the case of EAPP, since several interconnection projects are associated to the construction of hydro power plants, the approach for starting the cross-border energy transaction shall be the other way round with respect to SIEPAC: in a first stage, exchanges based on long term contracts with PPA between sellers and purchasers shall be set and only in a later stage short term transactions can start creating progressively a spot market. This very same approach has been suggested also for the ArcoNorte Interconnection project.

After a first phase with limited energy exchanges, the optimisation of the power dispatch at regional level together with bilateral contracts allowed to boost the

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**Fig. 13 – SIEPAC transmission corridor (source EOR)**

On the contrary, SIEPAC shows similarities with EAPP being the physical infrastructure enabling the establishment of:
- the Regional Electricity Market (MER)
- the Regional Regulator (CRIE)
- the Regional Operator (EOR).

The approach of SIEPAC for the regional integration was based on a gradual growth of a competitive regional electricity market based on reciprocal and non-discriminatory treatment that contributes to the sustainable development of the region protecting the environment. So the basic principles are: Competition, Gradualness and Reciprocity. This integration process, the achievement of which took more than two decades, was relying on a "Treaty of Regional Electricity Market" signed by governments in 1996 and ratified by national parliaments in 1998.
energy transactions inside the MER, from around 250 GWh in 2013 to 1,781 GWh in 2016.

In conclusion, the development of the SIEPAC system contains all the ingredients for the power system and market integration in East Africa, namely:

Endorsement of the integration process at the highest political level sealed by the signature of a Treaty

- Set up of regional institutions to coordinate the development of cross-border infrastructures (association of System Operators), harmonise the regulatory framework (association of Regulators), set up of market rules and platforms for energy exchanges (regional Market Operator)
- Adoption of a gradual process in regional integration both for the deployment of "hardware" infrastructures (transmission and generation in case of East Africa) and "software" assets (rules for the regional power market, mutual transfer of know how/knowledge sharing)
- Securing the investments through opening to private and public agents.

**Conclusions**

The consistent electricity demand growth driven by industrial development and increasing electrification will profoundly change the power system across all EAPP.

In response to such huge changes EAPP members could choose to evolve along different paths which will define future sustainability, affordability and security of the entire system. Significant benefits could be attended by increasing investments in intermittent RES generation assets. In fact, the abundant solar and wind potentials would give the opportunity to EAPP members to reduce energy costs, diversify generation mix and reduce dependence on imported energy sources (fossil fuels).

In the framework of a more intense RES development increasing the interconnection capacity would allow to maximise its benefits, opening to:

- Better exploitation of complementarity between generation mixes and renewable potentials of all EAPP members
- Enhancement of energy cost reduction

Key to interconnection development and the maximization of its benefits is a TSO coordination and regional system planning, including common regulation/market design. Moreover, such coordination allows to better integrate all new technologies arising across the overall power system value chain (i.e distributed generation, storage demand response, etc), and that represent both and opportunity and a challenge for the power systems. A coordinated approach could also allow to better find suitable financial structure, improving bankability of interconnections projects and fostering their development.

Moreover, an increased RES penetration together with an optimization of the overall system significantly reduces the environmental impact of power systems, also creating a social consensus both locally and internationally.

This virtuous path could represent the key for an optimal development of EAPP power system. If different evolutions of EAPP fundamentals and political willingness are always possible, the benefits of integration will continue to stand out compared to stand-alone approaches.
Methodological note to EAPP system modelling

This analysis does not want to represent our view of the optimal solution for future developments of the EAPP power system but is rather an exercise to show the potential long term consequences of the development of the system along different paths.

Therefore results presented here are for illustrative purpose and should be considered as an indicative estimation of such potential consequences.

The simulation has been conducted at an hourly level taking into account the interaction of all the relevant technologies and seeking the optimal solution which maximize system welfare.

The model BID3 is an economic dispatch model based around optimisation. The model balances demand and supply on an hourly basis by minimising the variable cost of electricity generation. The result of this optimisation is an hourly dispatch schedule for power plants and interconnectors on the system. In this analysis we have considered three thermal and five renewable categories of power plants. The thermal plants are grouped based on the fuel type: gas, coal and oil derived products. The renewable sources are: reservoir hydro, run-of-river hydro, solar PV, onshore wind and geothermal/biomass.

The scenarios have been developed using public available data from national incumbents and/or international organizations to estimate the potential power demand of the EAPP zone to 2030 and other relevant inputs:

- UETCL, "Grid Development plan 2015-2030", Uganda
- EAPP, "EAPP regional power system Master Plan", 2014
- Republic of Sudan Ministry of Water Resources & Electricity, "Sudan Potentials, Opportunities and challenges in Energy field", Sudan, April 2016
- Federal Democratic Republic of Ethiopia Ministry of Water Irrigation and Electricity, "The Ethiopian power sector: a renewable future", Ethiopia, March 2017
- World Bank, “Commodity markets outlook”, April 2017

The scenarios have been developed ensuring that they reach similar level of system security levels even if, in terms of flexibility availability, while Green and Green Integration reach enough flexibility, the Grey scenario presents excessive levels.