INTEGRATION OF VARIABLE RENEWABLE ENERGY IN THE NATIONAL ELECTRIC SYSTEM OF ETHIOPIA

ABSTRACT

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The study frame has been crafted and developed in close coordination with the Ethiopian Electric Power (EEP), coordinated by RES4Africa in 2018 in partnership with Enel Foundation and with the technical support of CESI.

Acknowlegments

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Executive Summary

Ethiopia is endowed with outstanding and diversified renewable energy resources, namely hydro, wind, solar, geothermal, and biomass. For many decades, the development of the electricity sector was based on the exploitation of huge hydro resources that made the electric power system dependent on water and particularly exposed to the climate change. The non-hydro renewable sources can be efficiently exploited in the power sector to improve energy diversification and support both short- and long-term power system resilience, in order to cope with current and future water challenges related to climate change and to support the national strategy to become a world class exporter of large amounts of clean and cheap renewable energies. However, the deployment of RES generation, especially if variable as in the case of PV and wind, shall be accurately designed to ensure the compliance with reliability standards and security constraints. The following study is focused on the integration of variable renewables into the Ethiopian electrical grid considering the development scenario until 2030. It analysed the maximum VRES capacity, as a proper combination of wind and PV capacity, that can be installed in Ethiopian system considering both technical and economic constraints (i.e. balancing resources, reserve requirements, generation fleet flexibility, security of supply, grid loadability and economic competitiveness of VRES technologies in the regional power pool). In this framework, the network interconnections with neighbouring countries and the generation fleet flexibility have been studied because they play a role of utmost importance to maximize VRES integration in Ethiopia, following the load pattern and dealing with the intermittency of wind and PV generation when a high penetration level is achieved in a Country.

The analyses clearly highlight that additional capacity from VRES generation can be integrated, on top of the projects already in the Country's pipeline, thanks to the exploitation of the future interconnection capacity and the operational flexibility ensured by the hydroelectric power plants. In 2025, the Country can integrate an installed capacity up to 2,400 MW from wind and 3,350 MW from PV; these capacities can be increased in 2030 up to 3,600 MW from wind and 5,300 MW from PV. This outlook of VRES generation development will allow to achieve a well-balanced energy mix with 25% of energy produced by wind and PV power plants, both in 2025 and in 2030. The additional VRES capacity will allow to increase the power export providing economic benefits for stakeholders; furthermore, it will ensure high standards of security of supply also improving the system resilience in case of extreme climate conditions.

Introduction

The Government of Ethiopia (GoE) aims at diversifying renewable energy sources to develop a cheap and clean energy mix for a sustainable development of the electricity sector. As highlighted by the Ministry of Water, Irrigation and Electricity (MoWIE) in the Ethiopian National Electrification Program, the GoE is focused on attaining a more balanced energy mix between hydro resources and solar, wind and geothermal sources. A diversified mix of energy resources will improve the security of supply and will help mitigate the effects of climate change. Pillar three of Ethiopia's 2011 "Climate Resilient Green Economy (CRGE) Strategy" requires that 15-20% of the energy supply should come from non-hydropower based renewable resources by 2020.

Ethiopia is endowed with outstanding and diversified renewable energy resources, namely hydro, wind, solar, geothermal, and biomass. Concerning hydro resources, 10 river basins (including important international rivers like Blue Nile, Omo, Wabi Shebelle, Genale and Dawa) with huge catchment areas and suitable rainfall ensure the highest water availability in Africa behind Democratic Republic of Congo. Large and small hydro potential is estimated to be 45 GW and only less than 5% is exploited today.

The approximately perpendicular incidence of sunshine, thanks to its latitude near the equator, confers to Ethiopia very high solar resources. The average value of global horizontal irradiation (GHI) is about 2,000 kWh/m^2/year; in favourable regions, GHI reaches 2,400 kWh/m^2/year. The sites with the highest solar irradiation are in the northern and eastern areas of the Country while the irradiation decreases towards the southern and western areas (Fig. 1).

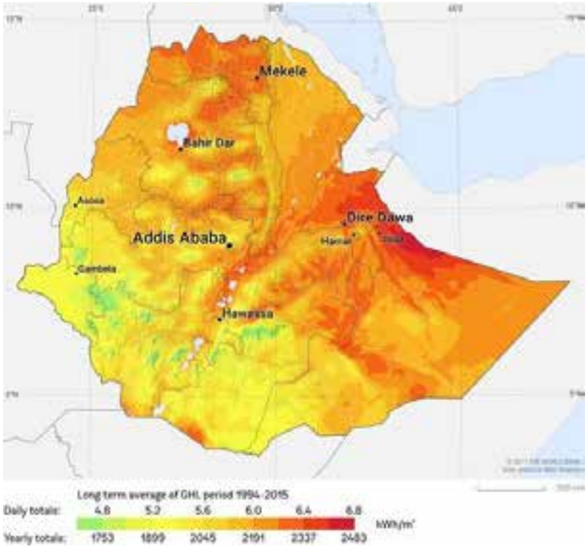


Fig. 1. Global Horizontal Irradiation in Ethiopia (© 2017 The World Bank, Solar resource data: Solargis)

The country has also a promising wind power potential. The average wind speed in the whole country is greater than 6.5 m/s, with favourable locations where the average wind speed achieves 10 m/s. The locations with the highest level of wind potential are the south-east and far south of the Country, but these are remote from the grid and correspond to areas with a low population density. Nevertheless, there are also locations with good potential (mean wind speed between 7.5 m/s and 9 m/s) close to the grid, with higher levels of population density in the area around Addis Ababa and in East Shewa and Dire Dawa (Fig. 2). Wind potential is estimated to be 1,350 GW but less than 1% is exploited.

In addition, Ethiopia has a good potential of geothermal resources (7 GW) located in the rift valley. Biomass resources from wood residues and sugar waste can also contribute to the energy diversification.

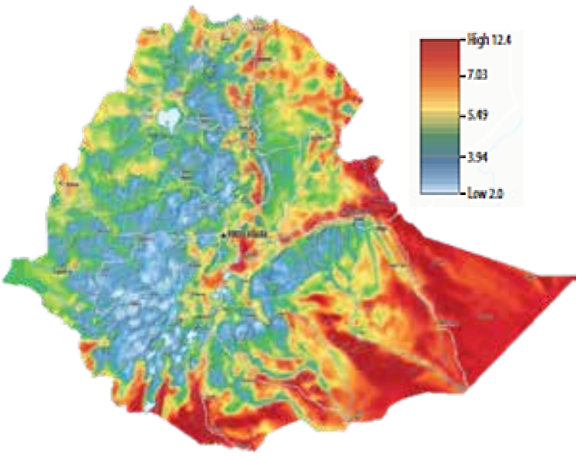


Fig. 2. Mean wind speed at 100 m height above ground level m/s (source: The World Bank – ESMAP)

The above renewable energy sources can be efficiently exploited to cope with the strong demand growth exceeding 12% per year. Furthermore, they can boost the exploitation of international interconnections and the strategic role of Ethiopia as cost competitive power exporter in the regional power pool.

Whilst hydro power is largely exploited in Ethiopia, wind power plants were only recently introduced, while solar power plants are still not very common. A wide deployment of variable renewable energy sources (VRES) requires proper integration strategies, so to warrant sufficient security margins and reliability levels.

The aim of this study is to estimate the optimal amount of VRES that can be integrated into the Ethiopian electric power system in the mid- and long-term (years 2025 and 2030), identifying possible criticalities and suggesting remedial measures concerning both the operation of the generation system and the network.

The execution of this study has been requested by Ethiopian Electric Power (EEP), supervised and coordinated by RES4Africa and Enel Foundation, and carried out in 2018 thanks to the technical expertise of CESI, in close collaboration with EEP.

The Ethiopian power system

Ethiopia's total electricity generation in 2017 was equal to 13.3 TWh, out of which 89% for domestic demand and network losses, 11% for export (EEP). The peak power demand, excluding export, was about 2.2 GW.

Annex 1 depicts the generation capacity mix in 2017. The generation heavily relies on hydropower with 3,800 MW equal to 89% of total generation capacity. An important project of water resources exploitation is ongoing: the Grand Ethiopian Renaissance Dam (GERD), which represents the largest dam in Africa. The project is close to be completed and 6,000 MW hydro capacity will be progressively integrated in the period 2020-2024. Wind is the second electricity source with 324 MW equal to 8% of total generation capacity, while biomass, geothermal and liquid fossil fuels provide only 2% of total generation capacity.

Concerning the interconnections with the neighbouring countries, the Ethiopian electric power system is currently interconnected with Sudan and Djibouti for a total of 300 MW net transfer capacity. But, an additional interconnection with Kenya (2,000 MW HVDC link) is in an advance stage of construction and the implementation of a new Ethiopia-Sudan interconnection is about to start (3,000 MW). The commissioning of these big interconnection projects and the signature of Power Purchase Agreements (PPAs) with the neighbouring countries are two actions fully coherent with the GoE's strategy to become a world class exporter of large amounts of clean and cheap renewable energies. VRES would play an important role in GoE's vision.

Scenario

The study covers the period until 2030, with special focus on two target years: a mid-term, year 2025, and a long term, year 2030.

The study performed by EEP and USAID-Power Africa named "USAID Grid Management Support Program – System Integration Study" has been taken as a basis to set up the reference scenario, named "*Enhanced VRES deployment scenario with normal water availability".* The reference scenario is based on the following main assumptions:

- reference demand growth pattern;
- average hydropower availability according to the historical data;
- adoption of the current water resource management policies;
- programmable generation fleet (hydro, geothermal, biomass and fossil fuels) according to the EEP-USAID System Integration Study;
- high integration of wind and PV generation including the feasible additional capacity that does not affect the reliability, integrity and efficiency of the electric power system.

Starting from the reference scenario, a set of sensitivities has been investigated. One sensitivity is related to the impact on the system operation of low rainfall periods with a prolonged drought as a consequence of the climate change (-34% hydropower availability compared to normal conditions); the benefits of VRES generation in this condition are assessed. Then, a multi-purpose sensitivity scenario has been examined increasing water exploitation for agriculture and household consumptions in Ethiopia, at the expenses of the electricity sector (-10% hydropower availability compared to normal conditions). Finally, the impact of a lower demand growth has also been investigated.

The analysis has been carried out adopting a complete generation and transmission network model of the Ethiopian electric power system, while simplified power system models have been defined for the neighbouring countries. A detailed generation model has been considered for Sudan and Kenya, while only an equivalent model of PPAs has been adopted for Djibouti and Tanzania.

Demand forecast

Demand forecast in the reference scenario is based on the EEP data[1]. The total domestic demand, including network losses, expected by 2025 is about 38.2 TWh/year; CAGR (Compound Annual Growth Rate) turns out to be +15.8% with a peak power demand of 7 GW. In 2030, the domestic demand reaches 54.8 TWh/year (CAGR +7.5% in 2025-2030) with a peak load of 10 GW (Fig. 3).

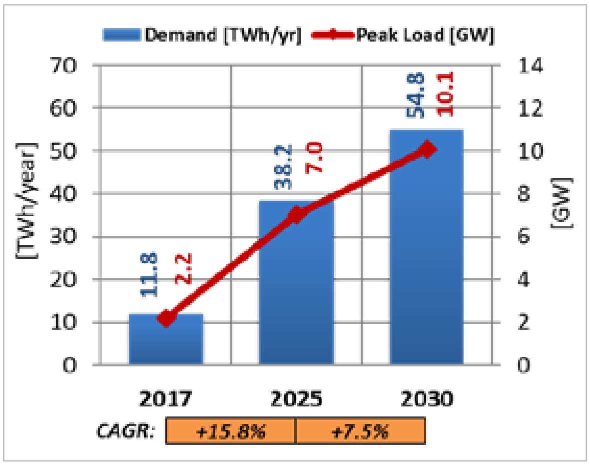


Fig. 3. Forecast of Ethiopian domestic consumptions for 2025 and 2030, including network losses (Reference Scenario)

[1] Source: Power Africa, "USAID Grid Management Support Program – System Integration Study"

An additional demand is estimated in the mid- and long-term due to power export. The future PPAs that will be signed with Tanzania and Sudan to exploit the new interconnections will be added to the existing PPAs with Sudan (100 MW firm capacity with 100% annual load factor), Djibouti (100 MW firm capacity with 65% annual load factor) and Kenya (400 MW firm capacity with 85% annual load factor).

An important growth of energy demand is expected also in Sudan: CAGR +14.0% in the period 2017-2030, with 48.3 TWh in 2025 and 89.6 TWh in 2030. The demand forecast is lower in Kenya, with a CAGR value of +7.7% in the period 2017-2030; 19.2 TWh are expected in 2025 and 27.4 TWh in 2030.

Generation mix

Evidently, such an important demand growth shall be sustained by a correspondent and robust power generation growth roadmap.

The master plan elaborated by EEP and USAID[2] for the development of the electric power system was the basis of the generation growth roadmap for RES4AFRICA reference scenario. The master plan foresees the decommissioning of old fossil fuel units and the commissioning of new programmable power plants (hydro, geothermal, sugar and waste-to-energy). Annex 1 shows the programmable capacity considered in reference scenario 2025 and 2030, and the VRES estimated capacity (wind and PV). The time interval from now to 2030 shall witness a rapid growth of RES power plants installations in hydro (+10,330 MW), geothermal (1,043 MW), wind (+3,276 MW), PV (+5,300 MW) and biomass (+496 MW). Both in 2025 and 2030, no fossil fuel generation is expected in EEP generation expansion plan.

Referring to the above generation scenario, the annual hydropower is higher than the domestic demand: about 39 TWh/year and 55 TWh/year are estimated in 2025 and 2030 from hydro power plants. In this context, the interconnections and the integration between countries are crucial for the integration of additional VRES capacity.

Levelized Cost Of Electricity (LCOE) from VRES technologies

An assessment of the levelized cost of electricity (LCOE) from wind and photovoltaic technologies has been carried out proving an indication of their competitiveness. Capacity factors of wind and PV power plants have been considered together with the investment costs, operating costs and lifetime[3] of these technologies to provide a qualitative assessment of LCOE that was considered in the cost-benefit analysis (Fig. 4).

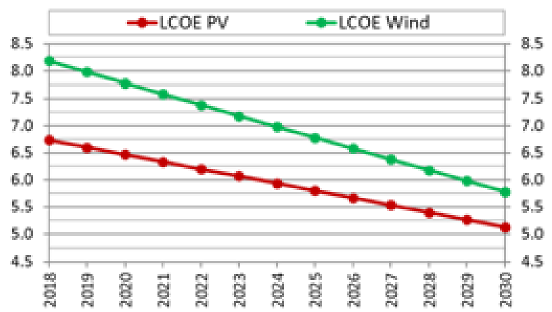


Fig. 4. Forecast of the Levelized Cost Of Electricity from VRES technologies ($c/kWh)

[2] USAID: United States Agency for International Development

[3] Lifetime has been assumed equal to the duration of PPAs that will be signed with the independent power producers; hence, 20 years instead of 25 years which is the typical lifetime of wind and PV power plants.

Interconnections

With the development of new important interconnection projects and the PPAs with the neighbouring countries, GoE is putting in place its National Vision to become a world class exporter of clean and cheap renewable energies. Ethiopia aims to be the energy hub in the Eastern Africa Power Pool (EAPP). Fig. 5 shows the maximum exchange capacities, related to the existing and new interconnection projects that have been considered in VRES integration study.

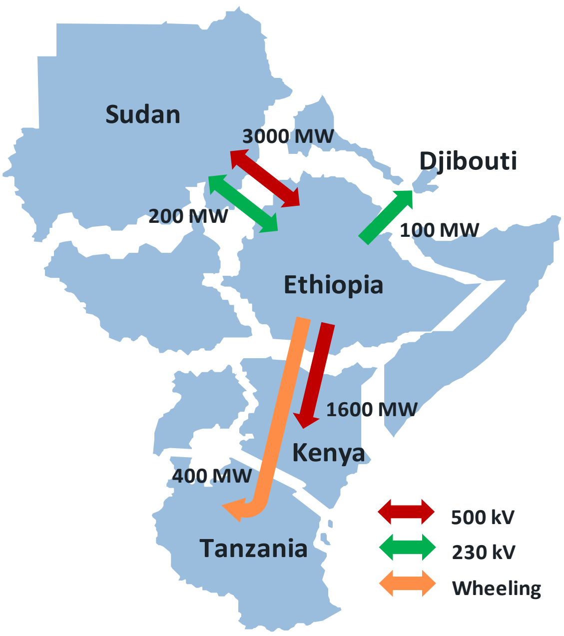


Fig. 5. Net Transfer Capacity between Ethiopia and the neighbouring countries in 2025 and 2030

Interconnection projects follow the important development plan of the Ethiopian transmission network in which several internal reinforcements are planned by EEP to improve the adequacy and the system security.

A key question arises on whether such generation expansion plan is feasible, and the grid development plan is adequate. In particular, the key questions to be addressed are:

- ✓ are the Ethiopian hydro power plants sufficiently flexible to cope with the variability of wind and PV productions?
- ✓ is the transmission network suitable to integrate additional VRES capacity?
- ✓ is there a cost opportunity in VRES investments to increase export towards the neighbouring countries where the electricity generation cost is higher?

Hence, an integrated approach has been developed for the in-depth analysis of technical and economic constraints that could have an impact on the enhanced deployment of wind and PV sources in the Ethiopian interconnected system.

Methodology

The approach adopted to evaluate the maximum wind and PV capacities that can be installed in Ethiopia in 2025 and 2030 includes different phases in which, progressively, technical and economic constraints are integrated and analysed. Fig. 6 shows the summary scheme of the integrated multi-phase approach. We get to analyse grid constraints (Task 4) starting from the energy balance constraints and the reserve requirements (Task 2), passing through the economic constraints (Task 3).

Task 2 allowed a preliminary assessment of the maximum theoretical VRES capacity that can be installed in Ethiopia considering only energy balance constraints and the impact of VRES on the operating reserve requirements by means of a simplified model of the Ethiopian interconnected system (neglecting any economic and network constraints). The main achievement of Task 2 was verified by means of more in-depth technical-economic analyses in Task 3. The economic constraints applied to a detailed generation fleet model and the optimal coordinated hydro dispatching performed to minimize the system costs allowed to select the cost-effective VRES capacity mix that could be integrated in Ethiopia. A cost-benefit analysis was performed focusing on the marginal net benefit of additional VRES capacity. Finally, in Task 4, a grid impact study of the VRES capacity selected in Task 3 has been performed, examining the system adequacy and the grid loadability, to define the optimal amount from both a technical and economic point of view of wind and PV that can be integrated in 2025 and 2030 in the Ethiopian electric power system, maintaining high standards of security of supply and improving the system resilience.

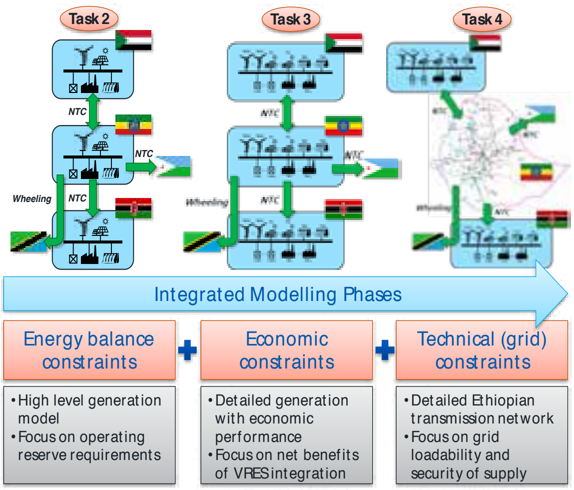


Fig. 6. Scheme of the integrated multi-phase approach

The analyses were performed through the application of state-of-the-art computational tools, developed by CESI, simulating the market mechanisms with a deterministic algorithm[4] and the system reliability with a probabilistic algorithm[5].

[4] PromedGrid software for market modelling. See www.cesi.it

[5] GRARE software (Grid Reliability and Adequacy Risk Evaluator). See www.cesi.it/grare

Wind and PV integration outlook

The study showed that additional capacity from VRES can be integrated in the Ethiopian electric power system, on top of the projects already in the Country's pipeline (Annex 2). The following wind and PV capacities can be installed in Ethiopia in the mid- and long-term:

- up to 2,400 MW from wind and 3,350 MW from PV in 2025;
- up to 3,600 MW from wind and 5,300 MW from PV in 2030.

These capacities can integrate the development plan of programmable generation fleet (hydropower, geothermal and biomass) defined by EEP (reference scenario with normal weather conditions and reference growth of energy demand) thanks to a greater exploitation of the future interconnection capacity, mainly with Sudan. In fact, the additional VRES capacity will allow to increase the power export providing economic benefits for stakeholders; furthermore, it will ensure high standards of security of supply also improving the system resilience in case of extreme climate conditions.

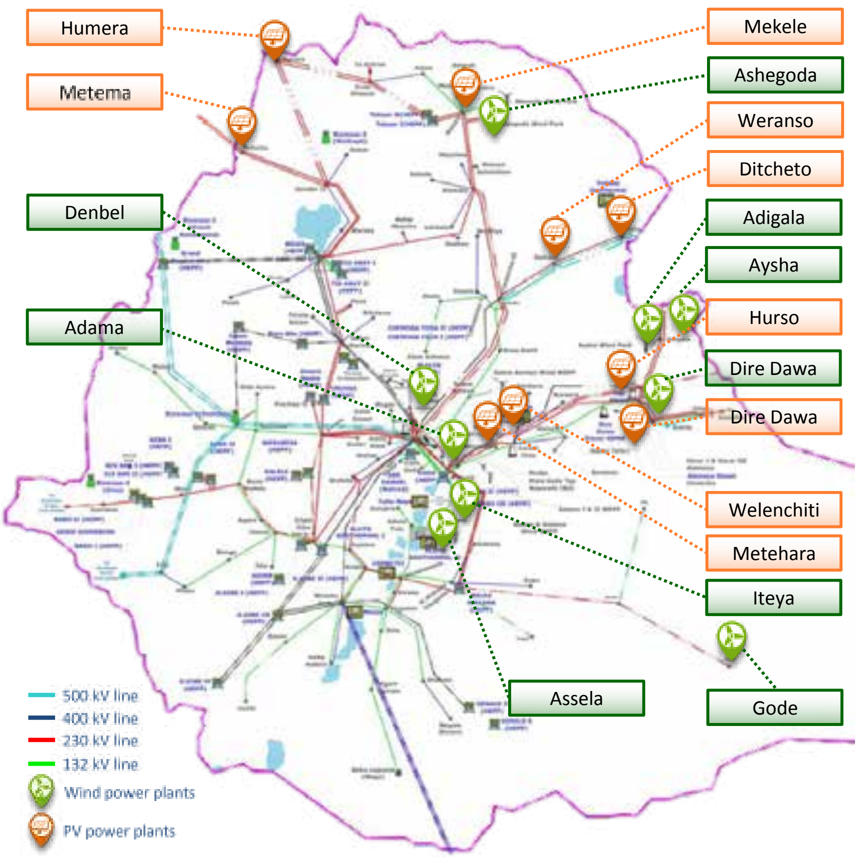
Annex 1 shows the generation capacity mix that could be achieved in Ethiopia in 2025 and 2030: VRES installed capacity attains 27% of the total generation fleet in 2025 and it grows up to 36% in 2030. The overall non-hydropower renewable capacity is estimated to grow from 9% recorded in 2017 up to 34% in 2025 and 43% in 2030. This outlook of RES generation development allows to achieve a well-balanced capacity mix.

In 2025, 68% of energy will be produced by hydropower plants (39.1 TWh/year), 13% (7.3 TWh/year) by PV and 12% (7.0 TWh/year) by wind power plants. In 2030, the percentages of PV and wind generation capacity remain unchanged with an increase of energy up to 11.6 TWh/year and 10.5 TWh/year respectively; hydropower increases up to 55.4 TWh/year (63%). VRES production curtailments are negligible and not very frequent (0.2% of potential production).

The wind and PV power plants already in pipeline were assumed to be connected to the grid in the substations listed in Annex 2. The additional capacity was distributed in the system considering the sites with higher wind and solar potential. Fig. 7 shows the location of VRES projects and the maximum wind and PV capacities that can be integrated at each substation. Such capacities comply with the Ethiopian reliability standards (network loadability) and they allow the maximum VRES energy integration at the target years, minimizing production curtailments due to network overloads or over-generation phenomena.

Security of supply

The quantitative evaluation of static reliability of the electric power system (adequacy) proved that a progressive deployment of VRES generation, notably PV and wind, will not worsen the security of supply both in 2025 and 2030. No risk of energy not supplied resulted from the simulations, since the high availability of energy sources and the suitable exchange capacity between Ethiopia and the neighbouring countries allow to cover both the domestic demand and the PPAs signed with the neighbouring countries.



Max wind capacity [MW]		
S/S	2025	2030
Adama	205	503
Adigala	280	470
Ashegoda	230	230
Assela	125	127
Aysha	240	320
Denbel	600	600
Dire Dawa	170	470
Gode	400	730
Iteya	150	150
TOTAL	2,400	3,600

Max PV capacity [MW]		
S/S	2025	2030
Dire Dawa	300	600
Ditcheto	125	250
Humera	450	550
Hurso&Gad	700	1,000
Mekele	400	400
Metehara	150	400
Metema	700	750
Welenchiti	100	1,100
Weranso	125	250
TOTAL	3,550	5,300

Fig. 7. Maximum wind and PV capacities that can be installed at each substation in the mid- and long-term

The role of the interconnections and the transmission grid

In a country with a huge renewable potential like Ethiopia, the interconnections and the integration between countries are crucial for the exploitation of the cheaper energy sources. The integration of the above-mentioned VRES capacities will allow Ethiopia to export 25.3 TWh/year in 2025 to Sudan, Kenya, Tanzania and Djibouti and up to 33.4 TWh/year in 2030.

The main importing country would be Sudan with 18.7 TWh/year in 2025 and 26.5 TWh/year in 2030. Sudan is expected to be strongly dependent by fossil fuel generation that could be replaced by cheaper energy imported by Ethiopia, whereas Kenya's demand will be mainly covered by its own renewable sources; hence, no room for additional import from Ethiopia is expected in Kenya over the existing PPA.

Without the additional VRES capacity, despite Ethiopia would result a net exporter, it should import power from Sudan in some hours to balance the demand. The exploitation of the new interconnection with Sudan is low without VRES energy, whereas, if an enhanced deployment of VRES energy is achieved in 2025 and 2030, Ethiopia will be a full exporter country as highlighted in the duration curves of power exchanges expected between Ethiopia and Sudan/Kenya shown in Fig. 8 and Fig. 9. The equivalent operating factor (EOF)[6] of the interconnection Ethiopia-Sudan is equal to 67% in 2025, growing up to 93% in 2030; EOF with Kenya is about 35-36% in 2025 and in 2030.

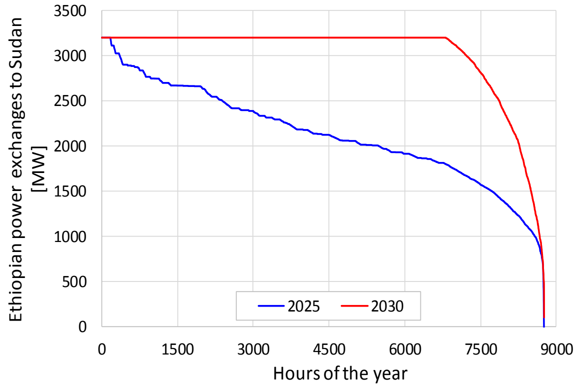


Fig. 8. Duration curves of the expected power exchange from Ethiopia to Sudan

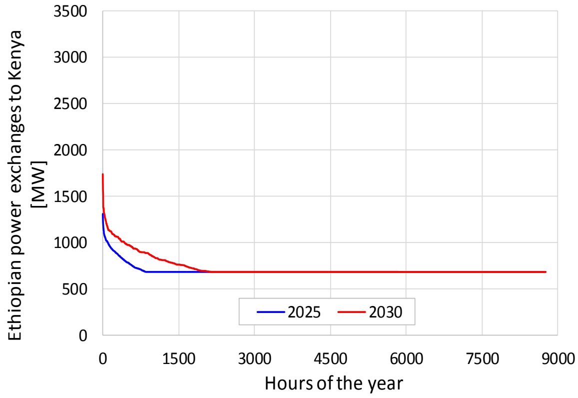


Fig. 9. Duration curves of the expected power exchange from Ethiopia to Kenya (including wheeling power to Tanzania)

Export to the neighbouring countries in presence of additional VRES capacity could lead net benefits up to $ 1.6 billion over the lifetime duration of the whole VRES installed capacity in 2025 (30 years from the commissioning date); net benefits grow up to $ 2.4 billion in 2030.

As highlighted in Fig. 8, the development of VRES projects will allow an efficient exploitation of the important interconnection project with Sudan (3,000 MW Blue Nile Energy Corridor) providing economic benefits both for Ethiopia and for Sudan. Ethiopia could increase the export of cheaper

[6] EOF is the ratio between the actual energy flowing through the interconnection (import or export) over a period (typically one year) and the maximum energy that could be met if the interconnection is operated at full capacity over the same period.

energy exploiting the flexibility of its hydro generation fleet to compensate the variability of VRES productions. On the contrary, Sudan could increase the import of cheaper energy from Ethiopia reducing generation costs from expensive conventional power plants, saving fossil fuels and avoiding some investments in new conventional power plants (low carbon development action in line with strategy of the Government of the Republic of Sudan).

The system reliability impact study showed that the transmission network expansion plan outlined by EEP would allow the development of a substantial amount of VRES generation both in the mid- and in the long-term. The grid development plan established by EEP allows the complete integration of the maximum VRES economic capacity assessed from the market analysis to 2030 (3,600 MW from wind and 5,300 MW from PV power plants). From the economic perspective, even in 2025 there is room to integrate a large amount of VRES capacity. From the market analysis (Task 3), 3,000 MW from wind and 4,350 MW from PV power plants could be integrated in 2025, but some network constraints limit the integration up to 2,400 MW from wind and 3,350 MW from PV. According to the EEP's grid development plan, these network constraints will be solved in the coming years, allowing the complete integration of the maximum VRES economic capacity in 2030. Therefore, considering the very high VRES penetration that can be achieved in the mid-term with the current grid development plan and the grid projects already defined by EEP between 2025 and 2030, no additional network reinforcements are suggested in 2025 to increase VRES penetration. The transmission network developments are well-planned by EEP to allow a gradual integration of VRES generation into the Ethiopian electric power system in the mid- and long-term.

The role of hydropower

The outstanding amount of hydroelectric generation in Ethiopia, largely coupled with high capacity reservoirs, ensures an operational flexibility that plays a key role in the integration of wind and PV power productions in Ethiopia. Ethiopian hydro reservoirs can act as a sort of storage for wind and PV generation during the daily dispatching. In fact, as shown in the daily hydropower production diagrams with and without VRES additional capacity (Fig. 10), water saved during high wind/PV production hours (daytime hours) can be used to generate more energy during low or null wind/PV production hours (typically at night time), increasing the export. Due to the intrinsic features of the primary source, unlike wind, PV power production is concentrated in a limited number of hours and therefore it can benefit more of the hydropower flexibility. Consequently, PV technology is more affected by the lack of hydropower if low rainfall periods occurs. Therefore, despite PV technology is cheaper than wind technology, a balanced integration of both technologies is recommended since this diversification improves the system resilience.

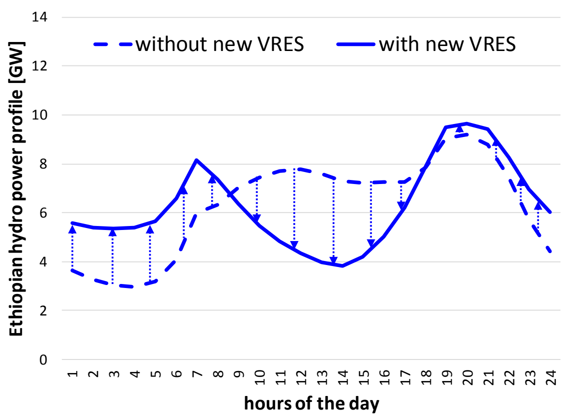


Fig. 10. Average 24-h hydropower production in Ethiopia, without and with new VRES capacity (year 2030)

As highlighted in Fig. 11, VRES integration changes the daily power dispatching: PV and wind power displace hydropower during daytime hours.

A coordinated management of renewable energy sources in Ethiopia would allow the hydro generation fleet to balance the variability of wind and PV generation, maintaining the security of supply. This improves the integration of VRES energy in Ethiopia and allows the peak shaving of expensive fossil fuel generation in Sudan by means of cheaper energy, with benefits for both Ethiopia and Sudan.

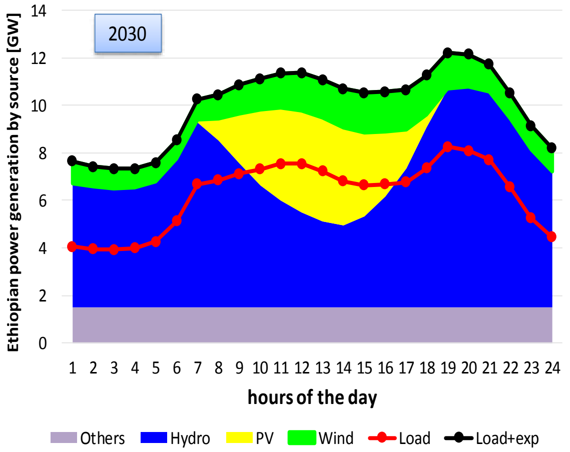


Fig. 11. Average 24-h power balance in Ethiopia, with VRES capacity target calculated for the year 2030

The Ethiopian generation system is closely dependent from hydropower and a very high exploitation of water for electricity sector will continue in the future. In this context, both long-lasting climatic changes and extreme natural events, which are becoming more frequent in the last decades, are expected to affect the demand, production and transmission of electricity; more generally the security of supply. An energy diversification strategy in the electricity sector including technologies with low water use needs, such as wind and photovoltaic, could offer an important technical solution for Ethiopia that could strengthen both short- and long-term resilience of the power system and may face current and future water challenges related to climate change. VRES power plants are less impacted by climate change and they can compensate the lack of hydropower if low rainfall periods or droughts occur. Furthermore, additional VRES capacity (up to +12%) with respect to the reference scenario could be integrated in the system to face drought periods, increasing both the economic benefits and the system resilience. VRES energy exploitation would allow to limit the power import from Sudan in case of low water availability.

The integration of VRES capacity in the Ethiopian electric power system could also be an important measure to reduce the water exploitation in the electricity sector and to increase the use of water in other sectors, improving the social welfare. VRES exploitation is a great opportunity to accelerate the achievement of GoE's targets to achieve a more advanced irrigation model using modern technologies. The analyses carried out on a scenario based on a new water exploitation strategy have proven that 10% of the upstream water consumptions of hydroelectric power plants could be used for agriculture and household consumptions and that VRES capacity could balance the missing hydropower ensuring a higher security of supply and maintaining a high exploitation of the interconnection (e.g. with Sudan, the equivalent operating factor under export condition achieves 70% in 2030, with only few hours of import).

Conclusions and recommendations

Thanks to the very favourable wind and solar potential in the country, the reduction of VRES investment costs, the on-going interconnection projects and the flexibility of the hydro generation fleet, wind and PV technologies can play a key role to reduce the dependence on water of the Ethiopian electricity sector.

The analyses clearly highlight that additional capacity from VRES generation can be integrated, on top of the projects already in the Country's pipeline. The following wind and PV capacities can be installed in Ethiopia in the mid- and long-term:

- up to 2,400 MW from wind and 3,350 MW from PV in 2025;
- up to 3,600 MW from wind and 5,300 MW from PV in 2030.

High VRES penetration levels can be achieved increasing the power exchanges towards the neighbouring countries and ensuring, at the same time, high standards of security of supply and improving the system resilience in case of extreme climate conditions. The long-term transmission grid expansion plan established by EEP allows the development of VRES generation outlined in this study without any major restrictions.

The achievements of this study provided an estimation of the optimal wind and PV capacity that could be technically and economically integrated in the Ethiopian electric power system. Further analyses are required by executing dedicated feasibility studies for each wind and PV project to be integrated in the system.

Moreover, innovative strategies for the control and operation of VRES power plants are recommended to maximise VRES exploitation and maintain a secure operation of the electric power system. These strategies will avoid critical situations due to VRES intermittency, reducing the risk of production curtailments due to over-generation phenomena (i.e. when the generation available in the system is higher than the demand). In particular, two actions should be considered during the integration process of VRES energy to reduce the risks concerning the power system operation in presence of a big amount of VRES power plants:

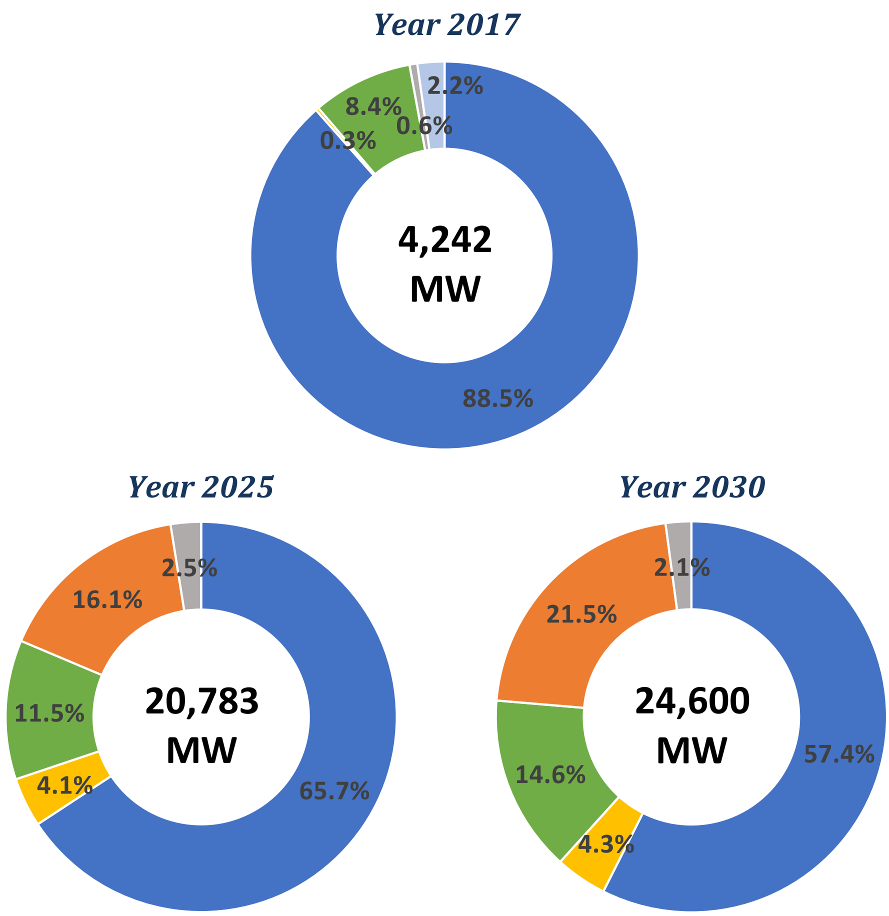
- A central control room for VRES power plants, with clusters of different plants, would allow a better forecast of generation lowering forecast errors and minimizing reserve need. A greater penetration of VRES generation is possible if the uncertainty of its prediction is reduced.
- Participation of VRES to ancillary services markets, for instance availability to decrease their production (downward reserve) to ensure the stability of the power system. In this way, VRES downward reserve can replace the hydro one.

These actions are usually addressed during the short-term and real-time operation of the power systems. Experiences in advanced markets with high VRES penetration show significant rooms for reducing VRES energy curtailments when appropriate real time control systems are put in place.

Annex 1

Capacity mix in 2017 and estimated at years 2025 and 2030 in scenarios with enhanced VRES deployment (MW)

Source	2017	2025	2030
Hydropower	3,799	13,662	14,129
Geothermal	7	850	1,050
Wind	324	2,400	3,600
Photovoltaic	-	3,350	5,300
Biomass	25	521	521
Conventional	87	-	-
Total	**4,242**	**20,783**	**24,600**



Annex 2

Wind and PV projects in the pipeline

Wind Project	Pmax [MW]	Substation
Adama I (existing)	51	Adama 220/33 kV
Adama II (existing)	153	Adama 220/33 kV
Ashegoda (existing)	120	Ashegoda 230/33 kV
Assela	100	Assela 230/132/33 kV
Aysha I	120	Aysha 230/33 kV
Aysha II	120	Aysha 230/33 kV
Iteya	150	Assela 230/132/33 kV
TOTAL	**814**	

PV Project	Pmax [MW]	Substation
Metehara	100	Metehara 230/123/15 kV
Ditcheto	125	Ditcheto 230/33 kV
Gad	125	Hurso 400/230/132 kV
TOTAL	**350**	

Who we are

RES4AFRICA

RES4Africa promotes the deployment of large-scale and decentralized renewable energy and energy efficiency in Sub-Saharan African countries to meet local energy needs. Since its inception in 2012, the association gathers the perspectives and expertise of a member network from across the sustainable energy value chain. RES4Africa functions as a platform for members and partners of emerging markets to foster dialogue and partnerships, share knowledge and build capacity to advance sustainable energy investments in Sub-Saharan African countries.

RES4Africa works with local, regional and international partners, agencies and organizations to pursue its mission and promote renewable energy and energy efficiency deployment in the region of focus.

ENEL FOUNDATION

Enel Foundation is a knowledge platform that focuses on the crucial role of clean energy to ensure a sustainable future for all. By developing partnerships with pre-eminent experts and institutions across the globe, leveraging on the vast knowledge of its Founders, Enel Foundation conducts research to explore the implications of global challenges in the energy domain, develop scenario analysis, define policy and regulation opportunities and design capacity-building programs to the benefit of scientific and institutional realms.

CESI – CENTRO ELETTROTECNICO SPERIMENTALE ITALIANO

CESI is an independent center of expertise and a global provider of technical and engineering services to customers throughout the energy value chain, including business and technical consultancy, engineering and operational support. CESI also act as owner's engineer and provide qualified third-party opinions to power utilities worldwide. Through their top-class modern testing facilities located in Milan, Berlin (IPH GmbH) and Mannheim (FGH GmbH), they are among the leading international organizations providing measurements and inspection, testing & certification and design review services to the global power industry.

Technical innovation is at the heart of much of what they do. Their network of more than 1000 highly experienced professionals around the world, working from offices and through representatives in 35 countries, is dedicated to delivering customized solutions. These include providing innovative, yet practical, answers to meet the energy-related challenges of modern equipment and processes. They uniquely combine expertise in strategic and policy consultancy with comprehensive technical and technological know-how.

RENEWABLE ENERGY SOLUTIONS FOR AFRICA

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