Ethiopian Energy Outlook

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Danish Energy Agency

Ea Energy Analyses

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Content

FOREWORD

The Ethiopian Energy Outlook (EOR) 2022 is to serve as input to the development of the energy policy of Ethiopia in key areas. The goal is to increase choice awareness, thereby fostering access to reliable information contributing to policy development and investment decisions.

The Outlook has been developed as a part of the Ethiopian-Danish Government-to-Government Cooperation. The cooperation on the Outlook has been designed and executed in close collaboration with the Ministry of Water and Energy of Ethiopia (MOWE), the Ethiopian Electricity Power (EEP), Energinet (the Danish Transmission System Operator), the Danish Energy Agency, Ea Energy Analyses and the Royal Danish Embassy in Ethiopia. As part of the process, a number of stakeholders have been consulted, such as Ethiopian Electric Utility; the Ministry of Transport; the Ministry of Mines and Petroleum; the Environ-ment, Forest and Climate Change Commission (EFCCC); and universities.

The report is composed of two main parts: energy landscape and power sector. The ambition of the en-ergy landscape is to highlight the challenges and opportunities of the implementation of the National Elec-trification Plan (NEP 2.0) as well as electrification of transport and the use of biomass and natural gas. The focus of the power sector is on generation mix, management of dry years and the potential for export of electricity.

A central part of the cooperation is the implementation of an Ethiopian power sector model. The model used is the Balmorel model, an open source partial equilibrium model. The model examines different scenarios for the development of the energy sector and includes data for Ethiopia and 11 East African countries. The development and implementation of the model has included intensive training, develop-ment of scenarios and least-cost analysis of possible power sector development pathways. The purpose of these scenarios is not to predict the future, but rather to explore various possible futures of the Ethio-pian power sector, and identify the risks, challenges and opportunities associated with its development.

An important part of power sector planning is that the models and tools use the best possible input data. Therefore, the Outlook is supplemented by a technology catalogue that presents techno-economic data for power generation technologies in an Ethiopian setting, including e.g. hydroelectric, wind, solar and geothermal plants. This catalogue is used as input data for the Outlook model.

The Outlook has been developed in close cooperation with all partners with strong commitment, open-ness and good discussions. It is the ambition that the Outlook in the same way can contribute to the de-velopment of the Ethiopian energy sector.

1. EXECUTIVE SUMMARY

The development of the energy sector is one of the key drivers of Ethiopia's overall development and transformation strategy as indicated in the Climate Resilient Green Economy strategy together with the long-term development plan 'Ethiopia 2030: Pathway to Prosperity (2021 – 2030)'. Access to adequate, reliable, affordable, and environmentally sustainable energy is fundamental for enabling the structural transformation of the Ethiopian economy and society, and for promoting poverty reduction, industrialisation and creating jobs for a young and fast-growing population.

The economic growth drives a strong increase in energy demand. Total energy demand grew by 30% from 2010 to 2018, while oil demand doubled, and electricity demand grew by 130% in the same period. Electricity generation is projected to increase by between 100 and 300% from 2018 to 2030. During the same period, oil demand is projected to double, while the demand for biomass is going to increase around 10%. Today, only one third of the population have access to electricity.

To meet this increased demand and being an engine for growth, the energy sector needs to develop to deliver increased and stable energy supply through investments in generation capacity, network extensions and upgrade to the distribution system. These challenges must be addressed by policy action. The National Electrification Plan already reflects this through targets like increase grid access from 33% in 2018 to 96% in 2030, and a focus on diversifying power generation to wind, solar and geothermal energy in addition to hydro generation that today account for 95% of electricity production.

A part of developing the energy sector there is a potential to leapfrog to modern and energy efficient technologies trough electrification of transport, industry and buildings. This will reduce the oil import dependency and subsequently reduce carbon emissions. Through electrification and thereby a possible reduction of biomass in the direct energy consumption it is also possible to increase protection and re-establishment of forests.

The Ethiopian Energy Outlook (EOR) 2022 is to be considered as a background report supporting the development of the Ethiopian energy sector by guiding the energy policy in key areas with regards to both describing status and challenges in the Ethiopian energy sector and through the modelling of relevant energy pathway scenarios towards 2030. Thus, the report is composed of two main parts: energy landscape and the power sector. The ambition of the *energy landscape* part is to highlight the challenges and opportunities of the implementation of the National Electrification Plan (NEP 2.0), as well as electrification of transport and the use of biomass and natural gas. The identified challenges can also be seen as inputs to defining the relevant model scenarios in the *power sector* part of the EOR. The goal is to increase the choice awareness in developing energy policy, thereby fostering access to reliable information to inform policy development and investment decisions.

It is especially through the scenario analysis that the EOR report provides new insights to the energy sector development. Therefore, this is also the main part of this summary. Further below is however presented some key aspects of the energy landscape analysis related to electrification, transport and the use of biomass.

Choice awareness: energy policy guided by scenarios

Based on well-documented and detailed modelling of the energy system, the EOR provides a scenario-based foundation for policy action by shedding light on the development of the energy system towards 2030. Scenarios are used to gain insight into the Ethiopian power system through different pathways including the potential costs and benefits of alternative futures. A large focus of the scenarios are linked to analysis of the generation mix and the potential for Ethiopia as a regional power hub through export of electricity.

The model used is the Balmorel model, an open source partial equilibrium model. To find an optimal solution, the Balmorel model considers the level of electricity demand, cross-border transmission grid constraints, technical and economic characteristics of technologies, fuel prices, as well as temporal availability of wind, solar and hydroelectricity. To achieve a detailed insight in the potentials for Ethiopian power system, Ethiopia and all countries that potentially could import power from Ethiopia – 12 countries in total from Egypt to Tanzania - are included in the model.

A base scenario and 15 alternative scenarios constitute the modelling analysis in the EOR. Each scenario is typically defined as one simple change compared to the Base scenario. The scenarios explore different least-cost development pathways of the Ethiopian energy system. Least-cost of energy pathways indicates the cheapest way to reach a certain target. The scenarios are not intended as "recommended" energy system pathways, but rather serve as indicative "what-if" scenarios. The scenarios have been developed to gain further insight into the policy options laid out in the NEP 2.0. For example, the objective of being a regional power hub has been analysed through different scenarios to gain the most insight into understanding the Ethiopian business case of being a power hub. The results have provided some interesting insights into the Ethiopian pathway towards 20230. The EOR can therefore be used to further spur political discussion by delivering concrete input for deciding the pathway for the Ethiopian Energy sector towards 2030.

Key findings of Ethiopian power sector scenario analysis towards 2030

Hydro continues to be the dominant power generation source - diversification of the power mix is not the only answer to the dry-year challenge

The power generation mix in Ethiopia will continue to be heavily reliant upon hydropower throughout the decade. Electricity supply is therefore vulnerable to dry years. Long-term climate change studies indicated that – in general – there will be more rain in Ethiopia, with increasingly extreme conditions, including prolonged periods of drought as well as extreme rain. Providing reliable electricity to supply the rapidly increasing demand with resilience to dry years are thus an important objective for the energy policy in a hydro dominated country like Ethiopia.

The analysis shows that a combination of the following three main options can provide an efficient management of dry-years in Ethiopia: 1) diversification (wind, solar, geothermal), 2) dispatchable generation like national fuel-based generation (e.g., natural gas), and 3) regional balancing with export/import of electricity with neighbouring countries. Other options could be demand response (e.g. deduction of industrial demand in case electricity shortage) or increased reservoir storage. These have not been studied in relation to this EOR.

A dry year will typically lack 10 TWh of hydro generation (2030) in Ethiopia compared to a normal year. Diversification can reduce this number, but cannot outweigh the missing generation, as wind, solar and geothermal generate close to the same amount of electricity each year – they cannot be increased in dry years. Thus, diversification can only be the sole solution to the dry year challenge if the generation capacity from these sources are increased dramatically. The model shows that this is not an economically viable pathway. The needed reserve margin (maximum generation capacity minus peak demand) through an excess investment in diversifying the energy mix could provide some resilience to dry years but incurs at an additional – not needed - cost to the utility and consumers. For example, to obtain a net export of 10 TWh in 2030, in a year with average rainfall, an additional 3,796 MUSD of capital investment in generation and transmission capacity is required before 2030. It could of course be argued that this excess power generation could be used as a strategic reserve, exported to neighbouring countries in normal years. Thereby providing a revenue stream of international currency. Actual export of electricity will depend upon sufficient high prices in the receiving country and the presence of international connectors.

However, Ethiopia could still consider increasing the weight on export/import to manage dry years. If a net export in a normal year is, e.g., 10 TWh then the balance in a dry year can be achieved by reducing export –

and still have a positive net export. The key is flexibility in the operation of interconnectors with neighbouring countries, such that the respective import and export volumes can vary from hour to hour, as well as from year to year to balance the system in an optimal way. This aspect of regional trade is further developed below.

In Figure 1, key economic results in 2030 are shown for different export scenarios i.e. a Base scenario (a least cost reference with no policy restrictions) and seven scenarios with different export requirements. The Base scenario has the lowest cost (total cost minus the revenue from export) to be covered by end-users. The other scenarios have higher costs, but they also have a higher revenue from export of electricity (hard currency). As an example, the scenario of Export of 10 TWh has extra costs of 117 MUSD/year (2030) but has also an extra revenue from export of 336 MUSD/year. For each extra USD accepted in total costs, an extra 2.9 USD is gained in hard currency. Limiting import results in reduced cost and additional trade revenue for Ethiopia. This provides evidence to support that Ethiopia receives greater than a 50% share of congestion rents from interconnectors, since congestion rents are divided equally between the selling and purchasing parties in Figure 1.

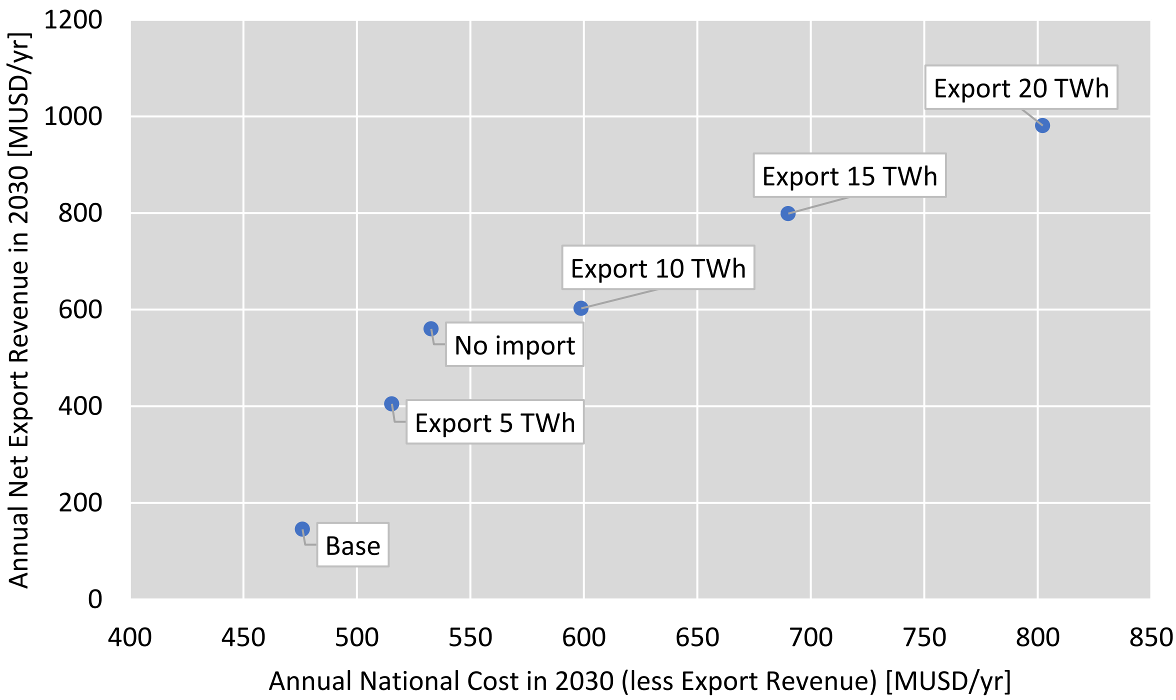


Figure 1: Key economic results for selected scenarios.

The scenario analysis shows that:

- Diversification should not be the only solution balancing the system in dry years.
- Dispatchable generation – e.g. through natural gas based combined cycle turbines supplied from the planned exploration in the Somalia region. A 600 MW plant could deliver half of the needed generation to fill the gap between domestic supply and demand in a dry year (2030).
- If the export from Ethiopia is 10 TWh per year in a normal year, then reduced export can balance the system in a dry year. This is further elaborated below.

The Ethiopian solution to the dry year challenge is therefore a combination of all three options with the largest focus on trade and diversification - using export/import could be the most attractive solution. Due to the typically well-defined rainy season in Ethiopia, the extent of a dry or wet year will be known towards the end of the rainy season. The hydropower plants can therefore be operated accordingly for the rest of the year, to mitigate the deficit or surplus in available generation compared to a normal year.

An energy hub based on dynamic international trade is to be preferred to a pure export strategy

Ethiopia is not an island. Export of electricity from Ethiopia can as illustrated above be an attractive way of creating revenue in hard currency. However, export of electricity will only take place if there are benefits to be shared: export from Ethiopia takes place when there is a higher price in the receiving country than in Ethiopia. The marginal price in each area is defined as the cost of supplying one additional unit of electricity. The economic export from Ethiopia increases with increasing fuel prices in neighbouring countries – and vice versa. Higher fuel prices increase the incentive to import electricity from Ethiopia as the hydro generation becomes more attractive. Comparing a scenario with no trade from Ethiopia with a scenario with full trade indicates that the total regional costs of running the power system are 218 MUSD/year less with full trade (2030) and for Ethiopia the national cost is reduced by 64 MUSD/year – mostly because of a reduced revenue from trade of 145 MUSD/year in 2030.

In the current situation with the absence of a dynamic power market, Ethiopia should pursue bilateral agreements that facilitate flexible trade. This strategy thus involves a significant amount of trust in the actual exchange of electricity in the region. This could be secured through dynamic bilateral agreements, which could act as a building block to the dynamic regional power market possible within the Eastern African Power Pool, EAPP. Dynamic trade with neighbouring countries can take place by sharing information about water values and marginal generation costs, and using a mid-price for exchange of electricity. In the longer-term, trade on a multinational power pool (EAPP) can take the trade to the next level.

Dynamic, international trade secures least cost electricity supply, international currency revenues and the most cost-effective method for supplying electricity in dry years. Dynamic, flexible trade agreements, either through a common market (EAPP) or bilateral agreements, provide a mechanism for purchasing electricity from neighbouring countries or exporting less in dry years, and enable optimal dispatch of hydropower generation in Ethiopia, in response to weather conditions and available power resources in the region.

The scenario analysis points in the direction of rethinking the Ethiopian regional energy-hub strategy. Hydroelectric generation has attractive dynamic properties (quick ramping and the ability to act as a storage). This could open for a new and important strategic business for Ethiopia by using the hydro resource to act as a buffer for not only national but also regional wind and solar resources. This entails being a buffer for the region by importing when prices are low and exporting when prices are high. A study of the flow on the lines between Sudan – Ethiopia – Kenya indicates that the variable generation from wind and solar to a high degree determine the flow and direction of these lines. Export agreements with constant export conditions are not economically efficient when there is significant wind and solar power in the system. This is also where one of the keys to dealing with the dry-year challenge in Ethiopia lays.

The scenario analysis on power trade indicates:

- The regional power buffer strategy would require dynamic trade agreements with the neighbouring countries. Dynamic trade is also strongly motivated by the dynamic nature of wind and solar power. With large wind and solar capacities in the region, fixed export is no more relevant. Power should flow from the cheap to the more expensive area – and that is changing from hour to hour. The scenarios show a strong position for Ethiopia being the regions buffer for wind and solar power.

- This strategy indicates that the benefits of selling flexibility to the region should be maximised. This could be done by introducing dynamic trade in the existing trade arrangement with Sudan and Djibouti and to secure that dynamic trade is a central theme in new agreements with neighbouring countries, including trade on the Kenya line. Full benefit of dynamic trade will be realised when the Eastern Africa

Power Pool, EAPP, power exchange comes into operation. Possibly the dynamic bilateral agreements can represent building blocks for the future regional power market within the frame of EAPP.

- An active participation in the ongoing Eastern African Power Pool (EAPP) project about shadow trade can give practical insight in dynamic trade. This approach could help Ethiopia unlocking the attractive business case of suppling balancing power to the region.

- To realise the goals of export of electricity, it is crucial that the development of the generation mix be focused on least-costs. Only by being able to generate electricity at low costs, export is relevant.

Cheapest way to 2030-targets is technology-neutral

A technology-neutral approach for determining generation capacity investment decisions will result in the least cost development of the power sector. The meaning of this is that the energy mix should not be fixed for the next decade. Rather, the diversification strategy, and investments in dispatchable capacity such as gas cycles, should be studied further and be adopted to developments in order to find the cheapest way towards 2030 bearing in mind security of supply.

Wind and solar power are *game changers* for the power sector. Lower investment costs for wind and solar power could results in a significant expansion of these technologies in the studied period until 2030. However, the expansion may mainly take place in the neighbouring countries that are potential importers of Ethiopian power, e.g., large investments seem attractive in Sudan and Kenya. These countries have large wind potential and the computed electricity prices are higher in those countries. This makes investment in wind power there more attractive than in Ethiopia. This leads to the analysis of the best energy mix (diversification) in Ethiopia.

The scenario analysis points to the following insights when it comes to the least cost development towards 2030:

- The goals of diversification should be formulated at the most general level as a desired share of non-hydro. There is no need to set individual goals for, e.g., wind, solar and geothermal. They can all deliver reductions in the share of hydro, and the search for the least cost blend of these technologies should be technology neutral – only dependent on the cost/benefit. The analyses indicate that with the current assumption, the most attractive wind sites present the cheapest option for non-hydro generation in Ethiopia.
- Ethiopia is a large country and a fair regional development has been stated as important in the energy policy. This regional distribution of power generation should be technology neutral. The reason can be illustrated with the case of wind power. Like hydro, wind power has a very regional nature, whereas solar is more evenly distributed. Ethiopia's wind resources are concentrated in a few areas. Only 2.3% of the land has an average wind speed above 8 m/s. The higher the wind speed, the lower the resulting costs for electricity. The cost of electricity from lower wind speed sites can be as high as double that of the best sites. Therefore, a more cost-efficient regional target could be an even energy distribution not linked to the source but to the energy provided.

- To realise the development and expansion of the energy system taken into account the regional distribution a development of a strong transmission system is important. A strong transmission system including interconnectors are a vital part of the development of the Ethiopian energy sector as it allows for harvesting the benefits of dynamic trade and the optimal energy mix allowing the use of the increasingly cheaper wind and solar.

To illustrate the above insights further, the results of the model runs of the two scenarios: base case and the case of export of 10 TWh (in the Base scenario there is an import of 0.5 TWh) are shown in

Table 1. An export of 10 TWh results in a higher degree of diversification (9% non-hydro, compared to 7% in the Base case. The extra capacity needed in the Export scenario is delivered by more hydro and wind power indirectly also adding to diversification. In chapters 7-11, further scenario results and insights are presented.

	Base	Export 10 TWh	
	Least-costs, no policy restrictions	*As base, but with 10 TWh export in 2030*	
Hydro	9226	11245	*MW*
Wind	754	934	*MW*
Solar	250	250	*MW*
Geothermal	107	107	*MW*
Waste	25	25	*MW*
Non-hydro as share of demand	7%	9%	*%*
Net Export, 2030	-0.5	10	*TWh/year*
Net revenue from export, including congestion rent (50%), 2030	145	603	*MUSD/year*
National costs, 2030	476	599	*MUSD/year*
Total investment 2020-2030	798	4,596	*MUSD*

Table 1: Key numbers for Ethiopia for two scenarios. Capital cost for existing and under construction plants and transmission lines are not included. Annual costs are found by using an interest rate of 11.65% and an economic lifetime of 20 years (25 years for hydro). Supply in the Ethiopian remote areas are not included here. See chapter 8 for results for the remote areas.

Energy landscape

The first part of the EOR contains a descriptive presentation of the Ethiopian energy landscape. Ethiopia has sufficient energy resources to secure self-sufficiency and even export of energy. Development of an efficient energy sector that can ensure access to affordable, reliable, sustainable, and modern energy for all is crucial for the future advancement of Ethiopia in line with the UN's Sustainable Development Goal 7 (SDG7).

Electrification

Supply of modern energy to all households will give benefits like access to lighting, telecommunication, and safe cooking. Ambitious plans for access to electricity to all households, schools and institutions exist. Access to stable power supply is also crucial for the development of industry, agriculture, and other businesses. In the energy landscape insights and characteristics of the current and future energy sector is presented, these have also provided input to the identification of scenarios in the power sector analysis. The text below touches upon a few issues related to the energy sector's role in the overall development strategy of Ethiopia, with a focus on electrification.

Access to electricity is probably the most important factor in developing the energy sector into an engine of growth for the country. Ethiopia has set out an ambitious target for providing electricity access to all its citizens: 65% on-grid and 35 off-grid by 2025 and 96% on-grid and 4% off-grid by 2030. In 2017, a survey explored the degree of supply of electricity to households. This survey shows that 44% of households have some supply (including supply from main grid, mini grids as well as small, individual solar home systems). It is important to note that only 4.5% of these households have a supply of more than 23 hours per day, and 85% have less than 8 hours of supply pr. day, see Figure 2.

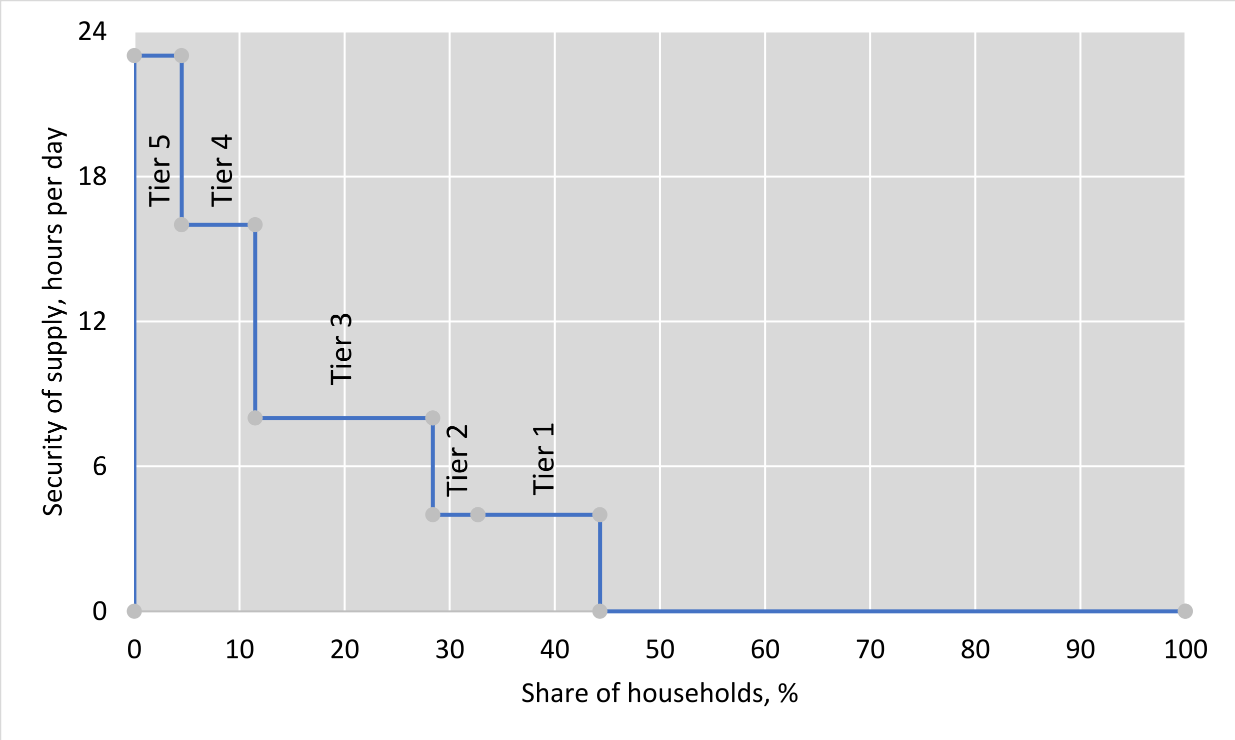


Figure 2: Graph illustrating a 2017 survey about supply of electricity to households. The difference between Tier 1 and 2 is the electricity load. Tier 1 has a load less than 50 W, while tier 2 has a load between 50 and 200 W.

Around one third of all households have access to electricity from the main grid – this includes both consumers with individual meters and shared connections. In the last 12 months, 330,000 households have been connected, resulting in 3 million households being connected (shared connections not included). In the last five years, the addition of new customers has been around 220,000 customers per year. Plans to significantly increase the number of connected households have been delayed, partly because of financing and challenges in obtaining the needed (imported) materials. In addition, additional training and capacity building of installers and planners must take place if the number of new customers should be expanded significantly. The analysis present the following insights:

- **Increase connection to main grid.** As indicated, there is delay in connecting more users to the main grid. It is proposed that different options are explored in handling this delay like allocation of more resources together with the development of an updated time plan.
    - Three different scenarios for the development of households per meter is analysed in chapter 3. If no shared connection exists in 2030, EEU must increase the household customers from the 3 million today to 25 million. If there will be 2.2 households per meter (as today), EEU needs to have only 11 million metered customers in 2030.
    - The importance of reducing share connections must be weighed against the benefit of supplying electricity to more households.
- **Develop an indicative plan for how off-grid solutions should be divided between solar home systems and mini grids.** It is suggested to reserve mini grids to those remote areas that would not be connected to the grid before 2030. Solar home systems could then be the main bridging technology for all areas that would be connected to the main grid before 2030.
- **Tariff structure should be revisited.** The incentive for Ethiopian's DSO (EEU) to connect new households may be reduced due to below-costs tariffs and the fact that the progressive tariff could reduce revenue when shared connections are reduced (a meter supplying several households could end at the most expensive tariff step). Both the households with existing meters and those with previous shared connection may end at a lower tariff step (see tariff in Chapter 2).

- **Improve statistics for the security of supply in the main grid.** Introduction of a small number of meters with remote reading would make it possible to monitor progress in improving the security of supply. Current statistics describes the interruption of lines, however monitoring with an end-user perspective seems highly needed.

The other side of electrification to energy access is the sector linkages from the energy sector to other sectors. This sector linkage of electrification is increasingly important – also for reaching the Ethiopian NDC targets. Below this is illustrated with regards to transport and the use of biomass.

Electricity in transport

The demand for imported fuels for transport is growing, increasing the burden on the trade balance. Thus, the country is a net importer of oil products, and this import is expected to increase. However, there is a potential to substitute oil, first of all through electrification of the transport sector. Electricity can substitute gasoline and diesel in cars, trucks, and busses. This also highlights a significant potential for reducing emission and reaching the targets of the Ethiopian NDC to the Paris Agreement – both in the form of local pollution and greenhouse gas emissions. The Ethiopian Ministry of Transport aims to incorporate around 150,000 vehicles by 2030, increasing electricity demand by only 2%.

The cost of batteries is currently decreasing and from 2025, electric vehicles are expected to be competitive with traditional car. Recent research also indicates that plug-in hybrid vehicles in practice are operated more on fuel and less on electricity – compared to earlier estimates. Policy to promote electricity in transport could benefit from focusing only on 100% electric vehicles (not plug-in hybrid, PHEV). As batteries are getting cheaper, it is also expected that longer range will become standard – so the electric vehicles will improve their competitive advantage over traditional as well as plug-in hybrid cars. This may make it attractive to promote electric vehicles in Ethiopia. Possible policy initiatives can include:

- A plan for developing nationwide infrastructure with charging stations could be a good preparation. The scope of electric transport can go beyond small cars and buses, scooters and trucks can also be electrified. The hydro-based electricity supply implies that Ethiopia seems to be well equipped for a significant shift (leapfrogging) in its transport fleet to electric vehicles.

- Broaden the goals for electricity in transport to include all forms for transport (also three-wheelers, motorcycles, busses and trucks) and to formulate goals beyond 2030.

- Develop a comprehensive plan for the framework to support the introduction of electric vehicles, including taxes, a plan for charging stations, and other incentive to promote electric vehicles (e.g. free access to express ways, prioritised lane);

Biomass

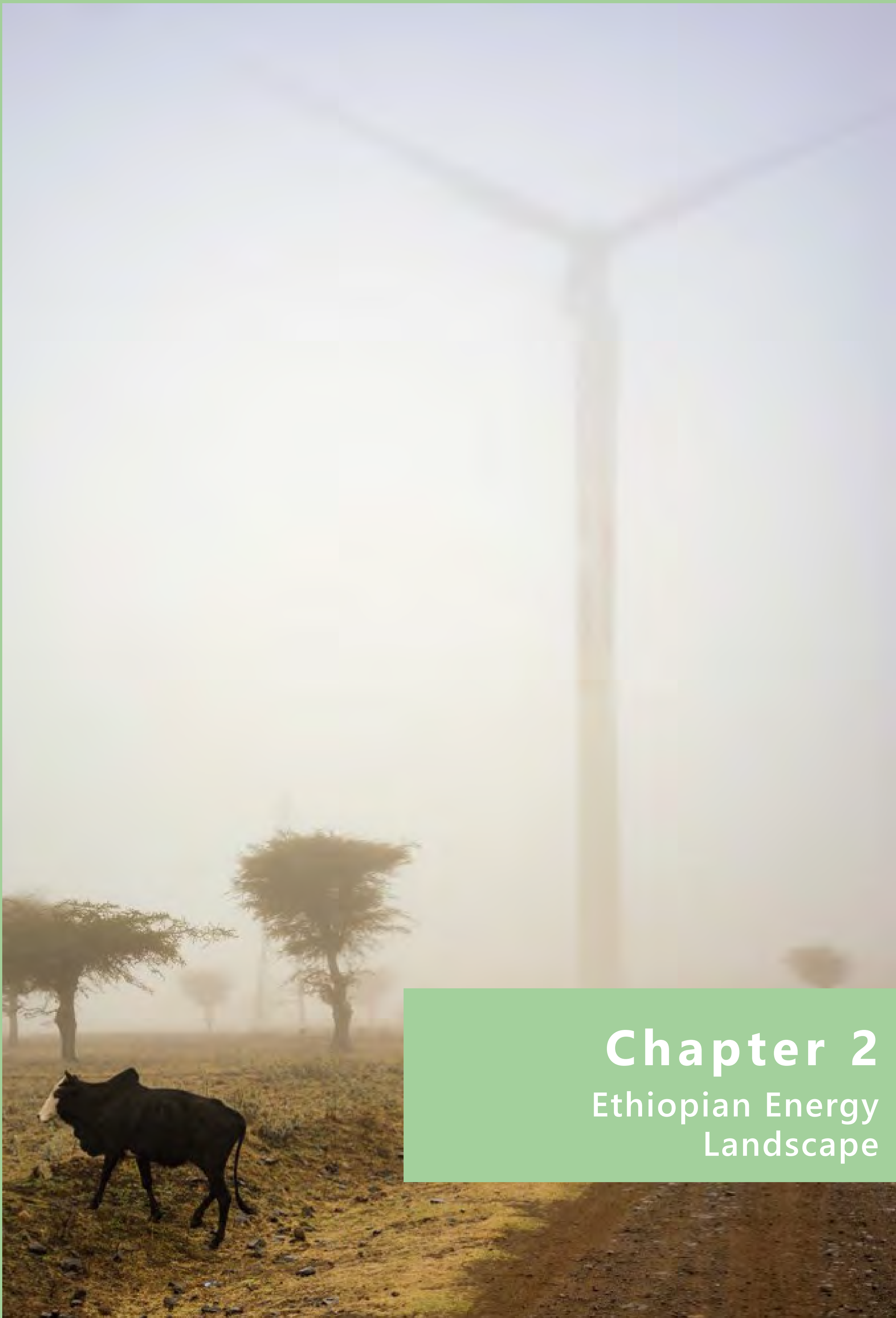
Biomass is by far the dominating energy source in Ethiopia accounting for 86% of total primary energy supply and the demand is still increasing. Fuelwood constitutes the largest share of fuel. The use of traditional biomass has negative consequences, e.g., indoor pollution and unsustainable management of forests. Efforts like electrification and the promotion of efficient stoves can help reduce the biomass consumption.

Woody biomass resources are overexploited, while biomass residues and other substitutes are underutilized. Two thirds of the fuelwood supply is unsustainably sourced from natural high forests and woodlands. It is estimated that the consumption of woody fuel is twice as much as the annual sustainable yield. Continued unsustainable biomass use will exacerbate climate change and affect the health and productivity of forests and woodlands and thereby reduce future wood supplies. Ethiopia produces a substantial amount of biomass residues. The total potential is estimated at 750 PJ per annum (47% forest residues, 34% crops residues, 19% livestock waste, corresponding to 35% of total energy supply. Parts of this largely untapped source of energy could be used for cooking, and for e.g. industrial process heat, such as cement production.

Fuel wood use could be considerably reduced through an increase in energy efficiency of cooking technologies as well as through substitution of wood by other sources such as biomass waste, LPG, ethanol and electricity.

To make electricity for cooking attractive, the security of supply of electricity from the main grid must be improved. Culture and tradition may slow the transition away from biomass in cooking. Population growth (400,000 new households per year, (MoWIE, 2019, a)) is also a factor in the continued growth in the use of biomass.

Energy Landscape



Chapter 2
Ethiopian Energy Landscape

2. ETHIOPIAN ENERGY LANDSCAPE

The role of the energy sector in the social and economic development

Ethiopia is the fastest growing economy on the African continent and the third fastest growing economy in the world. During the period of 2010-2020, the economy grew by an annual average rate of 9.2%. The fastest growing sectors were the industry with an annual growth rate of 23%. As a result of the economic growth, poverty rate has dropped from 30% to 24% during the 10-year period (Planning and development commission).

The past 10-year period also has seen a number of challenges. The growth has been largely driven by import: Import share of GDP stood at 26% while export stood at 10%. Unemployment has increased slightly over the period and stood at 19% in 2020. Much of the infrastructure investment has been debt financed and the external debt has increased significantly; transition from low-productivity to high-productivity sectors has been slow; investments have been hampered by limited access to finance and provision of social services and basic infrastructure have been deficient. Also, there is a lack of skilled manpower (Planning and development commission).

The rapid growth is expected to continue for the years to come, and the country intends to reach middle-income status before 2025 (National Planning Commission, 2016).

A number of additional challenges can be foreseen in case of a continued conventional development. While greenhouse gas emissions are still low compared to the size of the population, emissions are due to increase significantly over the coming years. Main drivers of this development are increased cattle production, increased crop production, continued deforestation for expansion of agricultural land, forest degradation caused by fuel wood consumption, growth in transport, industry and buildings. As a result, greenhouse gas emissions would increase from 150 Mt CO_{2e} in 2010 to 400 Mt of CO_{2e} in 2030. In addition, the increase in demand for oil products would put a pressure on foreign currency reserves (Federal Democratic Republic of Ethiopia, 2011).

In order to mitigate these and other challenges, the government has launched a green economy plan focusing among others on protection of forests, expanding electricity production from renewable energy for domestic and regional markets and promotion of energy efficient technologies in transport, industries and buildings.

The specific ways in which the energy sector is going to develop could have a large impact – positive or negative – on the above-mentioned challenges and concerns, for example:

- A successful electrification program would significantly support social and economic development in rural areas.
- A more reliable supply of electricity could increase productivity throughout the economy, support the development of high-productivity sectors, which are most often also more energy intensive, and thereby indirectly support the strength of the export-oriented sectors and increase the employment rate.
- Abundant domestic energy resources such as hydro, solar, wind and natural gas offer an opportunity of energy exports to the neighbouring countries and beyond, which would in turn improve the international trade balance and boost the foreign currency balance.
- A conventional growth of private transport driven by petrol and diesel would increase CO_2 emissions and burden the currency balance. This could be avoided through a well-planned electrification of the transport sector.
- A shift of cooking technology away from inefficient and wood fuel demanding cooking stoves towards more efficient stoves and non-wood fires stoves could vastly reduce the degradation of forests.

A successful and rapid development of the energy sector depends on other developments in the society. Particularly the infrastructure needed to supply the whole society with electricity calls for large financial resources of which the government can only secure a limited share. Private investment can be encouraged by securing better access to finance and by reducing investment risks in the sector. Also key energy sector institutions must be strengthened: financially they need to be strengthened by securing the financial sustainability, and in terms of capacity they must be provided with trained staff and a reliable chain of supply of hardware components needed for the expansion and operation of the infrastructure.

Ethiopia's contribution to the global greenhouse gas emissions is only 0.04%. However, the country is very vulnerable to climate change, the effects of which are already seen in the form of higher intra-year and inter-year variability of rainfall. The droughts and floods increase risks of soil erosion, food insecurity and increased levels of conflicts over access to resources (Federal Democratic Republic of Ethiopia, 2021).

The historic emissions, the business as usual development and the nationally determined targets are shown in Figure 3. In 2030 business as usual, Land Use Change and Forestry, LUCF accounts for 48% of emissions while livestock accounts for 35% of emissions. The energy sector accounts for only 3% (Federal Democratic Republic of Ethiopia, 2021).

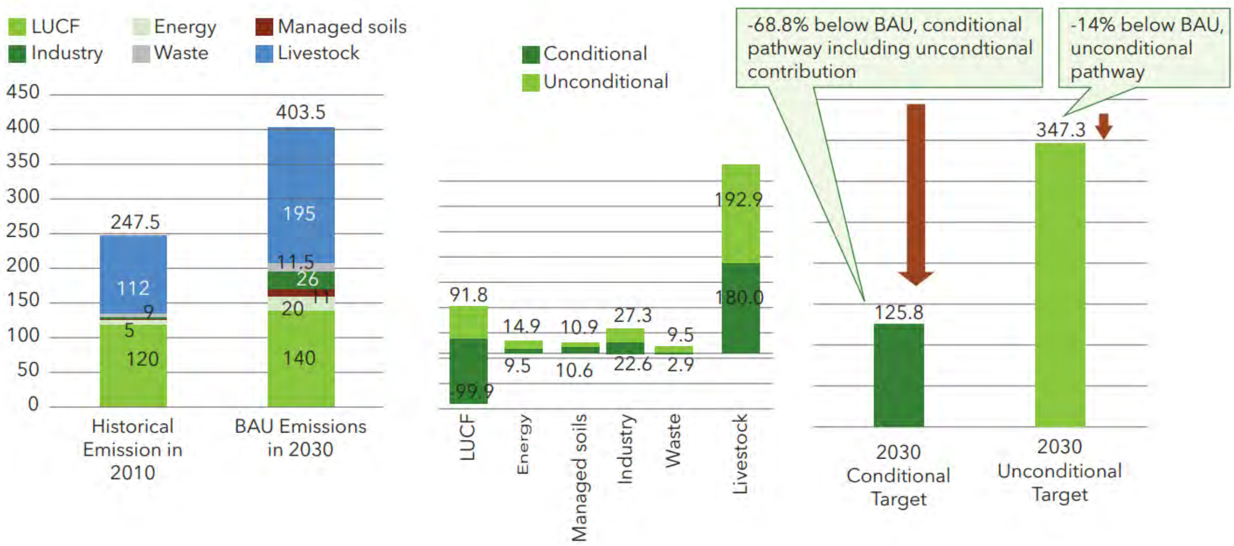


Figure 3: Historic, baseline and nationally determined GHG contributions (Mt of CO_{2e}). Source: Federal Democratic Republic of Ethiopia, 2021

The energy balance

Energy consumption in Ethiopia is strongly dominated by biomass (86%) followed by oil products (11%). Wood used for cooking in the rural households is a major part of the Ethiopian energy consumption.

Electricity only accounts for 2.4% of final energy consumption.

	Biomass	Oil	Coal	Electricity	Sum
Industry		0.8%	0.9%	0.5%	2.2%
Households	85%	0.4%		1.4%	87%
Transport		10%			10%
Other	0.7%			0.5%	1.2%
Sum	86%	11%	0.9%	2.4%	100%

Table 2: Total final energy consumption. 2017/2018. 100% = 1,668 PJ. (MoWIE, 2019, b)

Oil and electricity demand are projected to grow by about 10% p.a., but also biomass demand is projected to grow. Total energy demand is projected to grow by 34% from 2018 to 2030 (Figure 4).

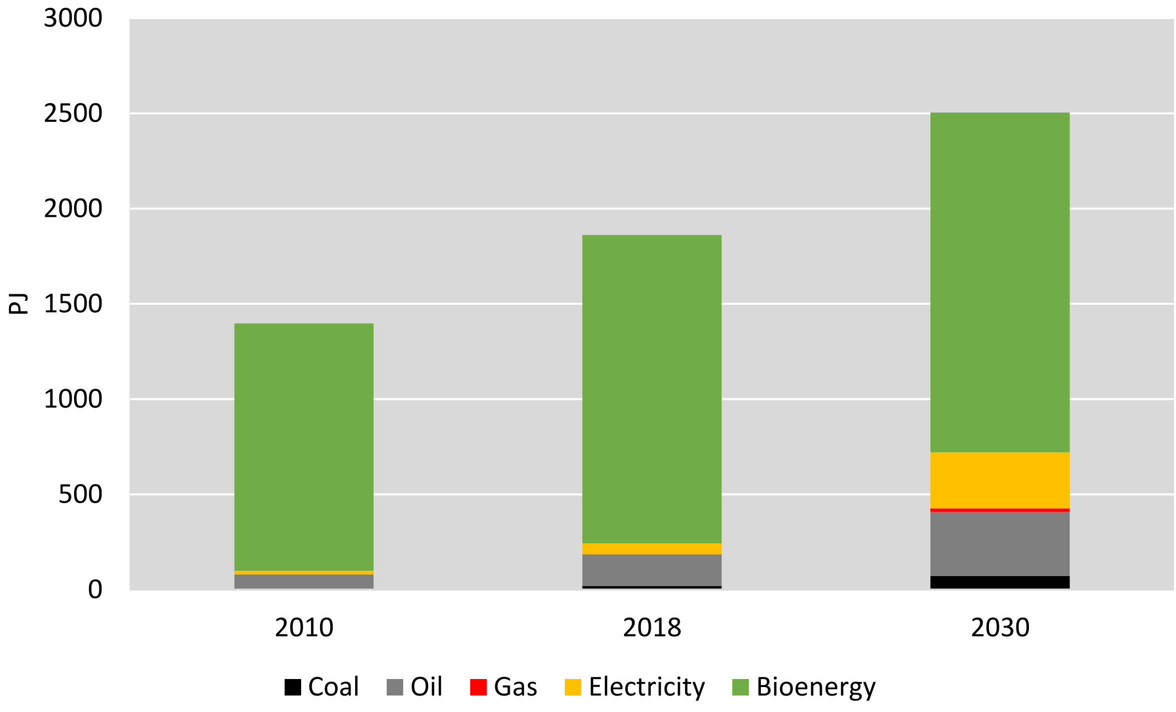


Figure 4 Historical and projected final energy demand. Source: IEA

Electricity generation is dominated by hydropower (96%). The remainder is wind power (3%) and waste energy (1%)

Domestic energy resources

The main energy resources of Ethiopia are the renewable sources of biomass, hydropower, solar and wind energy, as well as natural gas.

The total sustainable production of biomass in the country is almost 200 million tonnes/year. This exceeds the annual consumption of 128 million tonnes/year by 54%. While woody biomass is excessively exploited in an unsustainable way, biomass residues are only used by some 30% (UNEP, 2018).

In addition, ethanol is produced as a by-product of sugar production. Current output is 32 million litres/year. After implementation of planned sugar production capacity, output is expected to increase to 339 million litres/year, corresponding to around 10% of current transport fuel consumption.

A total technical hydropower potential of 159 TWh/year has been identified (Hailu, 2021), of which less than 10% is currently being exploited.

In addition, the solar and wind energy resources exceed current electricity demand by several orders of size (IRENA, 2014). Solar and wind power has large technical potentials and expansion is limited by economy – not by land area.

For wind energy we estimate that the short to medium term viable potential considering wind resource as well as distance to the grid amount to around 5 GW. For comparison, the annual electricity demand in 2020 was 14 TWh.

In addition, natural gas reserves have been identified. A total of up to 10,000 PJ have been found, and there is likely more to be discovered. Most of the contracted natural gas is committed for export, while a minor share is expected to be used for production of fertilizer.

Electricity supply

One of the top priorities of the GoE is to secure equal access to energy, particularly electricity. Stable and low-cost electricity is key to the development of the economy as well as to provision of welfare services, light, communication etc.

Power outage and lack of access to electricity are top two and three when companies rank business constraints (UNDP, 2017). The sustainable and reliable development of the electricity sector is therefore an important element in the socio-economic development and growth targets in Ethiopia. In 2020, the national electricity demand was 14 TWh (incl. losses).

The annual demand growth in the period 2001-2020 has been 12% p.a. (see Figure 5). The growth is driven by a strong socio-economic growth and increase of customers connected. However, there is still a long way to full access to reliable electricity supply. The majority of households have no access to electricity, and interruptions in power supply is frequent, although diesel backup generators are to some extent available.

In 2017, a survey explored the degree of supply of electricity to households. This survey shows that 44% of households have some supply (including supply from main grid, mini grids as well as small, individual solar home systems). It is important to note that only 4.5% of these households have a supply of more than 23 hours per day. See Figure 6. Electrification is analysed in chapter 3.

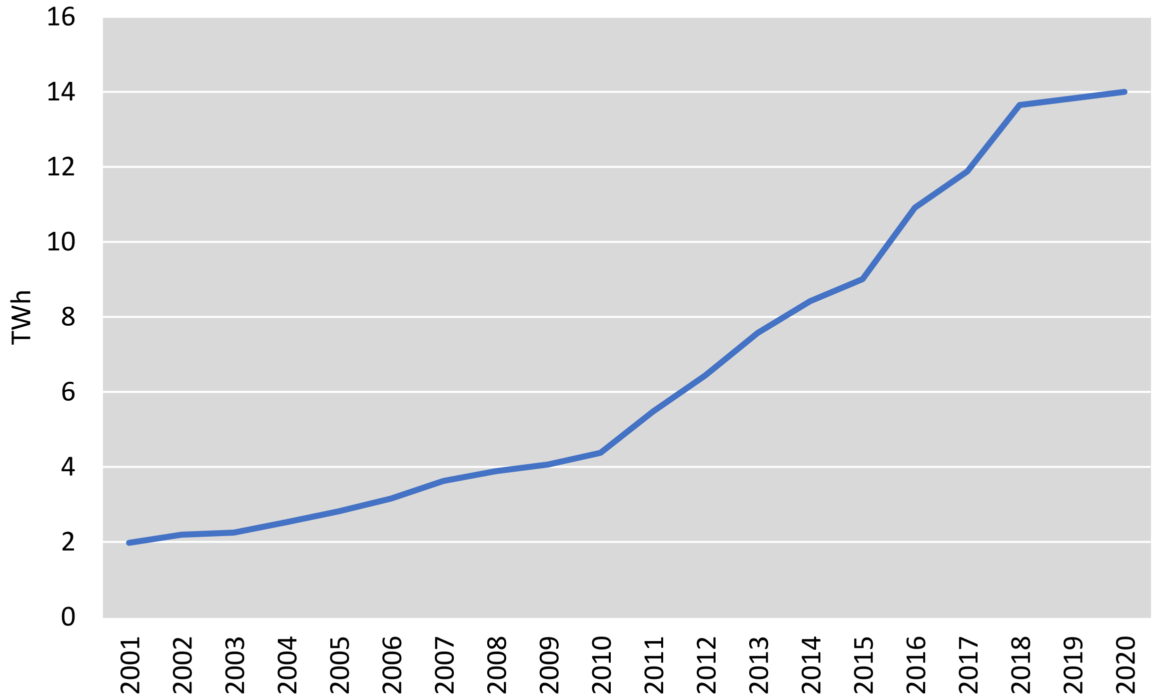


Figure 5: National electricity demand (incl. losses, excl. export).

One of the major challenges to reach general access to reliable electricity supply is the mobilisation of the required funding. The Ethiopian Electricity Utility, which is responsible for the distribution system, is underfunded as a result of below-cost electricity tariffs.

For households, the tariffs were unchanged in the period 2007-2019 at 0.47 Birr/kWh – resulting in a sharp decrease in the real cost for electricity due to inflation, with the revenues being far below actual costs. From 2019 to 2021, a tariff reform has resulted in increased tariffs – except for the lowest demand levels. The household tariff is a progressive tariff with seven steps (see Figure 7). If the monthly demand is e.g., 51 kWh/month, the whole demand is paid by the second tariff step. Further increase of the tariff is needed to make it cost-reflective. Tariffs below cost may be a disincentive for EEU to connect new consumers (GoE, 2016).

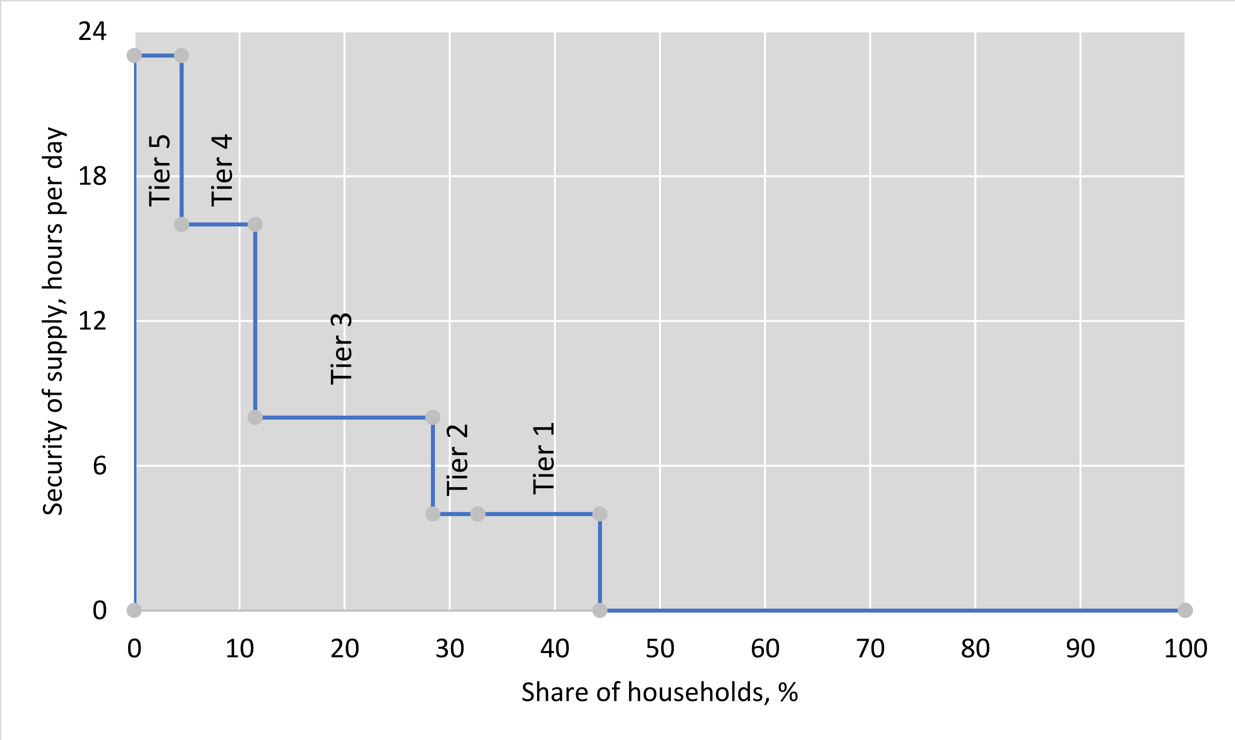


Figure 6: 2017 survey about supply of electricity to households. The difference between Tier 1 and 2 is the electricity load. Tier 1 has a load less than 50 W, while tier 2 has a load between 50 and 200 W.

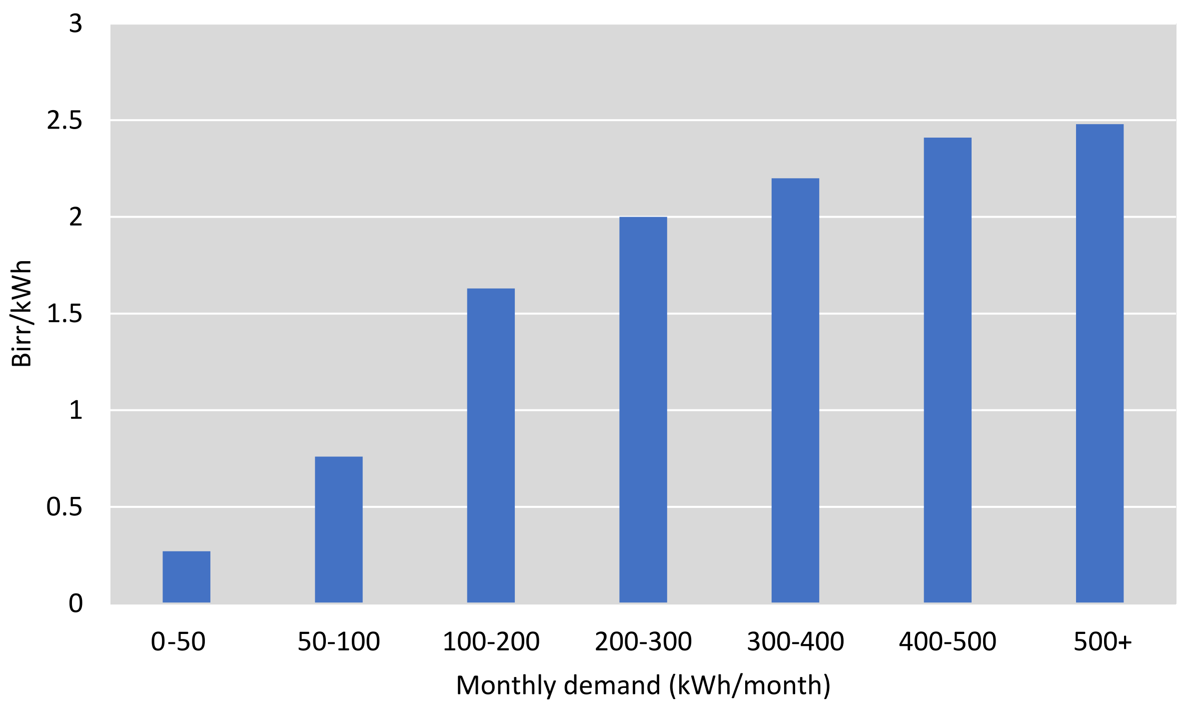


Figure 7: Household electricity tariff. 2021.

Key institutions in the power sector are the generation and transmission company EEP, the distribution company Ethiopian Electricity Utility (EEU), and the regulator Ethiopian Energy Authority (EEA). All three institutions are accountable to the Ministry of Water and Energy (MoWE).

Currently, sector reforms for the power sector are underway with the following elements considered (MoWIE, 2020):

- Provision of Universal Access
- Ensuring Financial Sustainability
- Operational Performance Excellence
- Regulatory Framework Strengthening
- Institutional Framework and Governance Improvement and
- Sector Restructuring and Contractual Framework

Energy efficiency

The regulator, EEA, has a focus on energy efficiency, standards and labelling and is developing a number of activities in this area (EEA) (EEA, 2018). Activities are planned in cooperation with Ministry of Trade, Ministry of Construction, Ethiopian Standard Agency, Ethiopian Roads Authority, EEU and industry. EEA and EEU have agreed to promote solar water heaters. Incandescent lightbulbs are not allowed anymore, however illegal import takes place. Increased monitoring and sanctions is planned. The first certified industrial energy auditors have been educated.

Activities with high priority includes:

- Energy efficiency awareness campaign
- Energy auditor and manager training
- Energy audits and voluntary agreements for industry
- Lighting standards and labelling
- Efficiency labelling program
- Electric motor standards
- Injera mitad standards
- Electric cook stove standards
- Efficient injera mitad manufacture
- Efficient welding systems

Also, on the supply side, EEU and EEP have a focus on reducing losses in the transmission and distribution of electricity. The supply and demand side management for energy efficiency will increase as tariffs become cost reflective. The recent increase of tariffs has led to increased interest for energy efficiency.

Economy and foreign currency

The energy sector of Ethiopia plays a key role in the economy. Energy supply is crucial for the social and economic development. The sector also has a considerable potential to generate export revenue from sale of electricity. At the same time, the development of the energy sector requires large investments, of which most depend on foreign currency.

The Government of Ethiopia (GoE) is focusing on improving economic conditions to increase investor presence. In 2019, the GoE initiated a series of reforms under its "Home-grown Economic Reform Plan" to improve economic conditions in Ethiopia. These reforms aim to transform Ethiopia to a lower-middle-income country by 2025 and are supported by the International Monetary Fund (IMF). The plan focuses on macroeconomic, structural, and sectoral reforms. Macroeconomic reforms will address foreign currency shortages, high inflation rates and debt vulnerabilities as well as improve access to finance. Structural reforms will aim at easing business constraints, e.g., by streamlining bureaucratic and regulatory procedures. Sectoral reforms will address sector-specific institutional and market failures. In this way, the reforms aim to build confidence in the Ethiopian economy as well as rebalancing growth and enhancing productivity.

Foreign exchange regulation and access to financing and foreign currency shortage are some of the most problematic factors of doing business in Ethiopia. Other challenges are high inflation, high unemployment and high debt burden. Provision of quality services (electricity, water, telephone, internet) together with weak institutional capacity are seen as key challenges (GoE, 2020), (WEF, 2018) , (UNDP, 2017).

To address foreign currency shortages, the Ministry of Finance is currently exploring the option of creating a revolving currency fund for PPP projects in the country. A revolving currency fund guarantees forex convertibility of PPP payments if the project company has no access to or cannot procure foreign currency through commercial entities. In this way, the project company will be able to safeguard the project against possible difficulties in accessing foreign currency.

PPP contracts' currency convertibility risk can be explained by the recent development in the ETB's exchange rate (see Figure 8). Here, the ETB has depreciated against the USD. Given the contract construction with payments in ETB and many costs in foreign currency, the exchange rate development below creates uncertainty for contractors. Better access to and payments in foreign currency would mitigate this risk profile of PPP contracts.

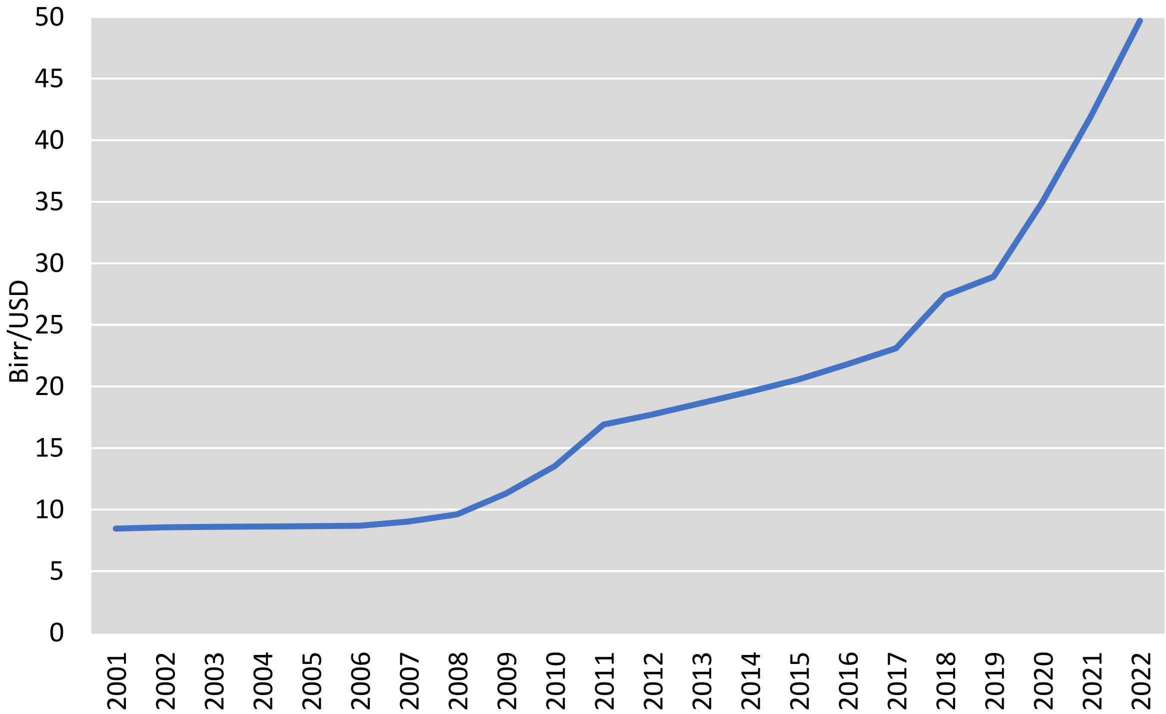
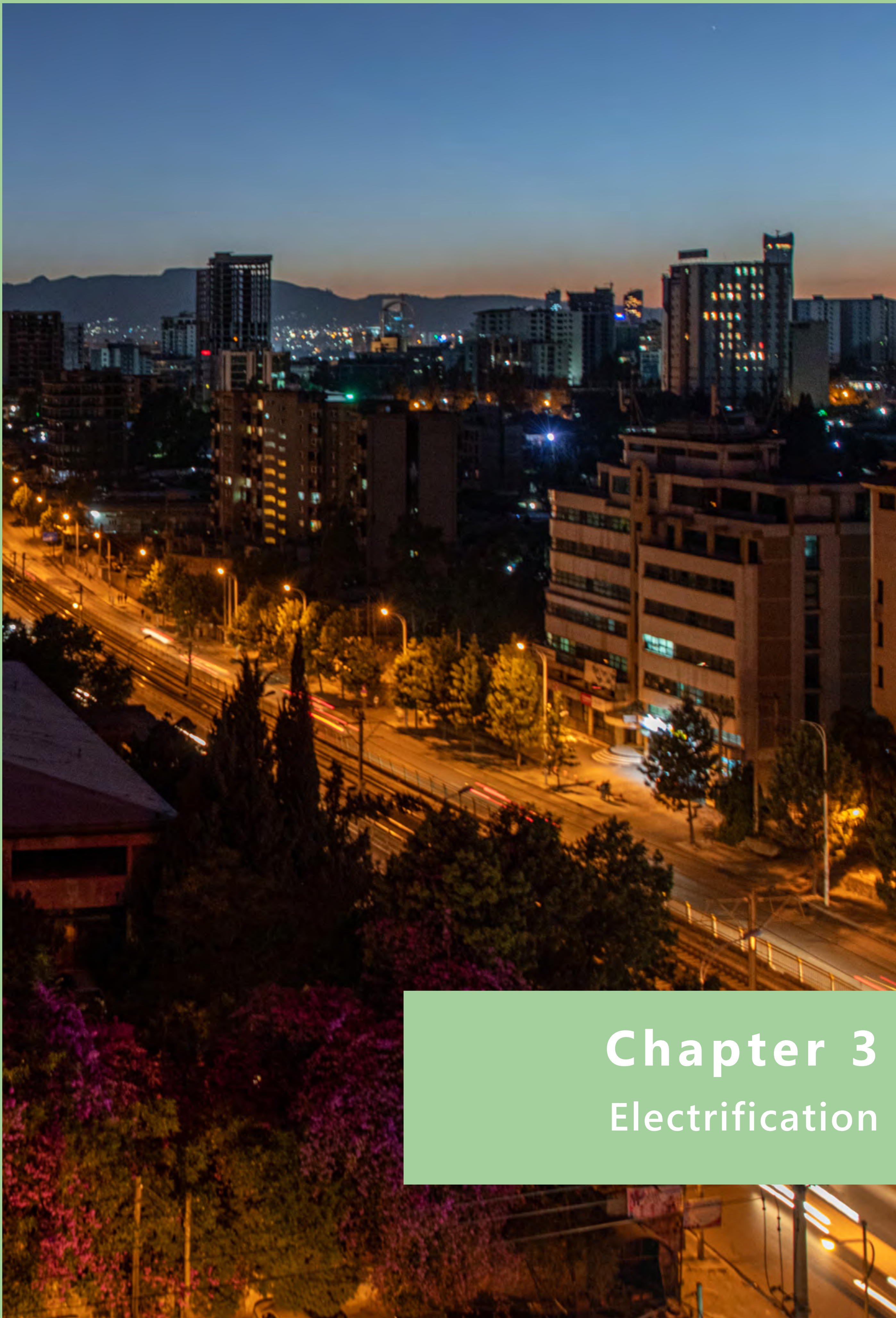


Figure 8: ETB/USD-exchange rate



Chapter 3
Electrification

3. ELECTRIFICATION

Achievement of universal access to electricity is one of the most important energy sector goals set by the government. Energy access is a catalyst to wider social and economic development, enabling education, health improvements, sustainable agriculture, and job creation. Access to energy is particularly important in terms of enabling local business innovation and creating a more vibrant economy for communities and countries, while also providing societal benefits (SE4ALL, 2012).

Ethiopia has implemented different programs and initiatives to enhance access to electricity. The first major rural electrification initiative was started in 1999, when the government undertook the implementation of the Rural Electrification Project. The project essentially focused on extending the electricity network to Woreda (district level) towns and major towns located close to sub-stations or existing distribution lines. In total, 164 towns were electrified from 1999 to 2004. In 2005, the government introduced the Universal Electrification Program (UEAP) to enhance grid electricity coverage to rural towns and villages throughout the country.

The UEAP is more ambitious than its predecessor, the Rural Electrification Project. Launched in 2005 for a five-year period, the UEAP primarily includes expansion of transmission and distribution networks. It also includes some generation, for example, the construction of nine small-localised off-grid electric power-generating stations. The main objective of the program is to promote socio-economic development in rural areas of the country by expanding the electricity network coverage to 90%. The scope of the program includes extending transmission lines, building substations, expanding low voltage distribution networks and installation of transformers. However, the tasks of connecting to individual customers has not been included in the scope of the UEAP. These tasks have been allocated to the distribution department in the Ethiopian DSO (EEU) (UEAP, 2016).

The UEAP is funded by several stakeholders, including the Ethiopian government, which allocates 2.5 billion ETB per year. Some of the other partners include the World Bank, Bank of Arab for Economic Development in Africa (BADEA), the Kuwait Fund, African Development Bank (AfDB) and bilateral cooperation from development partner countries such as the Indian Government (UEAP, 2016).

The Government of Ethiopia (GoE) formulated its new National Electrification Plans (NEP and NEP2.0) in 2017 and 2019, which strive for universal electrification by 2025 via a mix of on and off-grid electrification efforts to accelerate the electrification rate (MoWIE, 2019, a). More specifically, the 2017 NEP action plan stated that by 2025, 65% of all households should be connected to the main grid, and 35% should have access to off-grid technologies (individual solar systems and mini grids). While the EEU will be the primary implementing agent for the grid program, off-grid scale-up will be a combination of EEU and private efforts. By applying both on-grid and off-grid solutions, it is possible to:

(i) Balance efficiency and equity in the provision of access to electricity services,
(ii) Maximising the reach of the electrification program while minimising the time required before all Ethiopians have access to electricity services, and
(iii) Supporting economic growth and human development.

The key operational activities to achieve the NEP 2.0 targets are:

- A fast-paced, ambitious grid connection rollout program implemented by the EEU, and designed to scale up connectivity from 5.7 million households today (2020), to over 15 million households by 2025 (65% of the population in 2025).
- The rollout of a complementary off-grid access program (via a combination of public and private-led efforts), to provide access to electricity services for the remaining 6 million rural and deeply rural households without grid connectivity (35% of the population in 2025)

- Special focus on primary and secondary schools, hospitals, and primary health centres. In addition, the NEP prioritises connection (grid or off-grid) to locations with high economic growth potential, particularly in the agriculture sector.

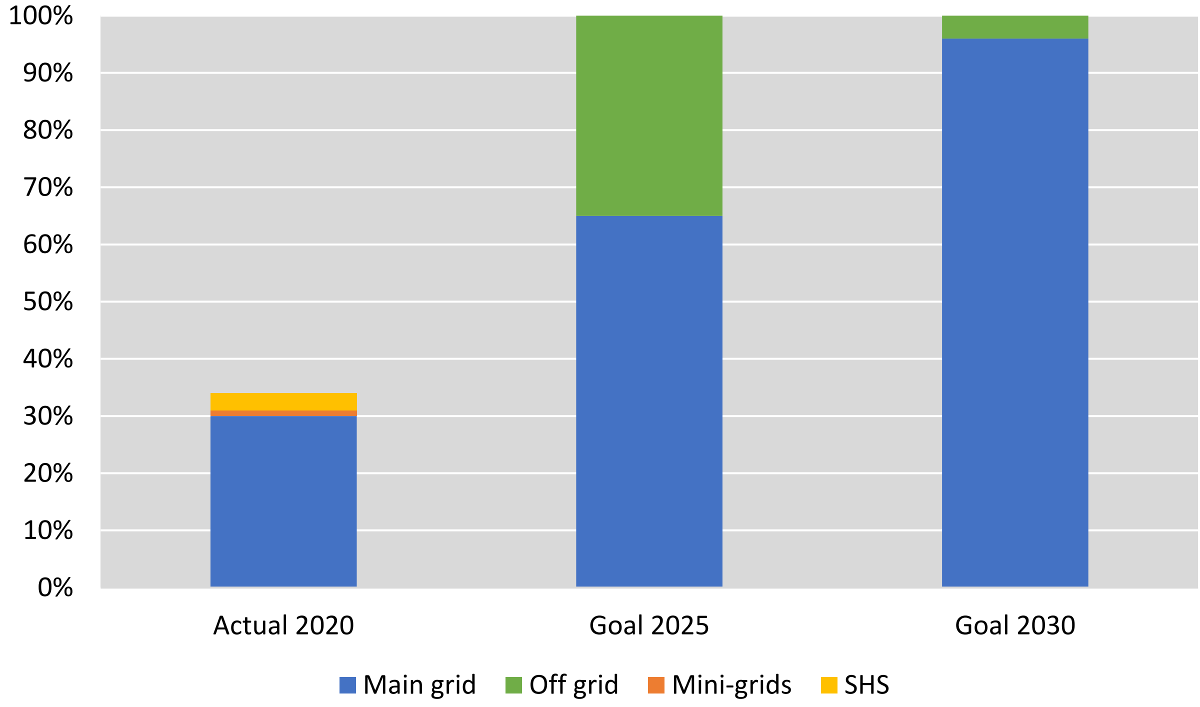


Figure 9: Goals for electrification for 2025 and 2030. Values for 2020 are estimated.

The overall financing requirements of NEP amount to USD 6 billion (USD 3.2 billion for grid, USD 2.5 billion for off-grid and USD 0.5 billion for a technical assistance component). For the off-grid component, the Government contribution is estimated to cover roughly 40% of the USD 2.5 billion cost, with the remaining portion being financed by development partners and private sector resources. By 2030, it is estimated that roughly 96% of the national population will reside within 25 km of the main grid and will therefore be most cost-effectively served by connecting to the main grid.

Based on experiences acquired during the first year of implementation of the NEP as well as geo-spatial analysis conducted in 2018, the NEP was updated. Furthermore, in 2019, a nationwide GIS least-cost connections rollout plan was finalised and provided a more detailed optimal sequencing of connections with associated costing. The NEP grid program also accounts for the activities conducted over the year and the progress achieved. It identifies the immediate program implementation support and technical assistance required, and activities needed for implementation of the NEP program. The NEP least-cost rollout strategic plan is underpinned by the following defining metrics of the spatial distribution of population clusters:

- It is estimated that 75% – 80% of the population lives within 5 km of existing lines, and 90%of the population resides within 10 km from existing lines.
- Electrification programs and utilities in most communities within 5 km of existing grid lines would be considered as targets for grid expansion within the short term, and a 10 km distance from the existing grid is considered to be within close range to the grid. The NEP grid program is designed to leverage the substantive extension of the grid infrastructure achieved by the UEAP program over the past decade, the plans for further extension, and the advantage offered by the proximity of the majority of the population to the existing network infrastructure.

- Around 96 percent of the current and future national population (by 2030) is estimated to reside within 25 km of existing grid lines and so will be most cost effectively served by grid expansion over the medium to long term.
- Despite the significantly higher connection cost, EEU does currently provide connections to customers within 100 km from a substation ("grid radius").

Grid-connected households

Population growth is resulting in an average of 410,000 new households per year, and this is also a driver for growth in connected customers. In 2021, around one third of all Ethiopian households (roughly 6.6 million) had a connection to the main grid. [1] This includes shared connections, where one meter typically supplies electricity to an average of 2.2 households.[2] During the last five years, the number of new EEU customers has averaged roughly 220,000 per year, with 387,864 (end of June 2021) new households being connected in the last 12 months. As such, despite the focused efforts to connect households, the number of new households continues to outpace the number of newly connected households.

A progressive tariff is used for billing electricity consumers, i.e. consumption at lower volumes is charged at lower rates, and vice versa. As such, connection of multiple households to a single meter results in higher tariffs being charged. Thus, there is a difference in the incentives for EEU and the consumers respectively when it comes to installing single meters. For EEU, there is a lack of incentive for all households to receive their own meter, as this will decrease tariffs paid. Conversely, consumers are incentivised to receive their own meter. Currently, there is a long waiting list for being connected and receiving an individual meter, where a deposit has already been paid for the connection.

	Households	EEU	Shared	Total	Share
2021	21.6	3.0	3.6	6.6	31%
2025	23.2			15.1	Goal: 65%
2030	25.2			24.2	Goal: 96%
	Mill.	Mill.	Mill.	Mill.	-

Table 3: Households connected to the main grid

The number of shared connections is uncertain today, and will likely be uncertain in the future. However, the number of shared connections, and how this develops going forward will influence the extent to which the NEP goals can be achieved. To illustrate this, the three scenarios described below have been analysed. The results of this scenario analysis are displayed in

Table 4.

- Scenario 1: The number of households per meter is reduced from 2.2. today to 1 in 2030 (0 shared)
- Scenario 2: The number of households per meter is reduced from 2.2 today to 1.6 in 2030 (50% reduction)
- Scenario 3: Constant number of households per meter (2.2)

[1] In NEP 2.0 it is assumed that there are 21.2 million households in 2020 and there will be 25.2 million in 2030.

[2] A shared connection can be with an extension line to another house. Typically, the electricity will be paid by the household with the meter, and the costs may be shared. This form of connection is illegal, and the connection may not be safe. To provide insight into the extent of shared connections, data for Addis Ababa has been studied. The EEU has 715,000 household customers in Addis Ababa and assuming there are 1,040,000 households, and that 95% have electricity, this corresponds to 1.4 households per meter. This is lower than the assumed national average of 2.2, however the factor may be higher in rural areas.

	Households	EEU	Shared	HH / meter	New meters per year
		Scenario 1: No shared by 2030			
2025	23.2	9.4	5.7	1.6	1.6
2030	25.2	24.2	0	1	3.0
	Mill.	Mill.	Mill.	-	Mill./year
		Scenario 2: Half shared by 2030			
2025	23.2	7.9	7.1	1.9	1.2
2030	25.2	15.1	9.1	1.6	1.4
		Scenario 3: Same shared by 2030			
2025	23.2	6.9	8.2	2.2	1.0
2030	25.2	11.0	13.2	2.2	0.8
	Mill.	Mill.	Mill.	-	Mill./year

Table 4: Three scenarios to fulfil the electrification goals – with different shared meters.

As highlighted in the table above, assumptions regarding the number of shared meters have a significant impact on the number of required new EEU meters per year to reach the NEP 2.0 goals. For example, in a scenario where the number of shared meters per household is unchanged (Scenario 3), this will require 1.0 million new meters being installed during 2021-2025, and 0.8 million per year during 2025-2030. However, at the other end of the spectrum, if the number of shared meters per household is reduced to zero by 2030, then these respective values increase to 1.6 million per year during 2021-2025, and 3.0 million per year during 2025-2030.

The resulting development in the total number of EEU connections towards 2030 in the three scenarios given the above input assumptions are displayed in Figure 10.

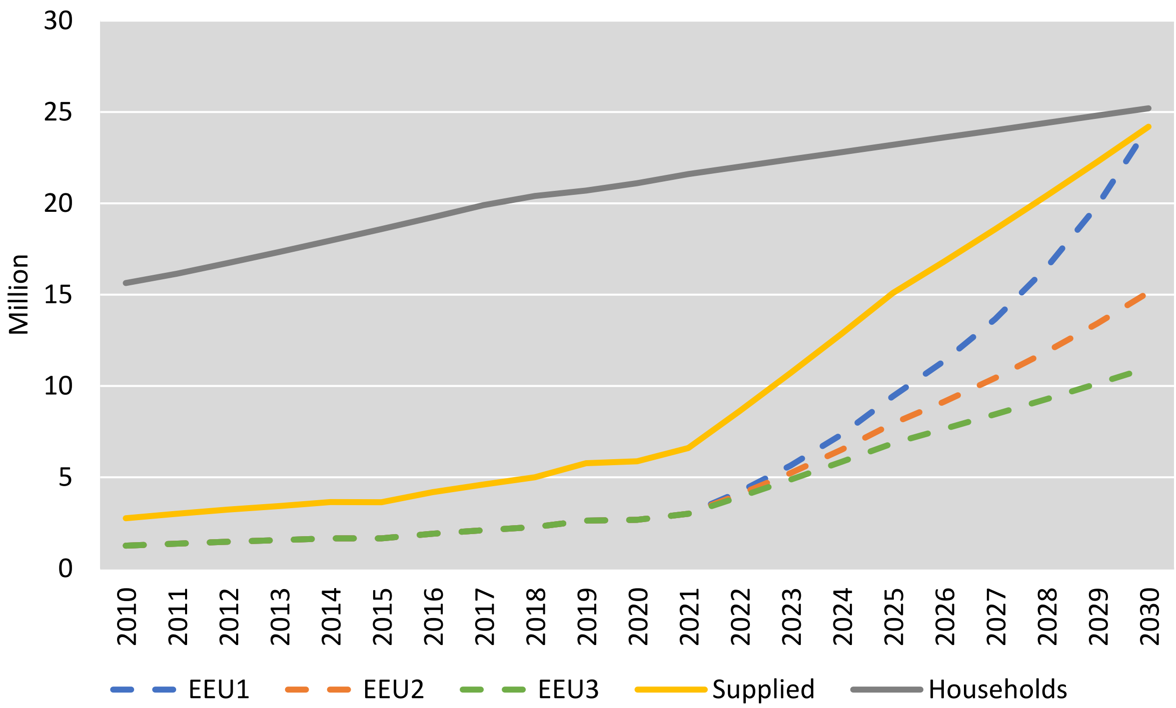


Figure 10: Number of total households and households with electricity supply. Three scenarios (EEP1-3) for the development of Share of households (2022-2030). The electrification goals are assumed to be fulfilled (Yellow line). See

Table 4.

Recalling that the number of new connections has averaged roughly 220,000 the past 5 years and nearing 400,000 for the 12 months up to June of 2021, the current rate at which new households are connected is not sufficient to reach the NEP goals, particularly when taking into consideration forecasted population growth. To meet the targets, new EEU connections will need to increase with a factor of 3 to 5 (dependent on the assumption regarding the number of future shared connections) until 2025 and a factor of 2.5 to 10 during the 2025-2030 period.

The main challenges for the electrification are lack of finance and challenges with import of equipment. In addition, the distribution infrastructure including substations need upgrading and expansion, and access to qualified manpower is a challenge. Shared connections enables a greater number of household to access electricity but has a number of disadvantages for the consumer including, increased tariff payments, reduced supply quality and potential safety risks, due to insecure connection.

Ethiopia Electrification Program, ELEAP

The Ethiopia Electrification Program, ELEAP, (backed by the World Bank) is supporting the implementation of the NEP, with a focus on scaling-up electricity connections in areas within the network reach. ELEAP has three pillars:

- On-grid electrification
  - The procurement of materials (meters, cables) for roughly 1 million household connections has been completed
- Off-grid service, stand-alone solar systems, and mini grids
  - 12 pilot solar mini grid contracts have been signed and implementation is underway. Eight projects have been commissioned with a total of 2,500 customers.
  - 25 additional solar mini grids which are financed by the AfDB and the GOE are under design and in the bid preparation stage
  - 250 solar mini grid projects are in the feasibility study stage.
- Sector capacity and institutional reform

The ELEAP is Payment-for-Results project, and the main objective is to connect 1,080,000 households to the grid during the 5-year period from 2019-2023. The project also procures materials that are necessary for the activities, and this is carried out by regional EEU and Universal Electrification Access Program (UEAP) offices.

In response to the ELEAP, EEU is working intensively to achieve the target, but there are delays due to several challenges. The main obstacles are delays in the procurement of goods, a lack of human resources, and capital shortage at national, regional and district levels of the EEU. To fill some of the gaps the government, through the Ministry, has committed to develop project proposals for the expansion of grid systems and increase accesses to electricity in the country.

EEU and MoWE are currently in the final stage of developing electrification projects and institutional restructuring to improve electrification efforts. This includes a targeted program component for social institutions such as schools, clinics, and industrial parks. Government supports of the development of micro, small, and medium enterprises and agro processing.

Off-Grid Program

The National Electrification Implementation Road Map (NEP-IRM) addresses the GoE's priority of advancing equity and inclusion and shared prosperity, irrespective of where one happens to live. This means ensuring that traditionally underserved rural populations and rural institutions such as schools, health centres, and administrative buildings are not left behind. In the pursuit of universal access to electricity, off-grid access provision plays a complementary and coordinated role alongside grid rollout.

The NEP includes the launch of an off-grid program, the implementation framework and operational design of which are informed by best practice and established international experience, especially in the solar products and systems market segments. In the achievement of universal access by 2025, off-grid solutions are expected to provide services to 35% of the population, while acknowledging possible short-term electrification solutions for those households and communities waiting to get a grid connection by 2025, for a total of 9 million beneficiaries.

To achieve prompt and adequate delivery of electricity services to the Ethiopian population, the components of the off-grid program are described below. To avoid stranded assets, and minimise the overall cost of supplying electricity, it is important that off-grid solutions, e.g. solar home systems and mini-grids, can continue operation and/or are compatible with grid connection after the beneficiaries receive on-grid connections, and suitable technologies are invested in. While solar PV systems may still contribute when connected to the main grid, batteries and diesel systems are likely to only have value where the grid is weak due to Ethiopia's vast reservoir hydro resources (which allow for low-cost integration of solar PV).

Short-term pre-electrification: The rollout of grid connections is estimated to take seven years to materialise, and numerous households will therefore have to wait an extended period of time before getting access to electricity services. The NEP therefore acknowledges the possible rollout of a short-term pre-electrification program. Estimated to encompass 3.3 million households within 2.5 km from existing lines, this pre-program would be private sector led and target those communities that are expected to receive a grid connection by 2025.

Mid-term pre-electrification: For the target beneficiaries residing between 2.5 and 25 km from the existing grid, connection to the grid is projected to be the least cost electrification option, but they may have to wait several years before they receive grid access. By 2025, the number of beneficiaries of off-grid technologies (off-grid solar or mini grids) is expected to be 8.1 million, corresponding to 31 percent of access in the country. Given their proximity to the existing network, these beneficiaries are expected to be connected to the grid by 2030. The eventual delineation of the geo-spatial location, number, and nature of prospective beneficiaries will be determined in coordination with the scale and speed of grid developments.

Long-term off-grid/deep rural: The last group entails target beneficiaries located beyond 25 km from the existing grid, which are largely remote and scattered household settlements and villages. They may also include some homes that are not far from the existing grid, but whose isolation from neighbouring settlements and transformers greatly increases the cost of connectivity. This categorise is estimated to comprise roughly 1 million households, or about 4 percent of the population by 2030. As their location is still within the EEU mandate (100 km), some locations may eventually be connected to the main grid in the long run, i.e., beyond 2030. The NEP off-grid program implementation framework focuses on two main technologies for service delivery to all segments: (i) solar off-grid solutions and (ii) isolated mini grids, as well as a coordinated combination of these technology solutions. The off-grid program is technology neutral, reflecting the needs of the population, and economic and administrative centres, as well as social institutions on the ground. However, the Government also recognises the opportunities offered related to the speed, scale, and improved quality of services offered by solar systems.

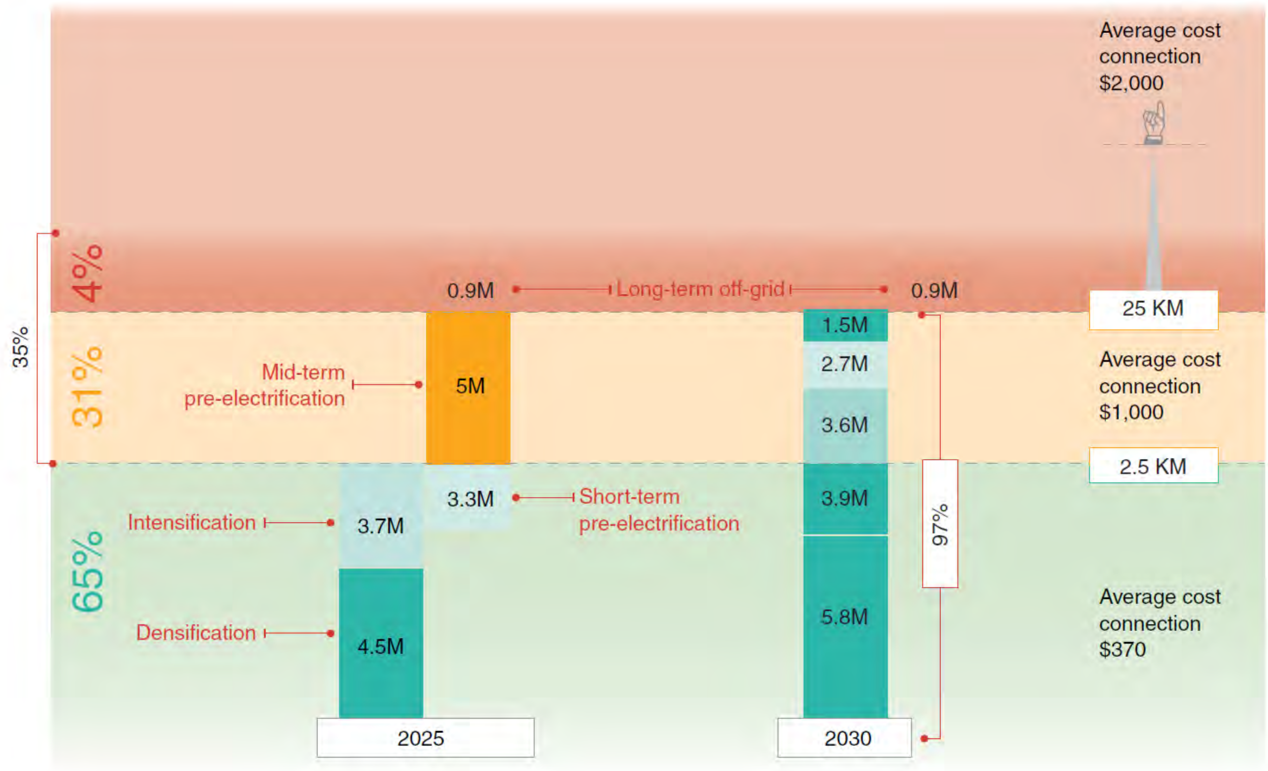


Figure 11: The national electrification program integrated on- and off-grid components.

Development in mini grids

Development of mini hydropower plants in Ethiopia started in the 1950s and they were the main electrification mechanism for rural populations for many years. As more areas become connected to the main grid, these mini grids dwindled in number. Of the more than 50 mini-hydro plants that were once in operation, less than five are left today, and all are operated and managed by local industries and NGOs. With an aim to assist in the national electrification goal and to improve grid stability, various stakeholders have recently initiated studies looking at the rehabilitation of these older plants as well as potential new plant development.

In 2018, it was estimated that 8,000 end-users were supplied by mini grids (GIZ, 2021). Currently, 12 pilot mini grid projects are under development. Of these, eight are in operation and have a total of 2,500 users. The total installed capacity of these 12 projects will be comprised of 3.8 MW solar, 1.0 MW diesel and 6.6 MWh battery.

Development of small solar systems

Electrification efforts in remote areas have benefited from the significant cost reductions in solar PV and battery systems. From January of 2014 to December of 2018, 2.5 million small solar systems were sold in Ethiopia. The total capacity of these systems is roughly 7 MW. From 2014 to 2018 the trend was a decrease in sales volume However, this changed in the last half year of 2018 (please see Figure 12). These systems typically supply electricity to smaller sources of electricity demand such as phones and lighting to roughly one million households.

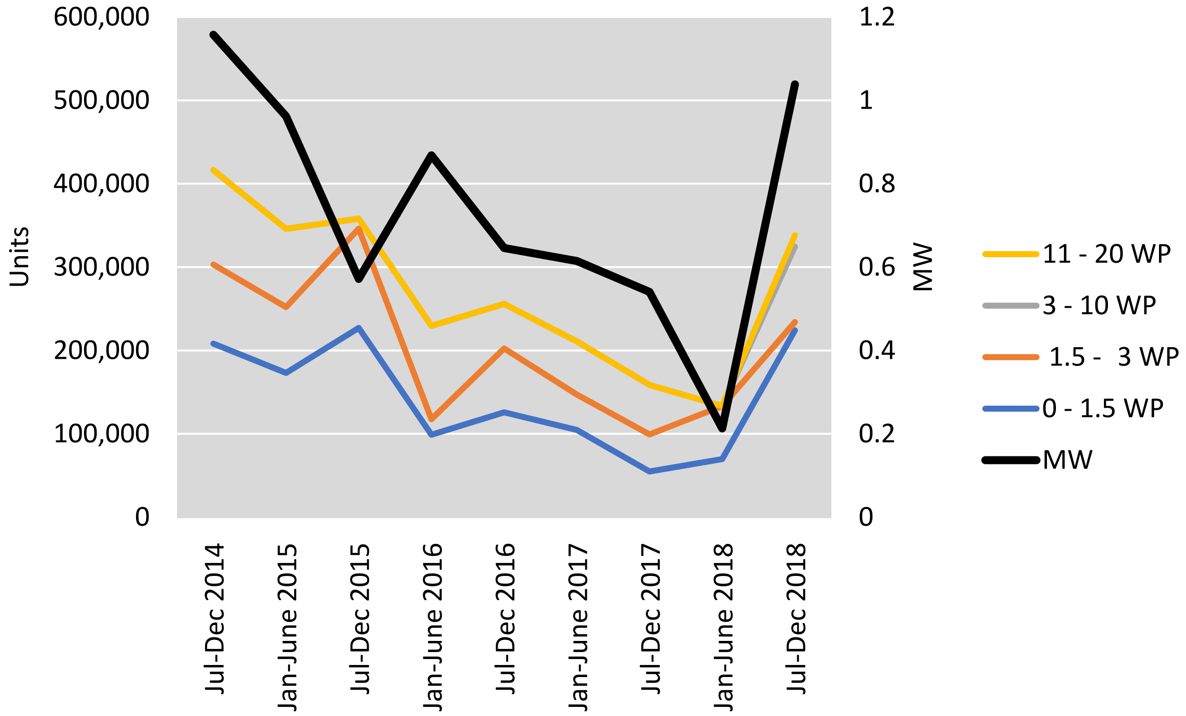


Figure 12: Sales volume of small solar systems. The WP value indicates the capacity, W_{peak}.

Policy and regulatory framework of solar development

Off-grid solar power development was launched in collaboration with development partners via a campaign entitled 'Lighting to All'.

The Ethiopian Energy Authority (EEA) published a mini grid directive in 2020, which consists of general requirements for mini grid licenses, a tariff methodology & guideline, a quality of service standard, and a technical standard for mini grid developers (EEA, 2020). To date, no such licence has been issued as an agreement regarding connection to the grid, in addition to some other regulation, is not yet in place. However, once issued, generation license shall authorise the licensee to:

- Generate electricity and sell it to a distribution network on the basis of a tariff approved by the appropriate organ or power purchase agreement pre-approved by the Authority
- Collect revenue, with exclusive or non-exclusive rights as appropriately designated by the Authority in the License
- Purchase electricity in bulk
- Operate a distribution network within an area designated by the Authority
- Distribute and sell electricity without discrimination to customers within such zone stated in the License, with exclusive or non-exclusive rights as appropriately designated by the Authority in the License.

In setting the tariff, the financial needs of the developer or operator need to be balanced with the Mini Grid community's ability and willingness-to-pay such that:

- The tariff level should ensure a good balance between the developer's financial viability and consumer affordability.
- A sustainable mini grid tariff must cover the system's efficient and prudently incurred cost comprising the capital expenditure and operating expenditure, including fuel costs, as well as a reasonable return on investment.
- No costs that have been paid for by grants or subsidies shall be accounted in the final tariff computation

Accelerating Distributed Electrification and Lighting in Ethiopia, ADELE

The Accelerating Distributed Electrification and Lighting in Ethiopia (ADELE) project supports the GoE in its efforts to achieve the targets in NEP2.0 primarily by focusing on off-grid areas. With the participation of public and private efforts, implementation of the program will start in the second half of 2021.

The off-grid program identifies investment requirements as well as the main barriers to scale-up of off-grid solutions and provides technical assistance and capacity building activities to improve the effectiveness and efficiency of the program. It also contains a set of interventions to engage women in service delivery e.g., focusing on financing and business skill gaps of female enterprises.

Alongside the grid program financed by ELEAP, ADELE complements the existing efforts by financing the off-grid program. ADELE provides financing for four major components:

1) **Network strengthening for improved reliability of supply in urban areas** (USD 100 million). This component will improve the reliability of electricity supply in Addis Ababa and 10 other key urban areas where near-universal access to electricity has been achieved, but deficiencies in availability, quality, and reliability of supply remain a challenge. This component will enable electricity consumers to take full advantage of the benefits of electricity services. The network upgrade and rehabilitation will include infrastructure investments in EEU's jurisdiction, including medium voltage and low voltage equipment as well as support for the Revenue Protection Program (RPP).
2) **Solar-hybrid mini grids for Rural Economic Development** (USD 265 million). This component will finance the rollout of solar mini grids along with battery storage and/or diesel backup. The mini grids supported under the Project will be rolled out through a combination of public and private sector-led approaches based on a pipeline of prioritised sites pre-identified using geospatial planning. These are: (1) EEU operated mini grids, and (2) Private sector-led demonstration projects operated by local and international private mini grid developers, as well as cooperatives. In addition to greenfield sites, investments will be made to hybridise the existing EEU-operated diesel-based mini grids. Diversification will reduce the carbon emissions of fulfilling demand, but could lead to reduced security of supply if the supply profile of VRE does not respective demand and supply profile of It is estimated that with an average investment of around USD 1,000 per connection, around 240,000 connections could be provided under this component, benefiting over one million people.

   EEU-led mini grids. EEU will lead the rollout of greenfield solar-hybrid mini grids. New solar-hybrid mini grids will be deployed by the EEU through Engineering, Procurement, and Construction (EPC) and short-term (e.g., 3 or 6 month) Operation and Maintenance (O&M) contracts. Upon conclusion of the short-term O&M period, the mini grids would be operated either directly by EEU or under a follow-on long-term O&M contract. This sub-component will also include the hybridisation of existing diesel-fuelled mini grids currently operated by EEU (primarily in the Somali region).

   Private sector-led mini grid pilot. In line with the goals set out in the NEP 2.0, the component will support the demonstration of different private sector-led approaches to leverage local and international private sector financing for mini grid scale-up. EEU will be the implementing entity for the two approaches in this sub-component. Private sector/cooperatives will be expected to procure, install, own, operate, monitor, and maintain the generation and distribution of assets, including meters and software. This component will finance through a competitive process for (i) Minimum Subsidy Tender, and (ii) Performance-based Grants.

3) **Solar home systems for households, small-holder farmers, and small businesses** (USD 50 million): This component will expand the availability and affordability of off-grid solar systems for households, small-holder farmers, and small businesses in rural areas, with a particular focus on deep rural and other underserved areas. This will be done by facilitating foreign currency to

importers of quality-certified systems and providing local currency financing to off-grid solar companies, distributors, and consumers to increase the offering and adoption of quality off-grid solar products in underserved areas on affordable terms.

4) **Standalone solar systems for health and education facilities** (USD 55 million). This component will finance the supply and installation of standalone solar systems for health and education facilities identified under the NEP 2.0. The project will target health centres and secondary schools located in underserved and remote rural areas and are identified as a priority by MoWE, in coordination with federal and local education, health, and energy agencies. Under this component, roughly 1,400 secondary schools and health centres will be electrified using standalone solar systems.

Possible policy initiatives

Based on the above analyses, the following actions may be considered.

Continued electricity tariff reform. Improvements have been made to the electricity tariff in recent years, thereby improving the credit worthiness of EEU. Planned increases in tariffs, to make them more cost-reflective, ended last year. To achieve sustainable financing of the sector, work should continue in the same vain and a plan should be developed and implemented to continue the reform.

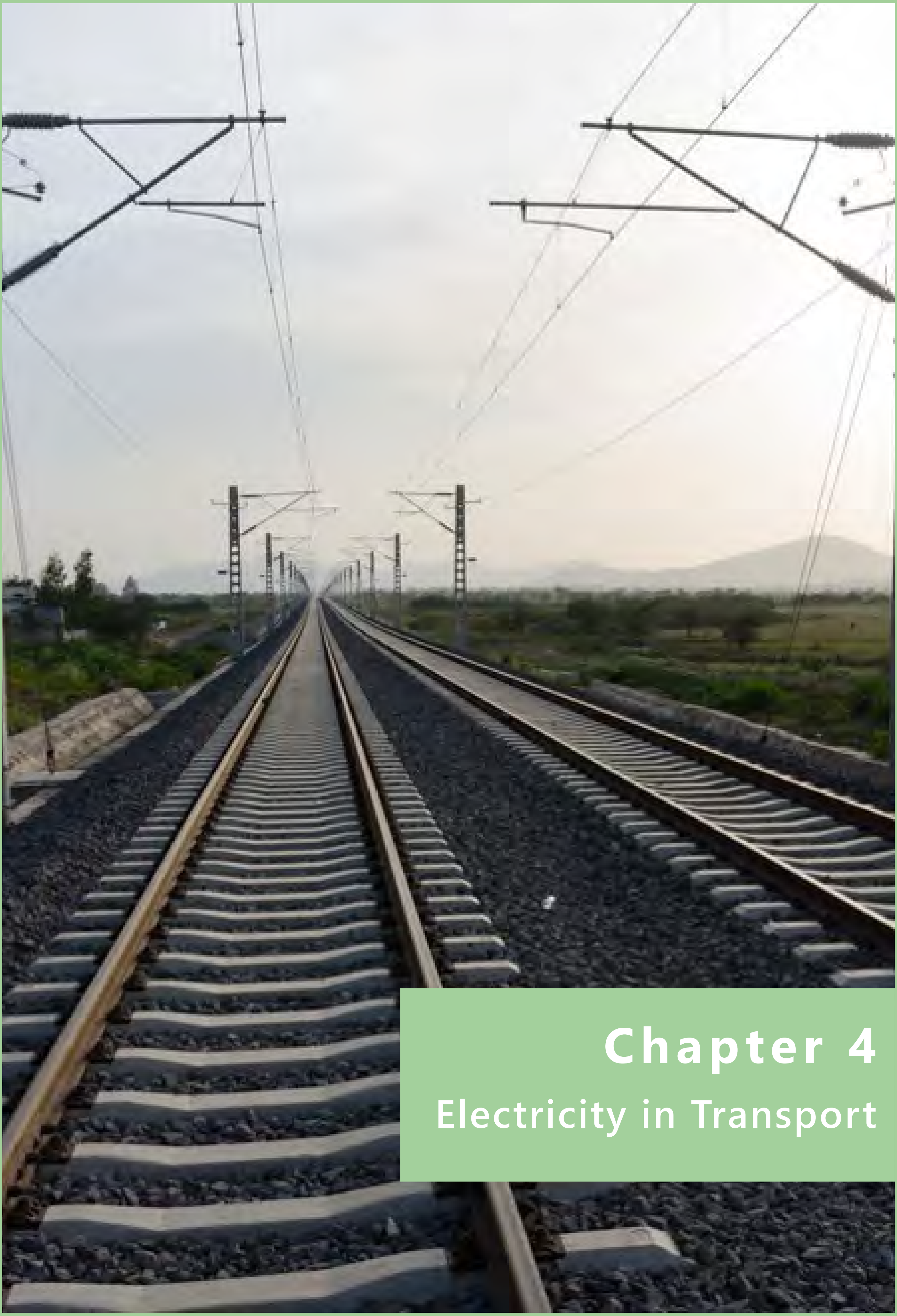
More detailed descriptions for off-grid solutions. In NEP 2.0, off-grid solutions include both mini grids systems and individual systems, such as solar-home-systems. However, the technical aspects as well as ownership structure of these two forms of electricity supply are very different. It is suggested to develop individual goals for mini grid system and for individual systems. The current goals could be maintained (on grid and off-grid), but an indication of how off-grid was expected to be divided into mini grids and individual systems would increase clarity.

Should mini grids be prioritised for deep rural areas? In NEP 2.0, 35% of households should be supplied by off-grid solutions in 2025, and most of these should then in 2030 be connected to the main grid – only leaving 4% to off-grid solutions. It is not described which share of the 35% is mini grids. However, it may be ill advised to invest in mini grids in an area that will relatively soon thereafter be connected to the main grid. While solar PV systems may still contribute when connected to the main grid, due to Ethiopia's vast reservoir hydro resources (which allow for low-cost integration of solar PV), batteries and diesel systems are likely to only have value where the grid is weak (which adequate grid planning should avoid in newly connected areas). Mini grids should be developed such that they can be used when connected to the main grid. In addition, it could be considered to focus on mini grids in remote rural areas where the main grid is first expected to be developed after 2030.

Better statistics about quality of supply in the main grid. Reducing interruptions in the main grid is key to a better quality of supply in the main electricity grid. While EEU record interruptions in lines, no statistics are available for interruptions of end-users. A survey from 2017 found that only 4.5% of all households are supplied with electricity more than 23 hours per day. Developing the distribution grid is key to improving these aspects, and good statistics are needed to follow the progress. This could be realised by implementing a sample of sensors distributed across key areas, e.g., 50 sensors across the country could provide a good indication of the security of supply.

Better statistics about shared connections. To monitor the development of electrified households, updated information about the number of share connections and the willingness to pay for individual connections should be established. A study investigating selected areas could provide a good estimate.

Delayed expansion of connections to main grid: The planned accelerated connection of new consumers to the main grid has been delayed. The number of new connections has averaged roughly 220,000 the past 5 years and is nearing 400,000 for the 12 months up to June of 2021. The current rate at which new households are connected is therefore not sufficient to reach the NEP goals, particularly when taking into consideration forecasted population growth. To reach the 2025 goal, between 1 and 1.7 million new household connections are needed per year (dependent on the assumption of the share of shared connections). For the period 2025-2030, between 0.8 and 3 million new household connections must be made per year. The challenge becomes compounded by each year that does not meet these targets. An updated and detailed plan outlining how these delays can be offset is therefore needed.



Chapter 4

Electricity in Transport

4. ELECTRICITY IN TRANSPORT

The Ethiopian transportation sector contributes significantly to economic and social development activities. The sector includes road, aviation, marine, and rail transport. However, the principal mode of transport in Ethiopia is via road, as it accounts for 90% of passenger and cargo transport within the country. With both the Ethiopian Roads Authority and regional institutions currently undertaking numerous road construction projects throughout the country, road transport is likely to continue to be the dominant transport form.

The transport sector is highly dependent on imported fuels, and it is one of the highest emitting sectors in Ethiopia – in terms of both local pollution and greenhouse gas emissions. In an effort to curb these emissions, the government has introduced emission standards and implemented an initiative aimed at replacing fossil fuels with renewable energy sources.

In 2020, there were roughly 235,000 passenger cars in Ethiopia – with 94% registered in Addis Ababa. With an estimated average annual growth rate of 10%, this would grow to 610,000 in 2030. Meanwhile, goods transport is expected to increase from 16 million tonne-kilometres (tkm) in 2020 to 23 million tkm in 2030 (a growth of 3% pa.).

There is some electricity demand from rail, as both the light rail in Addis Ababa and the train line to Djibouti utilise electricity (roughly 60 GWh annually in total) (USAID and Power Africa, 2021).

Transport policy

The government of Ethiopia's aspiration is to make the transport sector easily accessible, affordable, sustainable and climate resilient. To facilitate this, the government has set 10-year targets with the following objectives (Ministry of Transport, 2020):

- Development of a comprehensive, fair, and accessible transport infrastructure
- Ensure safer transport services
- Establish integrated, fair and accessible transport services
- Have efficient and reliable transport services
- Establish transport infrastructure and services that are resilient to climate change
- Development of capacity building and increasing the efficiency of the sector.

Recognising that road infrastructure contributes to rapid and sustainable economic growth and poverty reduction, the government is expanding, upgrading and maintaining a wide range of road networks. The target is to increase the road network from 144,027 km in 2020 to 245,942 km in 2030.

The government has a plan to reduce the number of deaths due to traffic accidents from more than 34/10,000 vehicles in 2020 to 10/10,000 vehicles by 2030.

The import of gasoline and diesel places a heavy burden on the country's trade balance, i.e., Ethiopia spends USD 2.5 billion annually on imported petroleum products, which is 20 percent of the country's foreign exchange (Ethiopian Natural Gas and Petroleum Industry, 2020). To slightly reduce gasoline imports, efforts have been made to blend ethanol into gasoline (see chapter 5).

Current CO_2 emissions from all vehicles is estimated to be 14 million tonnes of CO_2 per year[3]. The government plans to reduce the *growth* in CO_2 emissions by 13.2 million tonnes of CO_2 2030. One of the strategies to reduce the amount of greenhouse gas emissions in the country is to reduce the CO_2 intensity of the energy used by vehicles for public and freight transport. To both reduce CO_2 emissions and fuel imports, the Ministry of Transport has set a goal of having 148,000 small electric vehicles (including plug-in hybrid electric

[3] Own computation based on the number of vehicles and assumptions regarding vehicle efficiencies and km driven per year.

vehicles) and 4,850 busses on Ethiopian roads by 2030. To incentivise the purchase of these small electric vehicles, the excise tax for electric cars is 10%, compared with 20% for traditional cars.

Analyses of electric vehicles

Electricity can power all kinds of road transport, including bicycles, scooters, cars, busses and even trucks. The following section investigates the potential for shifting small passenger vehicles (cars) from gasoline/diesel to electricity. In Ethiopia, such a shift has several benefits (IEA, 2020):

- Lower variable costs
- Reduced import of oil products
- Use of hydro based electricity generated in Ethiopia
- Reduced local pollution
- Reduced CO_2 emissions

Cars were the focus of this analysis because this segment is currently seeing strong development in Ethiopia, and despite the number of electric vehicles (EVs) in Ethiopia currently being quite limited, the deployment of EVs internationally is growing rapidly. A key driver for this development is the fall in battery prices, combined with improvements in battery energy density. Improved energy density and lower battery prices make it possible to equip vehicles with larger batteries, thus providing the vehicles with longer driving ranges. Battery costs are expected to continue to fall, with an estimated 50% reduction from 2020 to 2030 (ICCT, 2019). Recently, each year witnessed many new models coming to market, and all major car manufacturers now have a series of electric vehicles in their program. In fact, a Hyundai assembly factory for electric vehicles started production in 2020 in Ethiopia.

Figure 13: Hyundai Ioniq EV made by Marathon Motors, Ethiopia.

While electric cars are currently more expensive than traditional cars, this is likely to soon change. Between 2025 and 2030, it is expected that the upfront costs of EVs will equal, and thereafter fall below that of their conventional vehicle counterparts. This is due to the simplicity of electric cars, which have much fewer moving parts, with only the battery currently being a more expensive element. From a total cost of ownership perspective, EVs will become cheaper than conventional vehicles even sooner, as O&M and fuel costs are generally lower for EVs. The majority of plug-in hybrids (PHEV), due to their double drive train, are anticipated to be more expensive than conventional vehicles for some time (ICCT, 2019).

A potential path to the above-mentioned target of 148,000 electric drive vehicles by 2030 is displayed in Figure 14. During the period, it is assumed that the total stock of cars increases with 10% p.a., and that the share of new car sales that have electric drives increases linearly from 0 in 2020 to 38% in 2030. This growth is assumed to be driven by the above-described cost reductions in batteries, increased production volumes and vehicle types to select from, and improved vehicle performance (i.e., increasing driving range). The distribution of new electric drive vehicles between EV and PHEV is assumed to be 50:50 in 2020, with the EV portion growing to 75% in 2030.

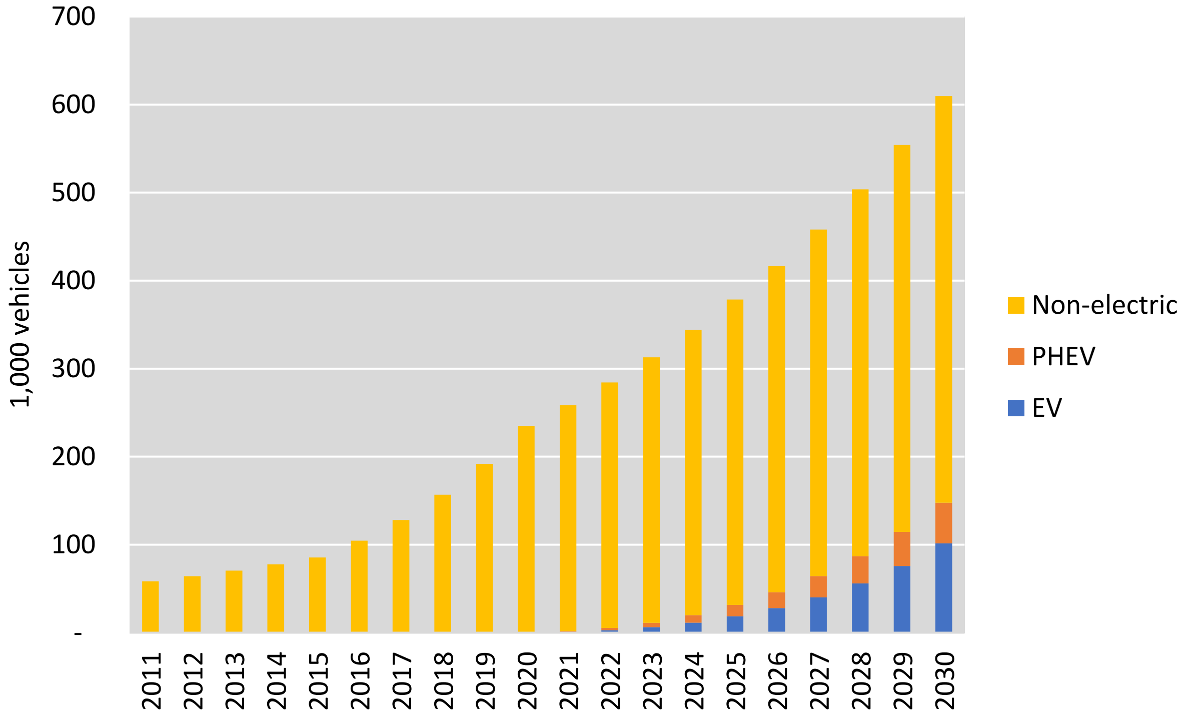


Figure 14: A possible development of the stock of cars.

Currently, electricity in Ethiopia is cheaper than gasoline/diesel per kWh. In the long term, as the electricity price increasingly becomes more reflective of its cost, the price of gasoline/diesel and electricity may be similar. However, as an EV is roughly 3 times more efficient than a traditional car (see Figure 15), the fuel cost associated with driving 100 km is significant less for the electric vehicle. For PHEVs, calculating the energy use per km is a little more completed. As PHEVs have both a traditional engine, as well as a battery and electric engine, the% of km that are driven via electricity vs. gasoline is largely determined by the length of each trip and the driver's propensity to charge the vehicle frequently. Recent analyses indicate that the share of km driven on electricity is lower than expected, especially with company owned vehicles where fuel costs are paid by the employer (ICCT, 2020). The analyses here deem that a 50% share of electricity may be realistic today, and that this value may increase as battery size and driving range increases.

It is estimated that 148,000 electric drive vehicles will consume 300 GWh electricity in 2030. This corresponds to 2% of the current electricity demand. This demand should be included in demand prognoses and in the planning of new power plant commissioning. The amount is not alarming, and a much higher number of electric cars can be integrated in the Ethiopian power system.

Electric vehicles can be charged at home or in public charging stations. Workplaces and shopping malls may be good locations for public charging points. For many users charging each night at home would be sufficient for normal daily use. However, for longer travel, additional options must exist, i.e., rapid charging stations along the highway net.

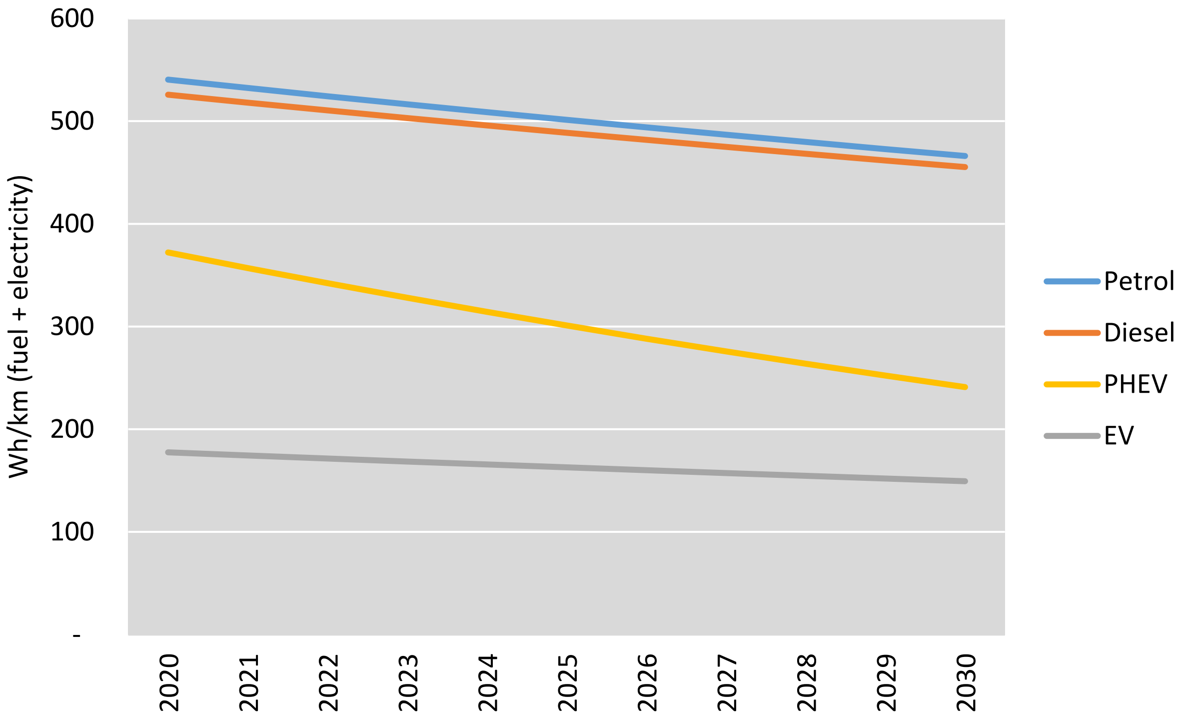
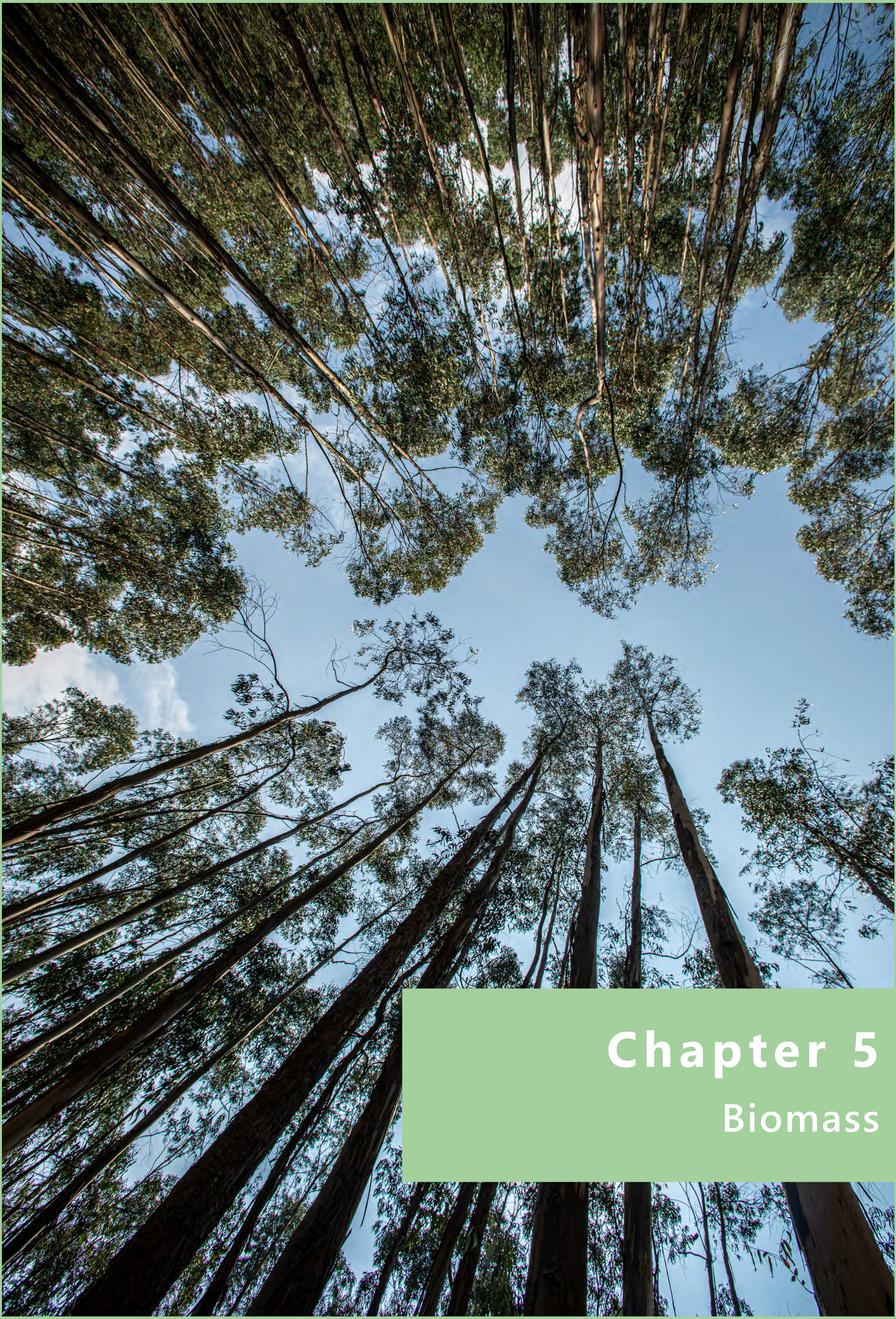


Figure 15: Estimated efficiency for traditional cars, plug-in hybrids, and fully electric cars. Fuel is converted to kWh. 1 l gasoline = 9.1 kWh. 1 l diesel = 10 kWh.

Possible policy incentives

The implementation of emission standards for traditional cars are underway. This will reduce pollution and provide an incentive to instead select an electric vehicle. In other countries, electric vehicles are given special benefits, e.g., reduced tax, lower fuel taxes, free parking, free access to toll roads, and access to bus lanes, etc.

A key area for promoting electric vehicles is planning for the infrastructure for charging. The initial focus could be on Addis Ababa, since 95% of all cars are registered here. Later, the ambition could be to create a nationwide infrastructure, including rapid charging stations along motorways. Charging spots could also be planned for shopping malls and parking garages.



Chapter 5

Biomass

5. BIOMASS

With nearly 86 percent of Ethiopia's current total energy demand being met by biomass fuels, biomass is by far the most widely used form of energy in Ethiopia. Biomass fuels include wood, charcoal, animal waste and agricultural residue, and are mainly used for cooking and baking in households and a considerable number of rural households also use biomass for lighting. In addition, biomass fuels are used in rural cottage industries (potters, blacksmiths), commercial establishments (food and beverage houses) and social institutions such as schools, universities, hospitals, detention centres and military camps. Charcoal is an important fuel in urban Ethiopia. It is mainly consumed in households and commercial institutions for cooking and making coffee and tea. Energy demand from biomass has grown steadily from roughly 1260 PJ in 2009/2010 to just under 1600 PJ in 2019/2020.

Firewood constitutes the largest share of total biomass (84%), while charcoal, crop residues and cattle dung make up the rest. Wood is used in both urban and rural areas, charcoal is mainly used in urban areas and agricultural residues and cattle dung are primarily used in rural areas. Solid biomass fuels are predominantly used for cooking and baking in the domestic sector. The commercial sector (e.g., restaurants and bakeries) is also a significant consumer of solid biomass fuels. Wood is also used as boiler fuel in tea and tobacco factories.

The wood fuel usage is increasingly unsustainable. 34% is harvested sustainably from forests and plantation woodlots. The remainder, 66%, is unsustainably sourced from natural high forests and woodlands (UNEP, 2018)

In rural areas, wood, crop residues and cattle dung are freely collected from forests, woodlands, farmers' croplands and homesteads and burnt for domestic fuel mostly in open hearths. In urban areas biomass fuels are purchased and used for domestic and commercial cooking using both traditional and improved stoves. As a result of reduced availability and access to wood fuels (as consumption far exceeds sustainable yields for most parts of the country) crop residues and cattle dung are used as substitutes for wood in rural areas. The degree of substitution of crop residues and cattle dung has been increasing in the past three decades.

The country has a substantial amount of biomass residues that are currently not being collected and utilised. These residues could be utilised without negatively affecting socio-economic or environmental requirements, and without compromising food security. The total amount of bioenergy available from residues was estimated to be 750 PJ per year (47% forest residues, 34% crops residues, 19% livestock waste, and 0.05% MSW) (Gabisa & Gheewala, 2018).

Use of biomass by sector and technology

Most of the solid biomass consumed in Ethiopia is consumed directly without any intermediate conversion. The only primary conversion for biomass takes place for charcoal, which is produced with traditional earth mound kilns at very small scales (only 0.5 tonnes of charcoal output per batch). There are few legal (organised) charcoal producers, but the vast majority of charcoal supplied to consumers originates from illegal producers in rural areas.

In the domestic sector, biomass fuels are commonly burnt directly in traditional stoves (open hearths). There are, however, notable exceptions where, for example, improved domestic stoves are now increasingly used for charcoal and improved cooking/baking stoves are being successfully promoted for wood.

Biomass cook stoves can generally be categorised as those for injeral baking (Mirt and Gonzye Stoves) and those for pot size general cooking (Mainly Tikikil). Typically, charcoal cook stoves include Mirchaye, Lakech and traditional metal stoves. Most Ethiopian households use three-stone or traditional stoves.

The dissemination of improved biomass cook stoves is one of the key components of the Climate Resilient Green Economy (CRGE) Strategy to reduce dependence on biomass-based fuels. As part of promoting clean cooking technologies, more than 16 million improved and efficient biomass cook stoves were distributed until 2020.

In the commercial and social sectors (including schools, universities, hospitals, and penitentiaries), biomass fuels are used for cooking and baking. In these sectors, cooking with biomass is again mostly done in open hearths and via other traditional means, which entail considerable energy losses.

Drawbacks of large biomass consumption

Indoor Air Quality: More than 85% of households cook indoors without any ventilation. The key indicator for health is 'indoor air quality', which can be directly measured at the household level or estimated based on stove emissions and cooking stove use (e.g., whether cooking is done indoors or outdoors and whether there is ventilation). Stove emissions would need to be measured through stove tests, which should consider local cooking conditions and practices. This would also require agreement on how this attribute should be defined and measured, and on specific issues relating to the typology of the stoves.

Time use: Convenience is determined by how long it takes household members to collect/gather fuel and prepare it for the stove, and how long it takes to prepare the stove before it can be used for cooking. The time spent on these activities in Ethiopia is considerable for much of the population.

Focus on biomass use in cooking

With so much biomass currently being used for cooking, and a growing awareness regarding the associated drawbacks, there have been a number of initiatives implemented to address these challenges. With the goal of improving stoves, it is first necessary to obtain a good overview of the current state of the affairs. The Multi Tiers Framework (MTF) survey for access to Modern Energy Cooking Solutions supplied a number of findings that are detailed below.

Three stone and open fire stoves are used by more than half of households, followed by other self-built stoves (19%) and manufactured stoves (22%)[4]. Only 4% of households use a clean stove with electricity as a fuel. However, there were large differences between rural and urban areas. For example, in rural areas, 67% of households use a three-stone stove as their primary stove, while 55% of urban households use a manufactured stove. In addition, the utilisation of electric stoves is considerably higher in urban areas (15.3%) relative to rural areas (0.6%).

Only 22% of households use a manufactured stove, despite a high willingness to pay for such a stove. I.e., 62% of households are willing to pay full price upfront for a manufactured stove, and 28% of households are willing to pay full price with a 6 to 24-month payment plan.

Households sometimes use several stoves (stove stacking) and fuels (fuel stacking) for cooking. The survey found that the majority of Ethiopian households (77%) primarily use one stove for their cooking needs, while the remaining number of households use more than one stove to meet their cooking needs (this refers to the main cook stove and not for stoves used exclusively for baking).

For most Ethiopian households, firewood is the main fuel (71%), followed by charcoal, which is used by 21% of the households. The survey findings show that just 4% of the households use clean fuels such as electricity, biogas and LPG.

Of the households that use a biomass stove, 64% have poor ventilation. Cooking is often carried out indoors with no exhaust system and two or fewer doors or windows in the cooking space.

In terms of time and resources spent on fuels for cooking, the survey found that 53% of households, including 59% of rural households and 32% of urban households, spend more than 7 hours a week acquiring

[4] A self-built stove is typically an enclosed stove made using stone, mud and flat clay and is considered to be slightly more efficient than the three stone fire stove, while a manufactured stove is typically a metal stove.

(through collection or purchase) fuel and more than 15 minutes preparing the stove for each meal. In addition, 28% of households allocate more than 5% of their monthly spending to fuel.

Rural Energy Technology Promotion and Development Centre

The Ethiopian Rural Energy Technology Promotion and Development Centre, EREDPC, was established to carry out national energy resources studies, data collection and analysis, rural energy policy formulation, technology research and development and to promote appropriate energy technologies in rural areas. The centre is working with regional energy centres to promote e.g., energy efficient stoves.

Biogas program

Biogas can contribute to reducing the heavy reliance on solid biomass energy sources, improving environmental sustainability, as well as the welfare of rural households. Biogas has the dual advantages of providing energy for rural households such as energy for lighting and for cooking, while at the same time providing high quality organic fertiliser from the slurry produced after the gas is extracted. The organic content of animal refuse is usually wasted or burned, or used for cooking in direct combustion in open fire stoves. Biogas increases agricultural productivity as it provides the necessary organic fertiliser and it further improves the quality of life of rural households as it reduces indoor air pollution.

With a livestock population of roughly 150 million (per 2010), Ethiopia has a large potential for biogas production. One third of this livestock is cattle, whose refuse can effectively be used for biogas generation. Recent estimates show that there are roughly 1.1 million potential owners of household-size digesters in the four major regions. In Ethiopia, the effort to generate biogas from cattle dung started in the early 1970s. However, over these past four decades, progress in biogas digester construction has been limited.

In 2007, the National Biogas Program (NBP) was initiated with a target of constructing 14,000 biogas digesters within 5 years. However, it only managed to construct an estimated 8,161. More recently, as the NBP managed to introduce an appropriate setup for the management of a biogas program at a national scale, the total installed biogas digesters reached 31,500 by 2020.

Ethanol today

Ethanol is a clean indigenous energy source that in Ethiopia is produced as a by-product of sugar production. The National Biofuels Policy plan promotes ethanol both for stoves and for blending with gasoline as a transport fuel. Ethanol stoves have a higher upfront cost than lower-quality stoves. However, the gains in quality, efficiency, and fuel cost can overcome the higher initial cost. It is estimated that an ethanol stove using 1 litre of ethanol can replace 2.5-4 kg of charcoal per day, 8-12 kg of fuelwood, 1.2 litres of kerosene, or 0.5 kg (1 litre) of LPG. (Global Bioenergy Partnership, 2021). Ethanol is therefore an attractive alternative to fuelwood, charcoal and kerosene not only because of environmental and health benefits but also because it is competitive with other fuels in terms of cost and can enter the market without subsidies. Moreover, ethanol fuel can use the kerosene infrastructure. This means that bioethanol can replace kerosene with limited infrastructure investment.

The development in Ethiopian ethanol production, as well as the distribution in its use between blending and industrial use is displayed in Figure 16.

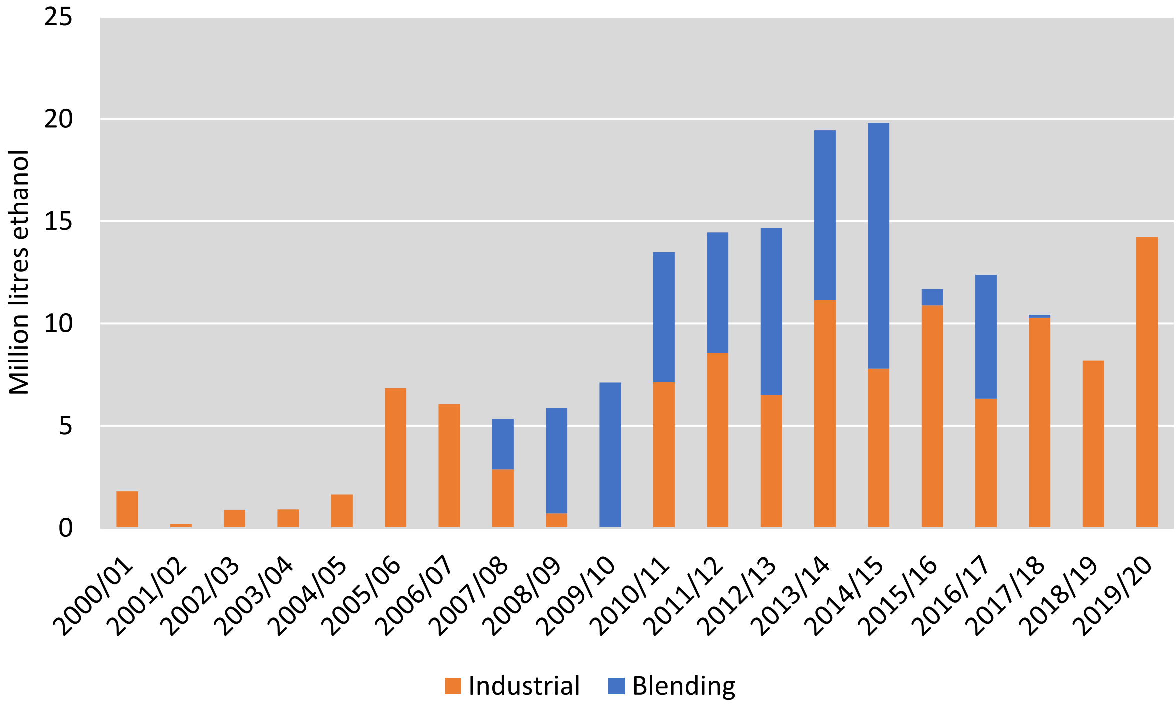


Figure 16: Ethanol produced. Fincha and Methara. Source: Sugar Corporation

Future ethanol and sugar production

Current annual Ethiopian production is roughly 400,000 tonnes of sugar and 21 million litres ethanol, while current sugar demand is 720,000 tonnes. However, based on sugar industry estimates, there will be a significant increase in the production of sugar and ethanol in the country. A number of new sugar factories and plantations have either recently started production or will soon do so. The location of the thirteen planned, under construction or operating sugar factories are mapped in Figure 17.

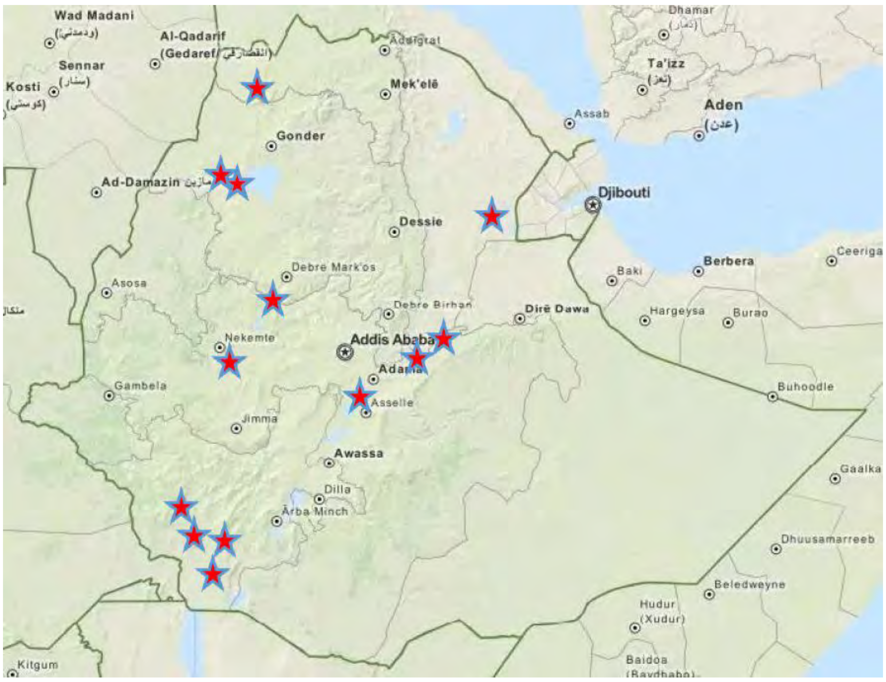


Figure 17: Sugar factories planned, under construction or operating in Ethiopia. Source: (Global Bioenergy Partnership, 2021)

When all 13 plants are running at full capacity it is anticipated that they will produce roughly 3.6 million tonnes of sugar and 339 million litres of ethanol per year (see Table 5 below). This will shift Ethiopia from being a large net importer of sugar to that of a large exporter. In addition, there will be a total of 250 MW of excess power capacity to the grid, as indicated in Table 5.

Sugar Factory	Sugar (1,000 tonnes)	Ethanol (litres)	Electricity	Status
Finchaa Sugar Factory	270	20 million (producing)	31 MW, 10 MW to grid	Operating, producing ethanol
Metahara Sugar Factory	136	12 million (producing)	9 MW	Operating, producing ethanol
Wonji Shoa Sugar Factory	220	12.8 million (projected)	31 MW, 20 MW to grid	Sugar factory modernisation completed
Omo-KurazSugar Factories I, II, III and IV	1,250	140 million (projected total)	225 MW, 145 MW to grid	Two completed, two under construction
KessemSugar Factory	260	30 million (projected)	26 MW, 15 MW to grid	Producing sugar and power
Tendaho	300	31 million (projected)	60 MW, 38 MW to grid	Sugar production trials completed
Arjo Diddessa	230	12 million (projected)		Operating
Wolkaiyt Sugar Factory	484	41.6 million (projected)		Construction 95% completed
Tana BelesSugar, 2 plants	484	40 million (projected)	45 MW, 25 MW to grid	-
Potential capacity	**3,634**	**339 million**	**250 MW to grid**	-

Table 5: Sugar factories in Ethiopia: production, electricity provided to the grid, status. Source: (Global Bioenergy Partnership, 2021)

In addition to the large plants discussed above, in 2015, Gaia Clean Energy and its collaborators published a comprehensive national strategy for Ethiopia on how to scale up ethanol fuel. One of the key strategies proposed in this document focuses on micro-distilleries that could produce 1,000 to 5,000 litres per day and would be designed to fit farm-scale operations and exploit niche feedstocks.

Chapter 6

Natural Gas

6. NATURAL GAS

The oil and natural gas sector is governed by the Ministry of Mines and Petroleum. Even though the natural gas sector in Ethiopia is in its early stage of development, with newly discovered resources it has potential for growth.

Resources

The Ogaden Basin in eastern Ethiopia covers an area of roughly 350,000 square kilometres and it is divided into 21 blocks (see Figure 18).

Figure 18: Ogaden Basin. (The Ministry of Mines and Petroleum, 2021)

The discovery of natural resources in the Ogaden Basin started back in the 1920s. The Calub and Hilala gas fields were discovered by an American oil company Tenneco in 1973 and in 1974 respectively. The Chinese company Poly GCL Petroleum Investments currently has a petroleum development and production sharing agreement, which enables it to produce and sell gas reserves in the Calub and Hilala locations. Initially 5,000 PJ of natural gas were discovered and Poly GCL is currently working to extract these 5,000 PJ. However, after further exploration work, additional gas reserves were discovered in the Doha area and total reserves are now estimated to be 6,300-8,400 PJ.

Exploration for oil and natural gas is taking place in other areas of Ethiopia, e.g., in parts of the Ogaden Basin in Southern Ethiopia, Afar in North-Eastern Ethiopia, Southern Rift Basin, and Main Ethiopian Rift Basin regions. In 2019, the Ministry of Mines and Petroleum announced that the British energy company New Age had discovered 1,700 PJ of natural gas reserves in Ogaden basin, Somali State, Eastern Ethiopia. A Petroleum Production Sharing Agreement (PPSA) for exploration/development was signed in 2010 with the UK company New Age for the Ogaden block.

Natural gas pipeline project

In 2019, Ethiopia and Djibouti signed an agreement to install a 767 km long gas pipeline that will stretch from the Calub and Hilala gas reserve areas in Ogaden to a gas treatment plant to be built at the Port of Djibouti. The pipeline will be built by Poly GCL and is expected to transport 460 PJ of natural gas per year, which corresponds to 28% of the current total energy demand in Ethiopia. The plant in Djibouti will transform the gas into liquid natural gas (LNG) for export, the largest share (390 PJ) of which will go to China. Once the natural gas pipeline project is constructed and commissioned, this will bring much-needed foreign currency to Ethiopia and Djibouti. However, due to the pandemic, the construction of the pipeline and the LNG terminal has been delayed.

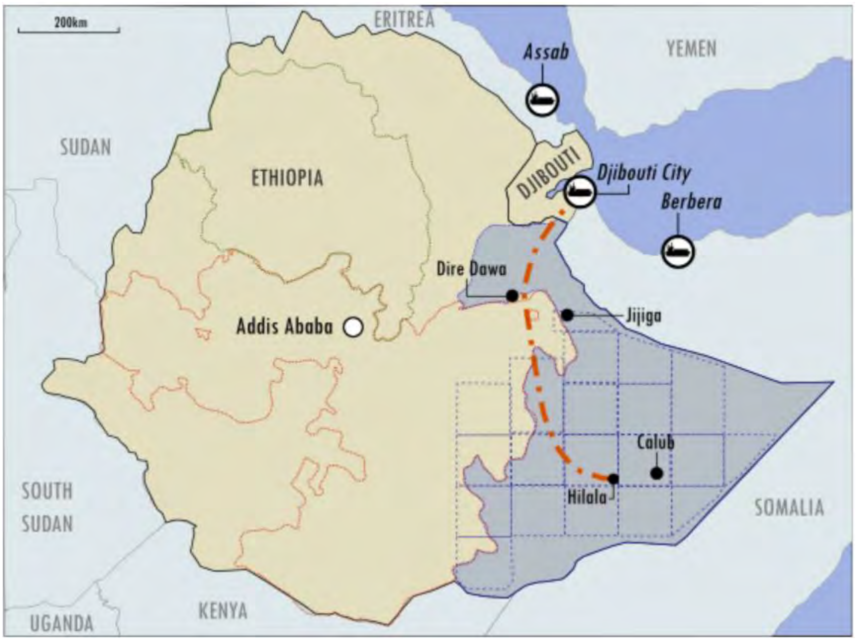


Figure 19: Ethiopia-Djibouti gas pipeline. (A2 Global Risk, 2021)

Local, regional, and global demand

Currently, there is no significant natural gas consumption in the country. However, depending on the success of efforts to connect commercial and residential consumers, and the demand from transport sector, total natural gas demand in Ethiopia could grow to 24 PJ per year in 2030.

As power generation in Ethiopia relies primarily on hydro resources, natural gas is not expected to play a significant role in the power sector. Nevertheless, it could be used for power generation, for example, in dry years. Please see chapter 9 for a further discussion about using natural gas in the power sector during dry years.

Ethiopia's natural gas demand centres are far from the discovered gas fields, and it would not be economically viable to build pipelines to the demand centre in Addis Ababa as it would require an immediate and relatively large demand. Therefore, Ethiopia is focusing on industrial demand that is closer to the scheduled pipeline to the LNG terminal in Djibouti.

Agriculture is the main sector in Ethiopia, and it requires natural gas for fertiliser production. A fertiliser plant is planned to be commissioned in Dire Dawa by the Moroccan fertiliser company OCP, and production will both satisfy local demand and have the potential for export. This means it would be a source of much-desired foreign exchange. It is estimated that the plant will have access to roughly 0.2 PJ of natural gas per day. It will use potash that will be mined in the Afar region and gas from the Somali Region as inputs to produce fertilizer.

Natural gas can also be used in the transport sector, particularly for fleet vehicles, such as busses or taxis. Some of the purported advantages of using natural gas in transport are lower emissions and lower costs relative to diesel or gasoline.[5] On the other hand, the use of natural gas in transport requires developing the necessary infrastructure. Lastly, vehicle ownership rates are quite low in Ethiopia, so the potential demand for gas from transport is relatively low as well.

[5] Due to gas-powered trucks being less efficient than their diesel counter parts, tailpipe CO_2 emissions savings when switching from diesel to natural gas will typically be in the range of 5-10%. However, as natural gas has a very high global warming coefficient, if there are gas leakages upstream, then these emission savings will quickly evaporate.

Liquefied petroleum gas (LPG) and gas liquids that are produced through natural gas processing can be used to substitute wood and kerosene. This would bring health benefits, as LPG is a non-toxic fuel that can be used for cooking and could help reduce deforestation in the country. The Calub and Hilala gas fields could produce around 20,000 GJ of LPG per day, which would exceed the current domestic demand of 0.2 PJ. However, it accounts for less than 1% of total biomass consumption. LPG could also be traded in the East African markets.

From a regional perspective, Kenya, Sudan, and Djibouti could potentially import natural gas from Ethiopia. However, the demand centres in Kenya and Sudan are also far away from the natural gas fields and building pipelines over such long distances would not be economically viable. In Djibouti, offtake of gas from the pipeline could be consumed in the power sector.

Ethiopia is aiming to access the global LNG market to ensure the viability of the above-described pipeline project. The supply of natural gas to the local Ethiopian industry and transport sector relies on the development of the LNG project.

The two largest LNG import regions are Europe together with Japan, Korea, and Taiwan, while most of the uncontracted LNG demand is concentrated in the Indian Subcontinent, China and Europe. However, it would be difficult to compete in Europe because of suppliers such as the US, Russia, and West Africa, that can offer more attractive prices due to shorter shipping distances. Ethiopia has more favourable conditions when competing in markets in India and China.

Prices

In Ethiopia, the price of natural gas is estimated to be roughly 3.5 US$/GJ. After being converted to LNG, it is estimated that the price will rise to roughly 5.5-6.0 US$/GJ. For comparison, in 2021 June, the average LNG price for delivery into Northeast Asia was around 8.7 $/GJ, thus leaving a shipping cost margin of 2.2-2.7 $/GJ.

Commodity	Unit	2020	Forecast			
			2021	2025	2030	2035
Crude oil, average	$/GJ	7.3	9.8	11.2	12.1	12.4
LNG, Japan	$/GJ	8.3	8.0	7.9	4.0	7.5

Table 6: Commodities price forecast (nominal US dollars), (World Bank, 2021 a)

However, as has been witnessed in recent years, and highlighted in the figure below, regional LNG market prices can fluctuate significantly over time as well.

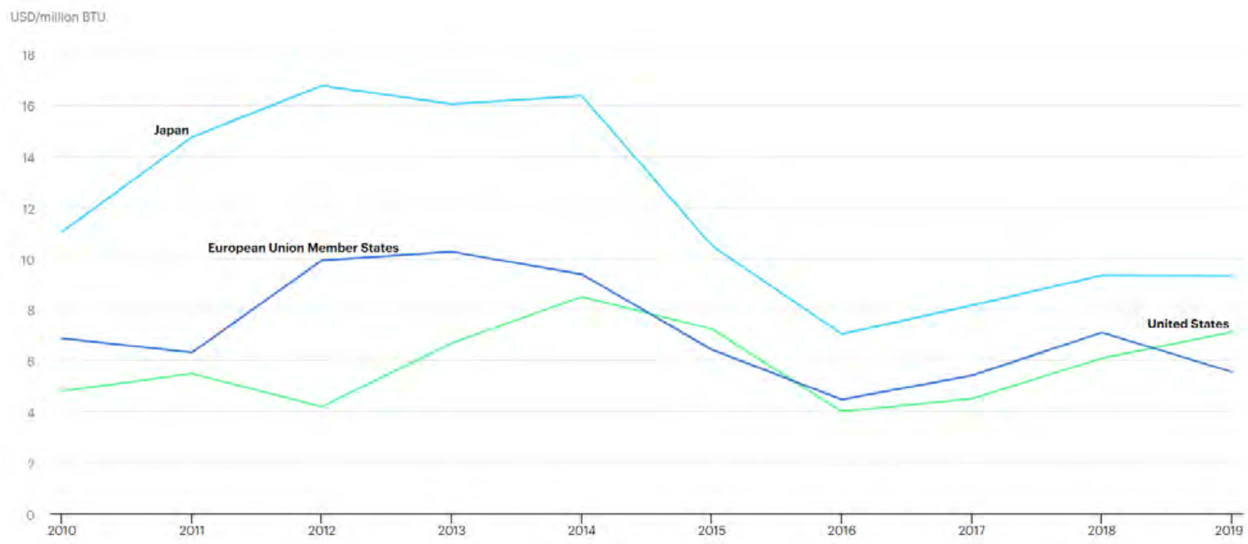


Figure 20: Selected LNG import prices (IEA, 2020)

Policy

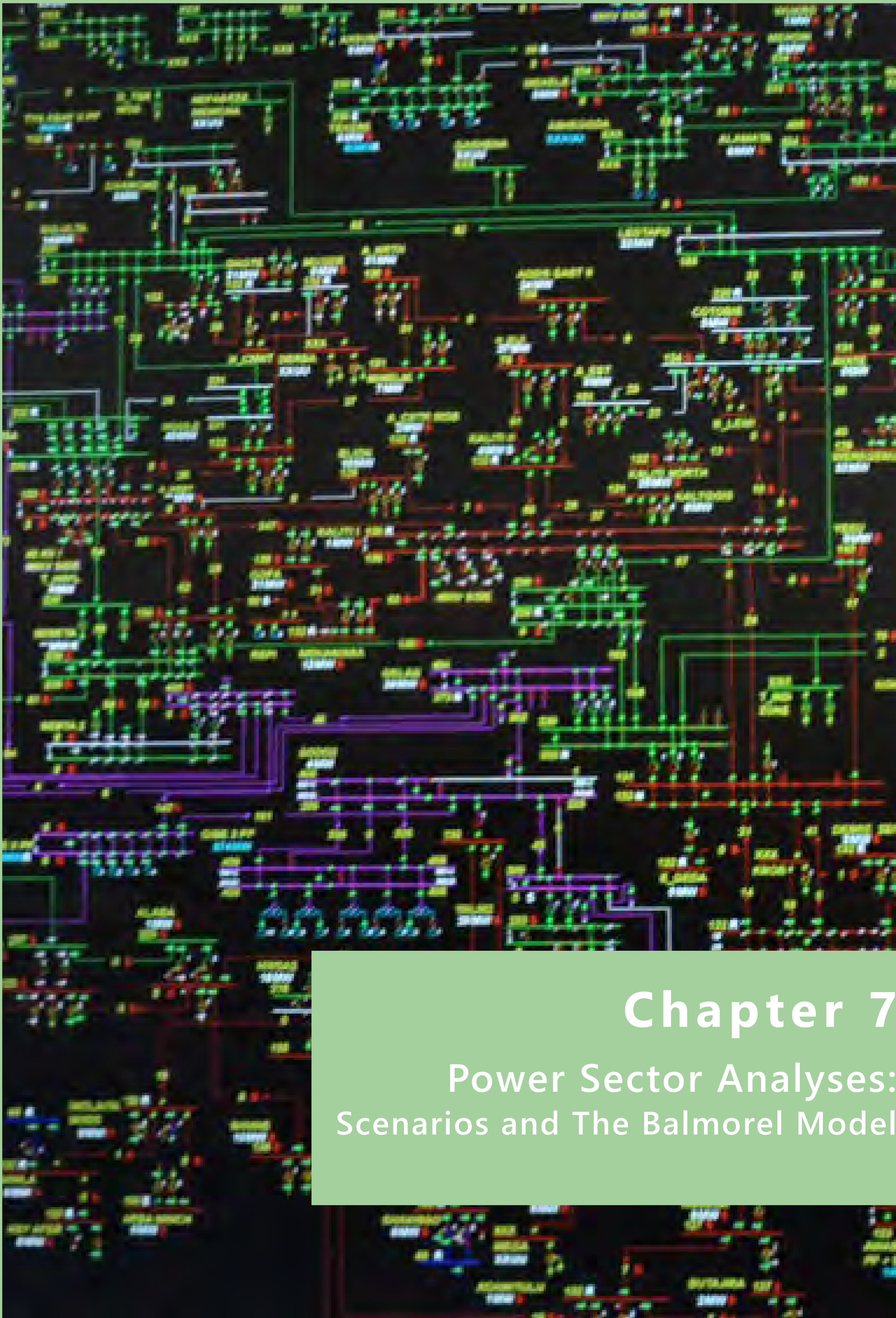
Though there are growing petroleum exploration and development activities in the country, as well as a rising demand for petroleum products, there has not been a national petroleum resource development policy governing and guiding the petroleum industry. Investment by the petroleum industry has been governed by old non-amended laws, contracts and general laws related to the sector. Therefore, there is a need to implement competitive legal and institutional frameworks in line with international norms. Importing petroleum has remained a burden on economic development in the country due to the high demand for foreign exchange. Ethiopia is therefore developing a clear policy for government, private sector, and other stakeholders (Ministry of Mines and Petroleum, 2020).

The Ethiopian Petroleum Resource Development Policy has several specific objectives:

- To conduct the necessary studies and gather information about the petroleum resources within the country and related petroleum operations ranging from petroleum exploration to petroleum utilisation.
- To create favourable conditions for competent and sustainable petroleum operations investment by introducing the sector's opportunities to domestic and foreign investors with the view to becoming a competitive petroleum industry regionally and internationally.
- To bring about economic transformation in the sector, establishing a system that would assist the improvement of the petroleum resources' sustainable development and utilisation by harmonising gender equality, employment, and environmental safety in the petroleum industry value chain to enhance the benefits from the sector.
- Identifying the value chain gaps of the petroleum sector and set a direction to fill these gaps.
- Utilise new technologies, best practices and inventions and apply them to petroleum operations and resource management.
- To contribute to the growth of other economic sectors, manage and utilise the petroleum resources and revenues appropriately and effectively.
- Establish coordination among federal and regional administrations regarding the petroleum sector operations.

According to the policy, natural gas exploration and development should be prioritised to help open the country's petroleum economic sector for companies and to encourage the investments.

Power Sector



Chapter 7

Power Sector Analyses:
Scenarios and The Balmorel Model

7. POWER SECTOR ANALYSES: SCENARIOS AND THE BALMOREL MODEL

Although electricity represents a small share of the current final energy demand in Ethiopia, the sector is crucial given the implications of electrification on socio-economic development. Electricity demand has been increasing by 12% per year in the last two decades, and universal access to modern energy is a key policy. Stable and low-cost electricity can support local manufacturing and can give households access to lighting, modern communication, and safe cooking. The purpose of studying the power sector and the generation mix is to investigate if options exist to give a less costly development, or a development with increased export, while providing high security of supply and robustness to dry years.

To be able to study the potential for export (and hard currency income) a regional perspective is used with detailed analyses of Ethiopia and all potential importers of Ethiopian electricity.

Future generation mix has previously been analysed in (Parson & Brinckerhoff, 2014), (USAID & Power Africa, 2019), and in EEP's 10 years plan (EEP, 2021).

The Balmorel Model

The Balmorel model is developed to support technical and policy analyses of power systems[6]. It is a detailed techno-economical model that can find an optimal dispatch and investment solution based on the least cost approach. In the investment mode, Balmorel determines the optimal level of investments in power generation, storage technologies, and transmission capacity. In dispatch mode, it finds an optimal utilization of available generation and transmission capacity.

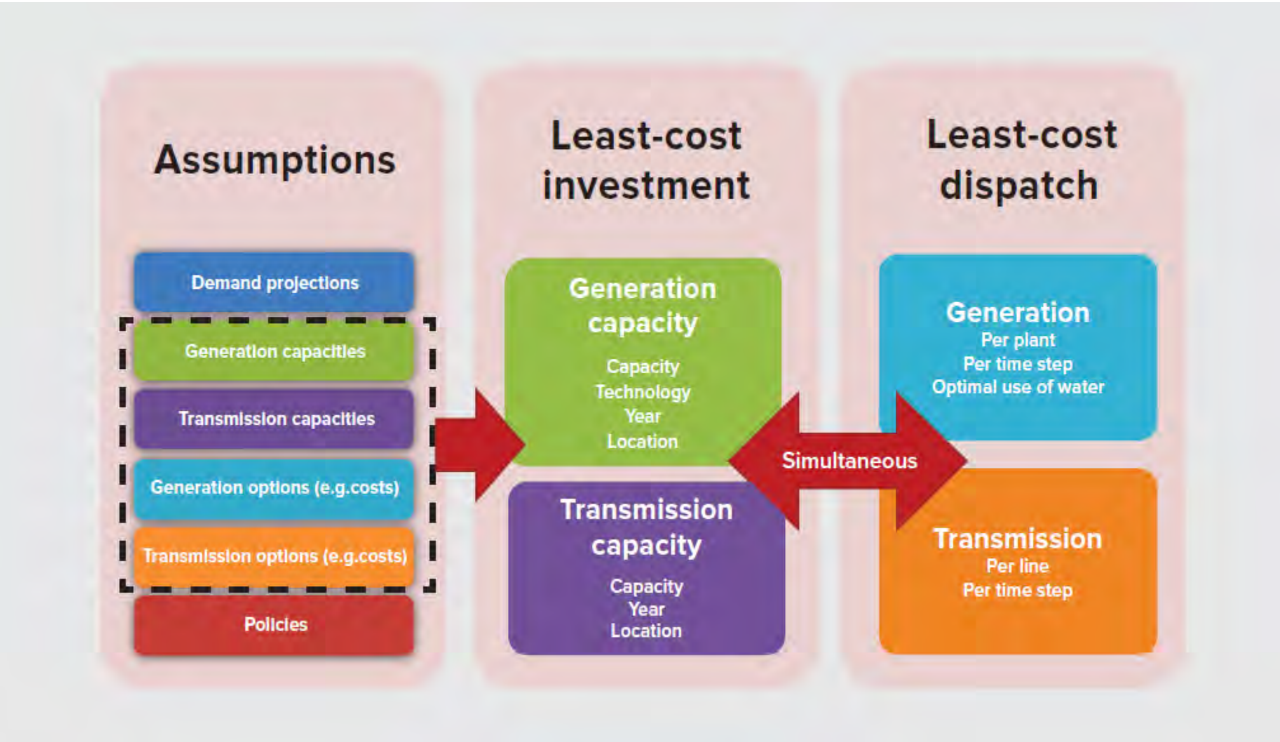


Figure 21: Concept of operation for the Balmorel model

To find an optimal solution, Balmorel considers the level of electricity demand, cross-border transmission grid constraints, technical and economic characteristics of technologies, fuel prices, as well as temporal availability of wind, solar and hydroelectricity.

[6] Balmorel is a partial equilibrium model for analysing the electricity and combined heat and power sectors in an international perspective. For further information concerning the characteristics of the model, see: www.ea-energianalyse.dk/en/themes/balmorel/

While the marginal costs of hydro generation are close to zero, "water values" are describing the electricity price above which it is optimal to use hydro. It is similar to the marginal costs for fuel-based generation, and it secures the maximum value of the limited hydro inflow. The water value depends on the costs of alterative generation, including fuel prices and the available capacity that is competing with hydro.

The model can manage various policy measures, such as requirements on generation mix, environmental limits, or fuel consumption constraints – and will find optimal solutions within these constraints. Thus, the model is well suited for long-term planning and scenario analyses.

The optimal dispatch and investments solution is characterized by detailed output data per units, per area and per time step (see Figure 21). It includes electricity generation, transmission, emissions as well as electricity prices and optimal investments in generation, transmission, and storage capacity. The hourly electricity demand, as well as the profiles for wind, solar and hydro inflow, are all input to the model. The results include stakeholder economics, unit profitability, total cost, and benefits of alternative scenarios.

Simplifications

Balmorel model results represent the least cost development for the whole analysed region. The total system costs for the region are minimised. As the model computes the optimal import/export, the solution will also be the optimal solution for each of the countries in the region.

Balmorel simplifications are made for two reasons: First, they can help to keep results clear and easy to interpret; second, they can reduce simulation time. The main simplifications include:

- Full foresight
- Simplified representation of transmission
- Short-sighted investment decision
- Perfect competition (perfect market or perfect planning)

For each year, the model has *full foresight:* Hourly demand, wind, solar, hydro inflow, and potential outage is known. No stochasticity is included. This is less relevant for a planning model (years ahead), while in practical operation (hours, days, weeks) the uncertainty becomes important.

Balmorel has a *simplified representation of transmission* network. In the model, the transmission is reduced to a single capacity between regions and regions are seen as copper plates. Therefore, Balmorel only considers the hourly energy balance between regions and does not consider voltages and grid stability. However, combination with other models – such as PSS/E – can help to ensure that the optimization results are feasible with respects to the grid modelling and safe operation (N-1).

The model is *shortsighted* in terms of investment optimization, as it does not consider power system conditions in future years, for example, fuel price developments or changes in investment costs. When alternative investments are evaluated, the model is comparing the *annual cost of the potential investment* with the reduction in total system costs. The evaluation is based on the year of the investment.

Finally, *perfect competition*, or perfect market, implies that the model does not consider misuse of market power. Perfect competition in a liberalized market has the same outcome as perfect planning in a vertically integrated power system.

Geographical Scope

The geographical scope of the analysis consists of Ethiopia and 11 countries: Burundi, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, South Sudan, Tanzania, Uganda and Yemen[7]. Somalia will later be

[7] The model also has data for Libya and DRC, but these has been excluded due to the remoteness from Ethiopia. Also, connection to other countries has been ignored.

added to the model. Data for the 11 countries is taken from the recent EAPP Power balance statement (EAPP, 2021). Figure 22 illustrates the geographical scope of the model.

Except for Ethiopia and Egypt, all countries are defined as a single transmission region. Ethiopia comprises two regions: The main grid and the remote areas (with the potential of supply from mini grids). Egypt is modelled with seven transmission regions.

The generation mix in Ethiopia as well as the potential export is highly dependent on the situation in neighbouring countries. The demand in Egypt is 74% of the total regional demand, while 8% is attributed to Sudan and 5% to Ethiopia. The total generation in the 12 countries is 306 TWh in 2020, growing to 517 TWh in 2030.

Figure 22: The countries included in the analyses.

Demand

The prognoses for domestic electricity consumption in Ethiopia are shown in Figure 23. Three of the prognoses (low, base and high) correspond to the cases presented in the Demand Forecast report (USAID and Power Africa, 2021). The average annual growth is 9, 11 and 13% p.a. in the respective low, base and high cases. In the High and Base prognoses, it is assumed that the goals for electrification in 2025 and 2030 will be met (see also chapter 3). A further extra high demand prognoses is considered, based on expectations for demand growth outlined in earlier prognoses (EEP, 2021), in which the demand prognosis is 25% higher in 2030 compared to the base case. Comparing the base case to the extra high prognosis (EEP, 2021), the expected industry and households demands are reduced by 31% and 15% respectively in 2030.

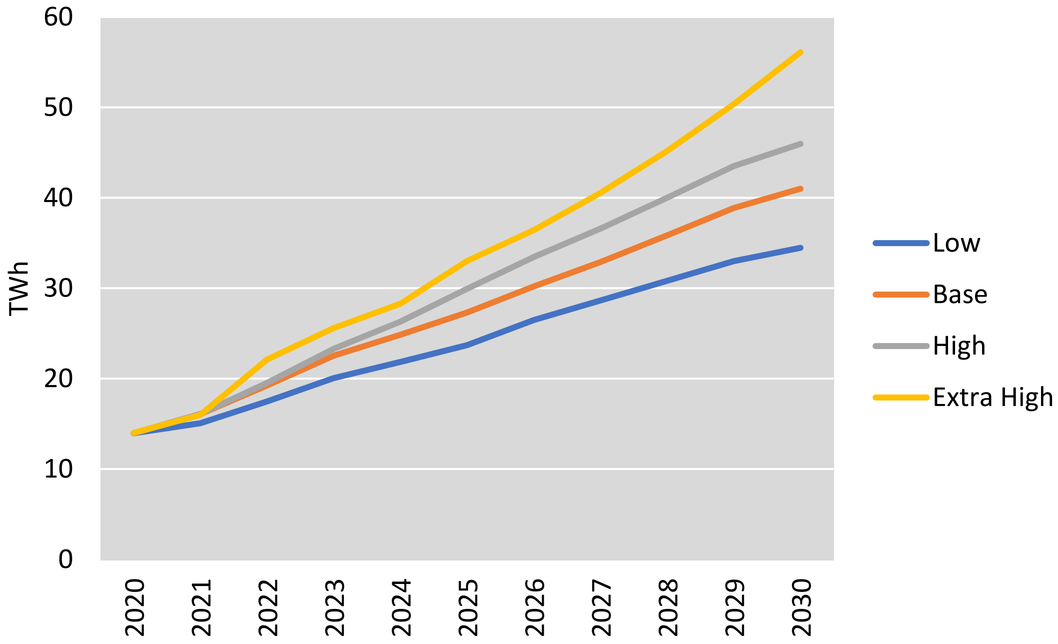


Figure 23: Demand prognoses for Ethiopia. See Figure 5 for historical demand.

Following this, it is important to note the difference between the Ethiopian demand and the actual delivered (sent-out) energy. This has implications for the analysis for the low, base and high demand prognoses provided in the Demand Forecast report (USAID and Power Africa, 2021). Sent-out energy, as defined in the Demand Forecast report (USAID and Power Africa, 2021) includes all domestic electricity consumption, including transmission and distribution losses, in addition to net electricity exports. The prognoses indicated in Figure 23 do not show exports. In the analysis, aside from in the Export scenarios described above, export (and import) from Ethiopia is optimised endogenously. A comparison of sent-out energy, which includes electricity exports, and Ethiopia demand (i.e. gross consumption), between 2020 and 2030, is presented in Figure 24.

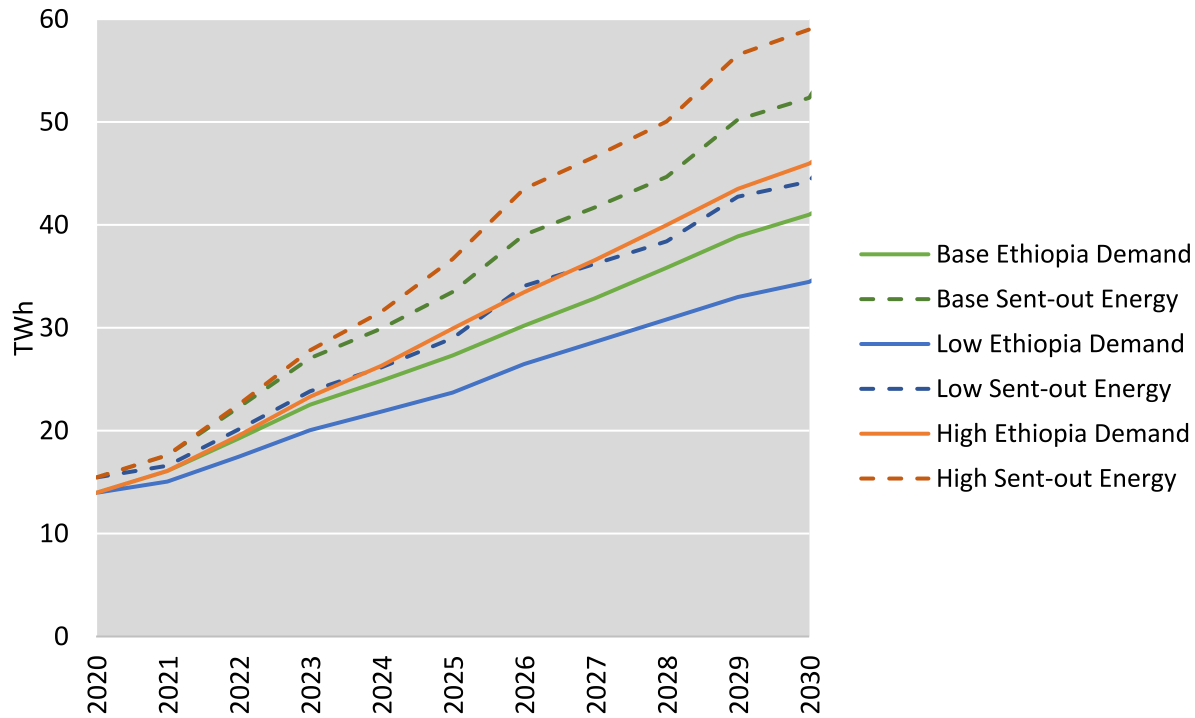


Figure 24: Demand prognoses for Ethiopia. See Figure 5 for historical demand.

There are significant uncertainties about the future demand. Not only is the rate of connecting more households to the main grid uncertain, so is the consumption in future industrial parks. This prognosis is balanced with the historical year 2020, and update of prognoses can take place each time data for a new historical year is ready.

Generation

Table 7 shows the existing Ethiopian generation capacity and Table 8 the capacity under construction. 5,720 MW new hydro is under construction. This new capacity will significantly influence the capacity balance in the years 2024-2025.

For geothermal two projects of 50 MW are included in Table 8. In both cases this is phase one, with an expected phase two to follow – each of additional 100 MW. These plants are planned to come online in 2027 and 2028. However, in this study the phase two projects are included as candidates and not as under construction.

When additional capacity is considered, it is in addition to the existing and under construction capacity. For the other countries included in the analysis, existing plants and plants under construction are taken from the EAPP Power Balance Statement (EAPP, 2021).

Name		Capacity, MW
Geothermal	Aluto Langano	7
Hydro	Aba Samuel	7
	Awash 2	16
	Awash 3	16
	Beles	460
	Neshe	97
	Finchaa	133
	Genale 3	254
	Gilgel Gibe I	184
	Gilgel Gibe II	420
	Gilgel Gibe III	1,870
	Koka	18
	Maleka Wakana	153
	Tekeze I	300
	Tis Abbay 1	12
	Tis Abbay 2	72
Municipal Waste	Reppi	25
Wind	Adama I	51
	Adama II	153
	Ashegoda	120

Table 7: Existing generation capacity.

	Name	Capacity, MW	First year of operation
Geothermal	Corbetti 1	50	2025
	Tolu Moye	50	2024
Hydro	GERD	600	2022
		690	2023
		2,760	2024
		3,105	2025
		3,600	2026
		3,200	2028-
	Koysha	1800	2025
Solar	Dicheoto	125	2023
	Gad 1	125	2023
Wind	Assela 1	100	2024
	Assela 2	150	2025
	Aysha	120	2022
Total (2028)		5,720	

Table 8: Generation under construction.

Interconnectors

Trade between countries in the region is facilitated by interconnectors. Two interconnectors are currently in operation between Ethiopia and its neighbours: a 180 MW connection with Djibouti, and a 200 MW connection with Sudan. All interconnector capacities are net transfer capacities, NTC, which indicate the practical maximum transfer capacity under safe operation. This value is dependent on the nature of the connected grid.

In addition, an interconnector between Ethiopia and Kenya is under commissioning and is expected to begin operation from 2022. From 2025, all the included countries are expected to be interconnected.

Several benefits are associated with increased interconnector capacity in the region. Pooling energy resources will lead to both reduced power supply costs and more effective resource utilization by exploiting synergies between different technology types. Interconnection enables also a higher degree of renewable energy penetration within the region. The best renewable energy sources from across the entire region can consequently be utilized, reducing total electricity costs. Additionally, exploiting wind resources from a variety of locations leads to the smoothing of the total wind power generation, i.e., mitigation of changes in power generation caused by local weather conditions, thereby reducing the respective periods in which deficit or surplus power is generated. The modelled area is more than 4,000 km (North – South) times 2,500 km (East – West).

Technology costs

To optimise future capacity expansion, it is crucial to have a good estimate of the development of the cost and performance of generation technologies. The Technology Catalogue for power generation in Ethiopia (MoWIE, EEP, DEA Ea Energy Analyses, 2021) is used as a basis for cost data throughout the modelled countries. For Ethiopia, a detailed list of candidate plants, including size, CAPEX and OPEX, is also defined for hydroelectric, wind, solar and geothermal generation investment options.

The Technology Catalogue provides estimates for investment cost, variable and fixed operation and maintenance (O&M) cost, unit efficiency and other technology characteristics from 2020 until 2050. Beside the well-known technologies like hydroelectric, wind, solar and geothermal, the catalogue also includes concentrated solar (CSP), floating PV to be located at water reservoirs, nuclear and batteries.

Initiated in 2017, a wind measurement campaign has been conducted by the World Bank to gather wind speed data from 17 different sites across Ethiopia. A complete year of measurement data was available for all sites from 1st July 2019 to 30th June 2020. Based on these measurements, the LCOE at each site has been calculated. The results are presented in Figure 25 for all wind sites that have an average wind speed above 5.5 m/s. The inputs used for calculating the LCOE are outlined in

Table 9. Smoothening of the wind turbine power curves has been applied, to account for imperfect conditions at the wind farm, e.g. wake losses, unavailable turbines and varying wind speed.

Wind Category	Low	Medium	High
Average Annual Wind Speed (m/s)	> 5.5	> 6.5	> 7.5
Wind Turbine	Gamesa G114-2MW	Nordex N117-2.4 MW	Vestas V126-3.45MW
Nominal Investment Cost (MUSD/MW)	1.77	1.51	1.32
Specific Power (W/m²)	196	223	277
Hub Height (m)	100		
Fixed O&M Cost (USD/MW/yr)	46		
Variable O&M Costs (USD/MW/yr)	4.0		
Technical Lifetime (yr)	20		
Discount Rate (%)	11.65%		

Table 9: Wind Site LCOE Analysis Parameters

The economy of a wind project is heavily dependent upon the wind resource (wind speed), as illustrated in Figure 25. The LCOE values at high wind speed sites, Aysha, Kebri Beyah and Gode, are significantly lower than at other sites, primarily due to two factors: lower specific turbine cost and higher capacity factor. Connection costs are not considered in the LCOE analysis presented, which could impact the development costs at each site disproportionately, depending on the distance from the wind site to the main grid. However, grid connection costs typically comprise less than 15% of project costs, so grid connections are unlikely to affect project costs drastically. From a simple least cost perspective (excluding system aspects like smoothening and integration costs), it is most attractive to develop wind projects with the lowest LCOE, i.e., prioritising high wind speed sites.

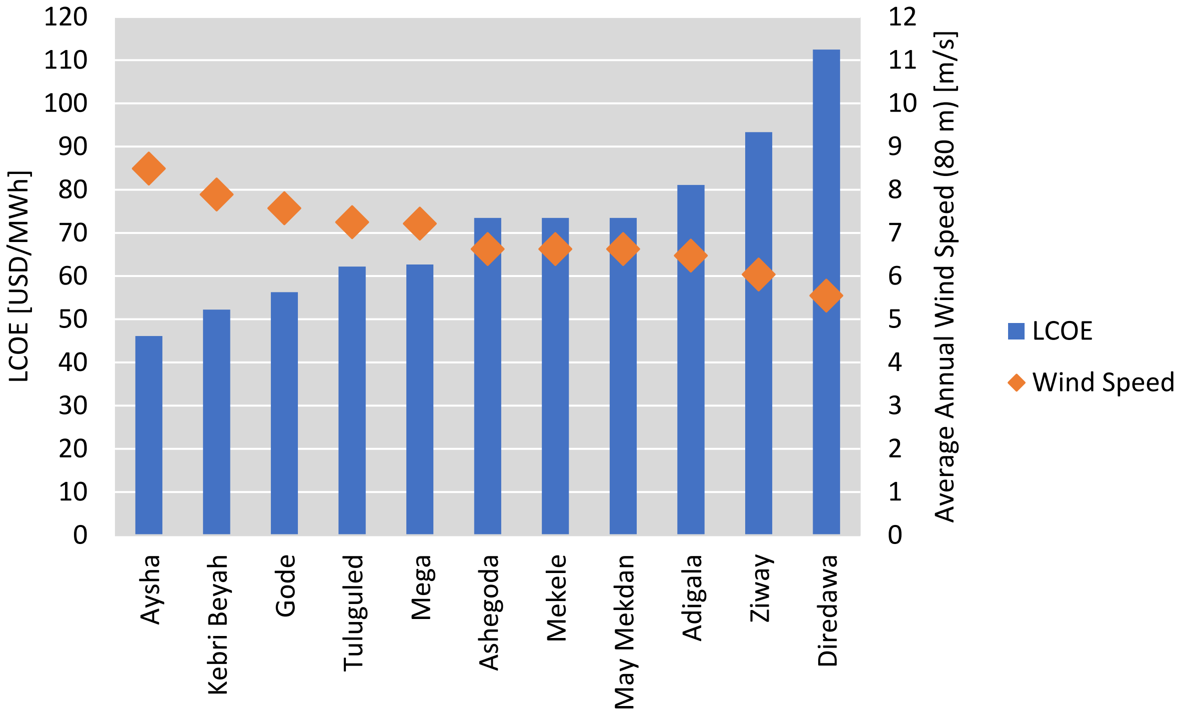


Figure 25. Levelised Cost of Electricity, LCOE, for sites with +12 months of wind measurements and average annual wind speed exceeding 5.5 m/s.

Fuel prices

Fuel prices have been derived from IEA's World Energy Outlook scenarios (2020). In most scenarios, the IEA Stated policies scenario is used. The prices are expected to be stable in the considered period, 2020-2030. IEA has two other scenarios (Delayed recovery and Sustainable development), that both have lower fuel prices.

Scenarios

Scenarios are used to gain insight in the Ethiopian power system – and the potential costs and benefits of alternative futures. Key interests are to study the generation mix and the potential for export from Ethiopia.

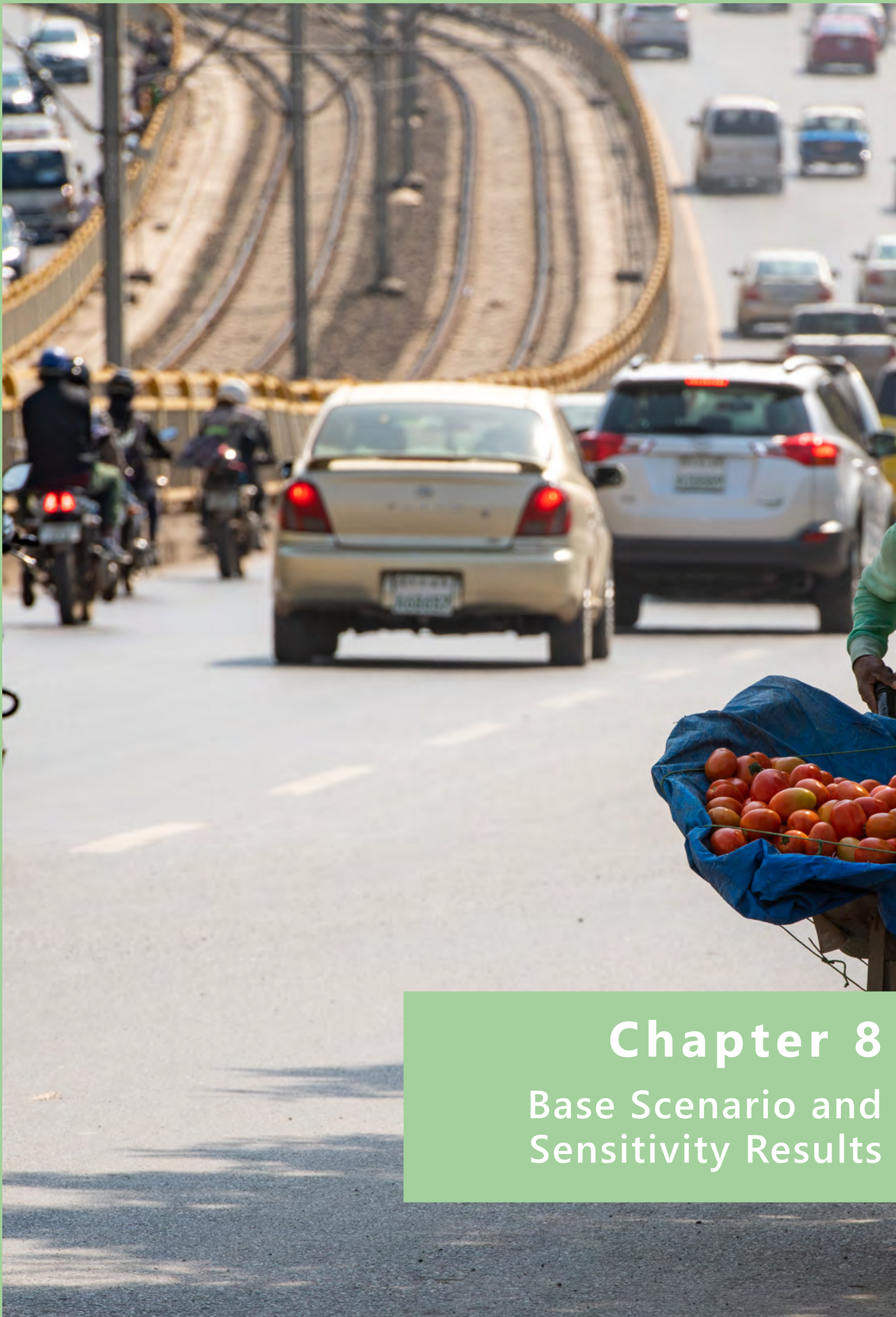
A base scenario and 15 alternative scenarios constitute the modelling analysis. Each scenario is typically defined as one simple change compared to the Base scenario. This makes it easy to understand the results. The scenarios have been developed to gain further insight into the policy options laid out in the NEP 2.0. For example, the objective of being a regional power hub has been analysed through different scenarios to gain the most insight into understanding the Ethiopian business case of being a power hub. This has provided some interesting insight into the political choices concerning the Ethiopian position in the region as both exporting country and balancing actor in the region. The scenarios are described in the table below and the results further explored below.

Value of unserved demand

The value of unserved demand applied in Ethiopia is 1200 USD/MW, for on-grid consumption. For off-grid consumption, the value is assumed to increase linearly from 150 USD/MW in 2020 to 200 USD/MW in 2030. This specification provides the upper limit of the cost that that can be incurred to fulfil a single unit of demand. If the cost of supplying demand exceeds these values, then the demand will not be fulfilled, i.e. load shedding will take place.

Scenario	Definition	Remarks
Main		
Base	Least cost, no policy restrictions	Acts as a reference for all other scenarios
Diversification		
Diversification (3 variations)	Requirements on the generation mix in Ethiopia: – 25% non-hydroelectric (with and without natural gas as an option) – 25% non-hydroelectric with the follow distribution: geothermal, wind, and solar: 11/9/5% (i.e. "Mix" scenario)	To illustrate diversification pathways and the costs compared to Base. The percentages are relative to the national demand. Hydro can have a larger share than 75%, if export take place.
Delayed investment in wind and solar in neighbouring countries	Max 100 MW investment per year per technology in Sudan and Kenya	To illustrate how wind and solar in those two countries compete with the export from Ethiopia.
Export		
Export (4 variations)	Requirements on net export from Ethiopia: 5, 10, 15 and 20 TWh in 2030. Linear increase after 2025.	To illustrate how this influences the generation mix in Ethiopia, the cost and the value of export
Restricted trade (2 scenarios)	– Ethiopia as an electric island (no import or export) – Only export from Ethiopia allowed, no import to Ethiopia	To provide a reference to illustrate the benefit of trade
Other sensitivity analyses		
Demand	To test alternative demand prognoses, including different degree of electrification: Demand in 2030: 34.5 (Low) / 41.0 (Base) / 46.0 (High) / 56.1 (Very High) TWh	To illustrate the impact of different demand prognoses
Interest rate	To test the impact of alternative planning interest rates: 8 (Low) /11.65 (Base) / 15 (high)% p.a.	To illustrate the impact of interest rate. Economic lifetime is set to 20 years, except for hydro generation, where it is 30 years
Fuel prices	Based on two IEA scenarios: Delayed recovery and Sustainable development	Both have lower prices
CO_2 price	Added a shadow price for CO_2 of 50 USD for all countries to introduce a regional focus on reducing the CO_2 emissions.	To illustrate how different countries will react to this. It can also be regarded as a high fuel price scenario.
Dry year	All investments as Base, but with 25% less hydro inflow in Ethiopia	A simple stress test

Table 10: Overview of scenarios.



Chapter 8

Base Scenario and Sensitivity Results

8. SCENARIO AND SENSITIVITY RESULTS

The results presented in this section indicate the least-cost development pathway for the entire modelled region, without any policy restrictions. The economic dispatch of generating capacity and optimal investments in both generation and interconnector capacity are determined to minimise the total system cost of the region. The scenario represents the lowest possible total cost. It is not a preferred scenario, but a good reference for all other scenarios.

Figure 26 illustrates the least-cost development of generation capacity in Ethiopia. Generation expansion (on top of existing capacity and capacity under construction) in Ethiopia is (only) 60 MW wind and 214 MW hydro in 2030. Endogenous investment only in Ethiopia occurs only in 2030 and no additional investment takes place in solar, geothermal, waste, natural gas or nuclear in Ethiopia (in the main grid[8]) throughout the time horizon. Use of these technologies would incurs an additional cost when used to substitute hydroelectric and/or wind power in Ethiopia, or generation in neighbouring countries. This also means that the planned 200 MW geothermal is not found to be a least cost solution.

There are significant investments in wind and solar capacity in the region; however, the capacity is mainly located in neighbouring countries (see Figure 27). The main reasons are that both the electricity price and the wind and solar potentials[9] are higher in Kenya and Sudan than in Ethiopia. The transmission losses applied to interconnectors further reduce the competitiveness of investing in solar in Ethiopia for export. In the Baseline scenario, endogenous investments in solar PV capacity occur in South Sudan, Sudan, Tanzania and Yemen, while wind investments occur in all countries except Burundi, Rwanda and Uganda.

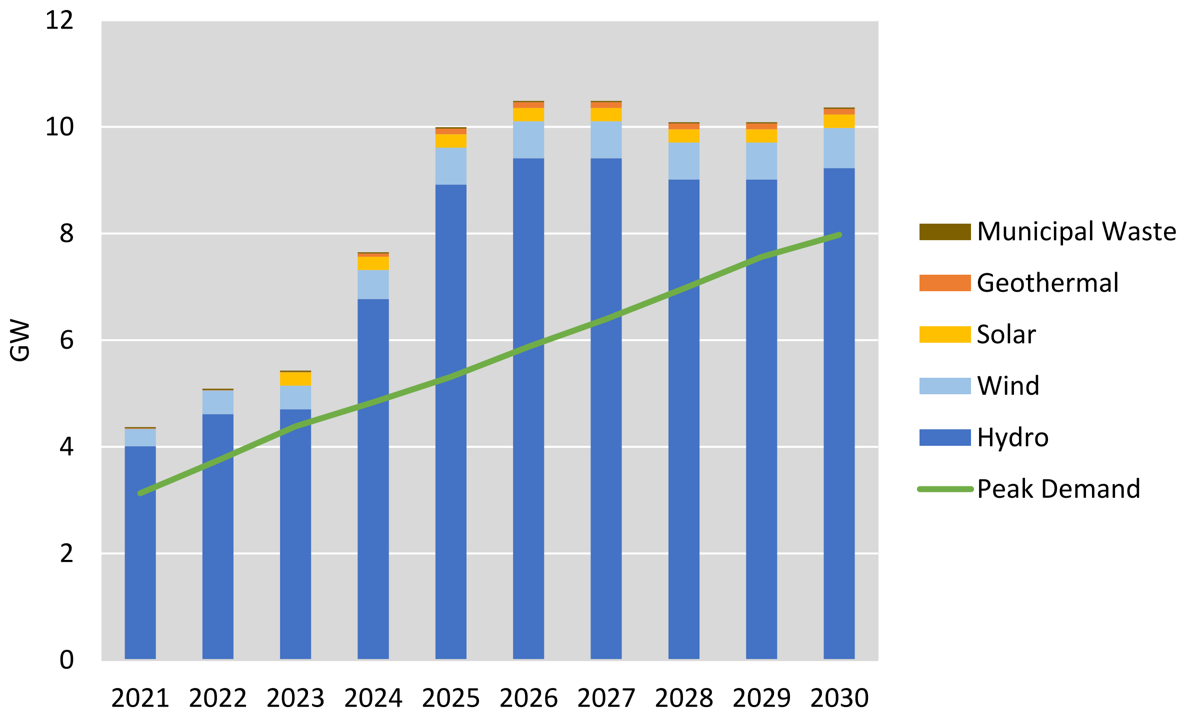


Figure 26: Peak demand and capacity in Ethiopia, Base scenario.

[8] See below for the Ethiopian remote areas.

[9] E.g., the area with average wind speed of more than 9 m/s is 236,000 km² in Sudan, 26,000 km² in Kenya and 5,500 km² in Ethiopia. Own calculation based on Global Wind Atlas.

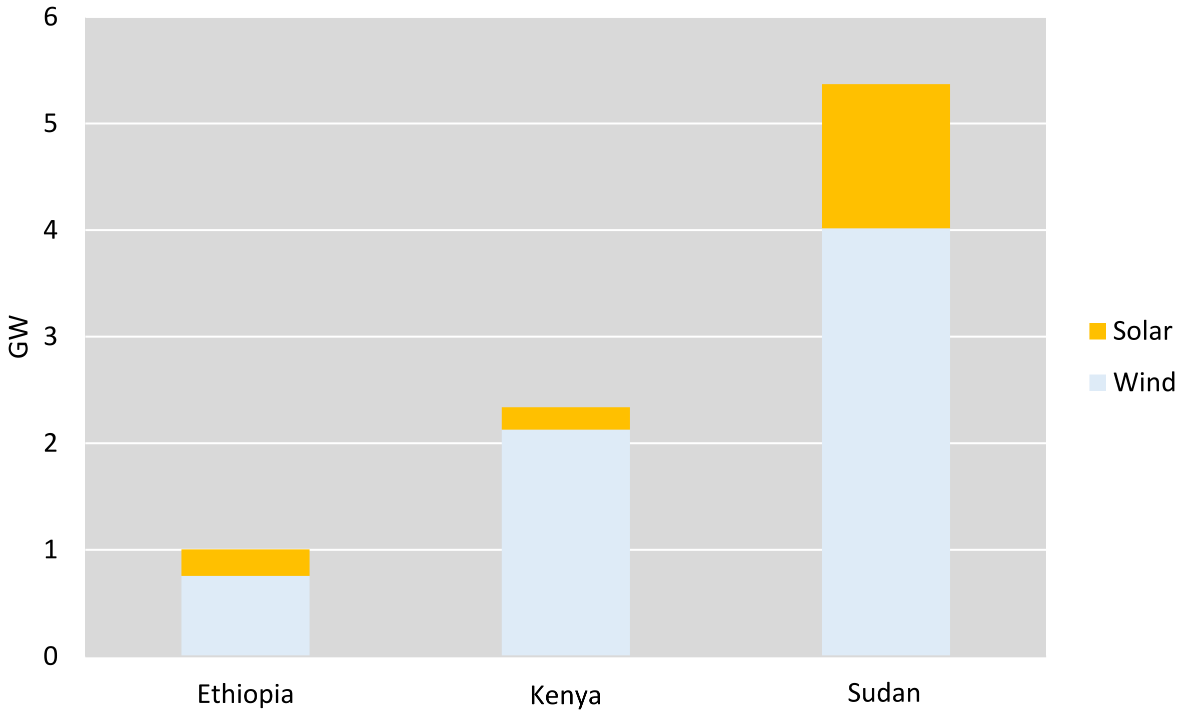


Figure 27: Wind and solar capacity in selected countries in 2030. Base scenario[10].

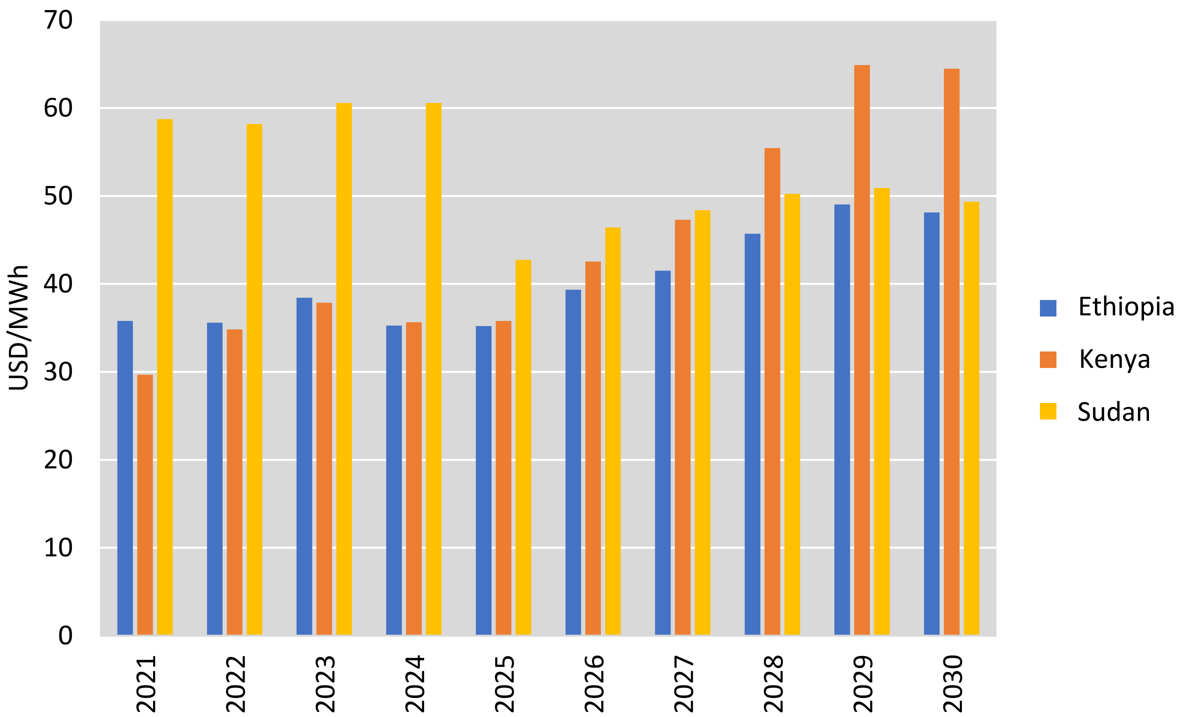


Figure 28: Average electricity prices. Base scenario.

Figure 29 illustrates the yearly generation and consumption in Ethiopia, from 2021 to 2030. New capacity in the model, i.e., model-based investments, are first allowed for most technologies from 2025, with the exception of wind and solar capacity, which is allowed from 2023. These restrictions reflect the differing construction times required for different technologies. Installed capacity of hydro and wind power plants does

[10] The least cost expansion of wind and solar in Sudan and Kenya in the Base scenario is higher that is planned in those countries. In the EAPP Power Balance Statement, they have reported 2,200 and 2,300 MW in 2030.

increase in 2023, by 690 MW and 250 MW respectively, compared to 2022. However, the increase in demand outpaces the increase in installed capacity and no investments in wind or solar capacity are made endogenously. Instead, net import occurs in 2023, as indicated in Figure 30 by the deficit in generation compared to annual demand, since wind and solar investments are preferred in neighbouring countries. See Figure 30 for the origin and destination of traded electricity. In 2030, the generation from non-hydro will correspond to 7% of the national demand (wind: 4%, geothermal: 2%, solar 1%) in the base scenario.

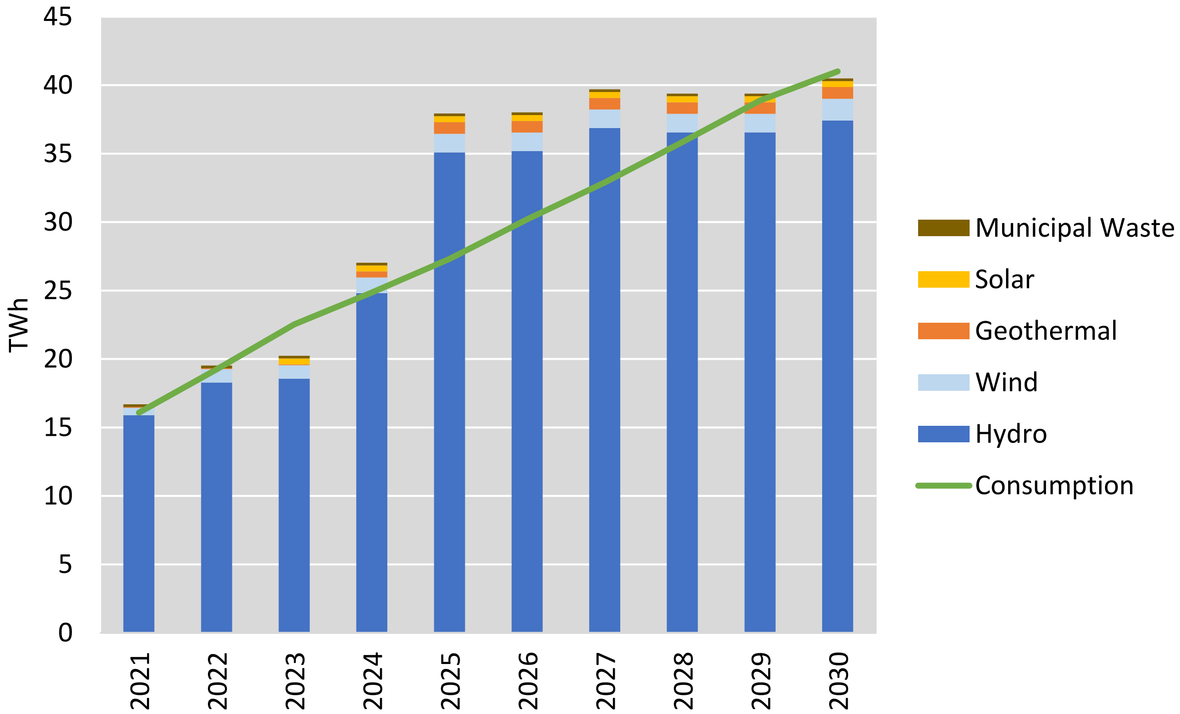


Figure 29: Electricity demand and generation in Ethiopia, Base scenario.

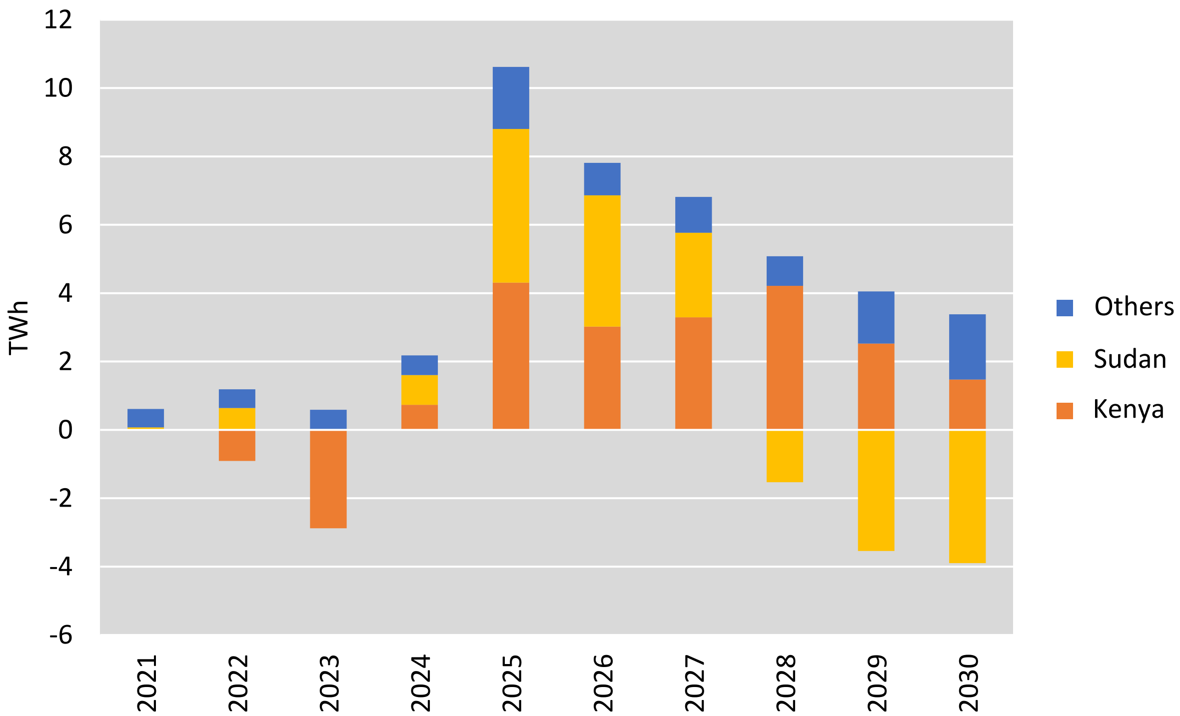


Figure 30: Export from Ethiopia, Base scenario. Others include South Sudan, Eritrea, and Yemen.

In *Figure 31*, the total national costs for the Base scenario are shown. Total national costs are defined as the sum of the annuity of the total investment (generation and transmission) and O&M costs, minus the revenue from trade. Revenue from trade comprises revenue from export less cost of import plus 50% of congestion rents. Normally, fuel cost is also accounted in the total costs, but no fuel costs exist for the Ethiopian main grid. Capital costs for existing and under construction projects, i.e. sunk costs, are not included. Capital costs are shown in more detail in

Table *11*[11].

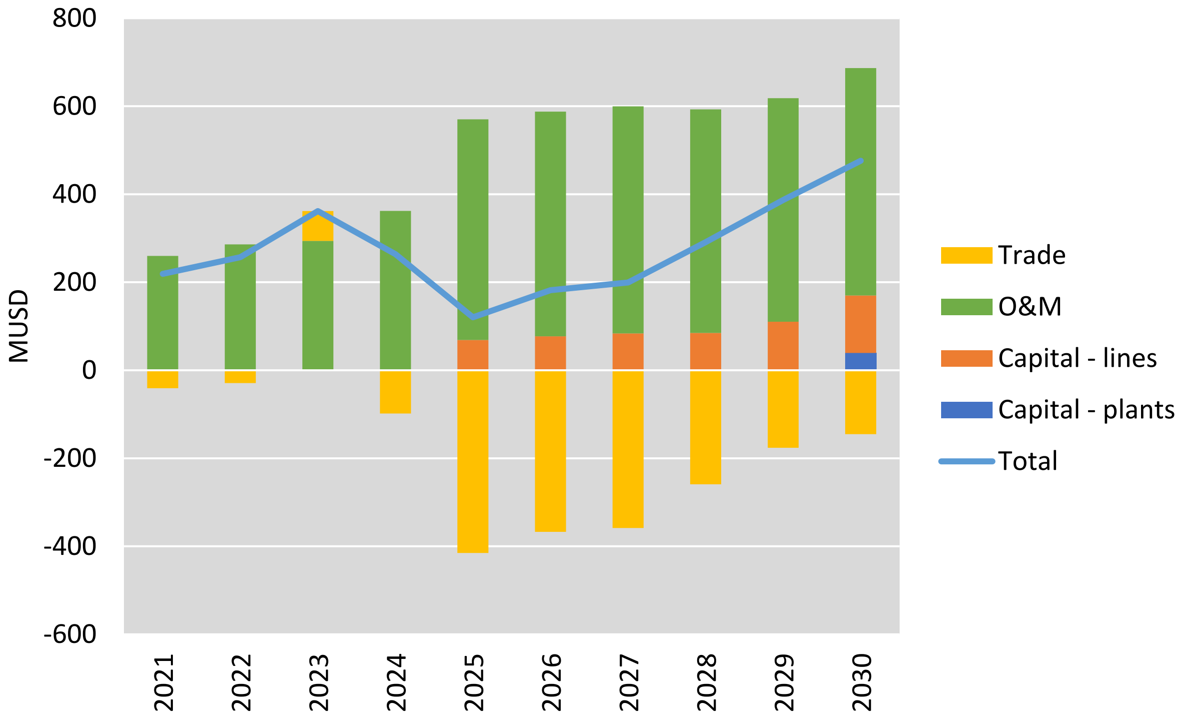


Figure 31: National costs for Ethiopia. Base scenario, only main grid. Note that capital costs for existing and under construction plants and lines are not included. Capital costs are presented as annual costs. Negative values indicate income.

Capital costs	Hydro	Wind	Transmission lines	Sum
Annual costs in 2030, MUSD/year	30	10	65	105
Total investment 2025-2030, MUSD	227	73	499	798

Table 11: Investment costs in the Base scenario.

Figure 32 shows the development in Ethiopian interconnector capacity. Existing interconnector capacity with Sudan is 200 MW. An additional 1,277 MW of capacity is required by 2030 in order to effect the least cost scenario. Also new connections are made to South Sudan, Eritrea and Yemen. The net transfer capacity (NTC[12]) of the Kenya connection is assumed to be increased in three steps: 400, 800 and 1,200 MW from 2022 to 2024.

[11] An interest rate of 11.65% p.a. is used. Economic lifetime is 20 years for all investments, except for hydro plants, where 30 years is used. The annuity factor is therefore 13.9% (13.0% for hydro).

[12] The NTC indicate the maximum transfer capacity in safe operation. Restrictions in the connected network can reduce the transfer capacity.

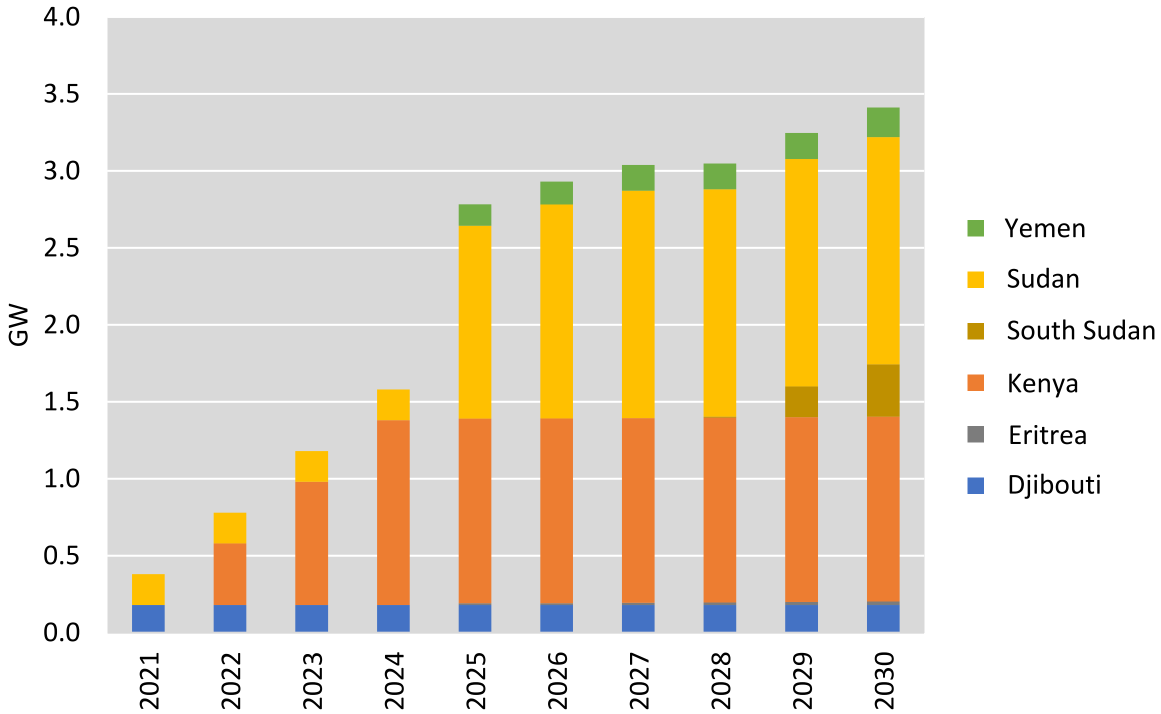


Figure 32: Transmission capacity from Ethiopia. Base scenario. Model based investment can take place from 2025.

Sensitivity scenarios

Generation in Ethiopia is sensitive to fuel prices despite no fuel consumption in the country's power sector. High fuel prices increase the incentive for export, and vice versa. In the CO_2 scenario (which is similar to a high price scenario) the generation in Ethiopia is increased by 10 TWh in 2030 compared to the base scenario. The extra generation is supplied predominantly by hydro (9.0 TWh), along with wind (1.2 TWh) and solar (0.2 TWh) power.

Low fuel prices reduce the competitiveness of investments in renewable energy sources. Therefore, the invested capacity and electricity generated in Ethiopia is lower when low fuel prices are considered. This applies only for the final year in the modelling horizon, since it is only in 2030 that endogenous investments occur. The net import in 2030 increases from 0.5 TWh (base scenario) to 1.6 TWh when low fuel prices, corresponding to the IEA sustainable development scenario, are applied. Fuel price development is an external factor that has significant impact on Ethiopian export. Note that in most of the scenarios, the highest IEA price prognosis, i.e. the stated policy scenario, is used. If significant steps are taken in reducing the world's fuel demand, lower fuel prices can be expected.

A low interest rate (8%) leads to an increase in generation from both hydro and wind in Ethiopia, by 0.1 TWh and 0.7 TWh respectively. The increase in electricity generation from wind in Ethiopia is 40%. The same trend is observed for investments in the entire modelled region, where wind capacity increases from 51.4 GW to 74.8 GW in 2030, when interest rates are reduced from 11.65% to 8%. Though solar capacity does not increase in Ethiopia, it does so for the region. The solar capacity in all countries in 2030 increases from 8.2 GW to 13.2 GW.

In the scenario "Delayed", it is assumed that wind and solar generation in Sudan and Kenya is restricted to 100 MW/year (per technology, per country). Such deviation from the optimal investment will make investment in hydroelectricity and wind more attractive in Ethiopia. See Figure 33.

It can be seen that across all scenarios, that it is hydro and wind power that is changed.

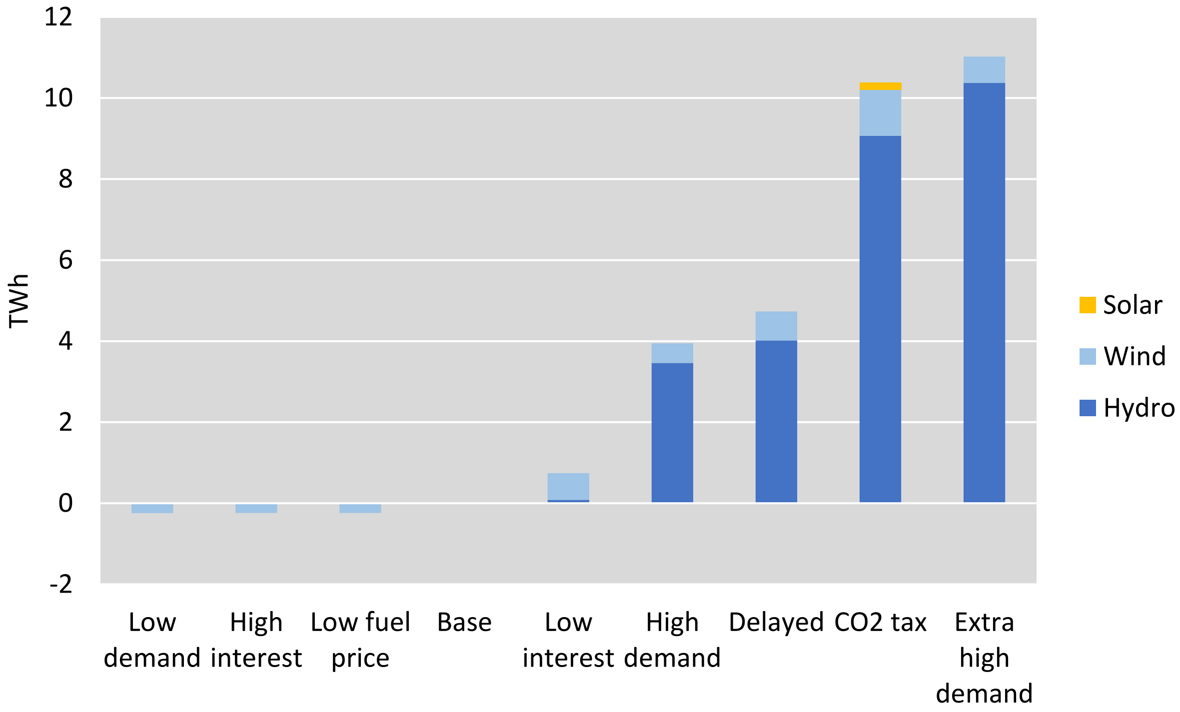


Figure 33: Parameter variation: Change in generation in different scenarios compared to Base scenario. 2030. For simplicity, marginal changes in the generation from waste and geothermal is not included here.

Remote areas

In a separate and simple analysis, the supply of electricity in the remote areas of Ethiopia is studied. The focus is on investment in mini grid solutions, based on a combination of solar, diesel and batteries. The demand to be supplied from mini grid is assumed to increase from 2.4 TWh in 2020 to 3.8 TWh in 2030, corresponding to 8% of the total national demand in 2030.

As a special feature, the model applies a penalty for not supplying electricity to cover all demand is reduced to 0.15 and 0.20 USD/kWh in 2020 and 2030 respectively – compared to the much higher value used in the main grid: 1.2 USD/kWh. All investment costs in the remote areas are assumed to be 50% higher compared to investments in the main grid. This is to reflect the small size of the units in the remote areas.

Figure 34 shows the optimal investment (GW) in the base case. There is no investment in batteries. Figure 35 shows the supply and the energy not served. In 2030, 40% of electricity is supplied solar, 53% from diesel and 7% is unserved. It is an open question whether this level of fuel demand is acceptable.

The result is sensitive to variation in the assumptions, see Table 12. With a higher fuel price, there is no investment in diesel and the share of unserved energy increases to 58%. With a low interest rate, batteries are included and solar now covers 53% of the total demand, and energy not served is reduced to 2%.

Table 12 indicates that the solar share varies between 38% and 48% across scenarios shown and that the share of unserved demand is particularly sensitive to fuel price, given the assumptions applied regarding the costs of unserved demand.

For the 12 mini grid pilot projects currently under development in Ethiopia, as outlined in the Electrification section, the installed capacity is 3.8 MW solar, 1.0 MW diesel and 6.6 MWh battery. The capacity mix of solar/diesel is similar to that shown in Table 12. However, the model results do not have batteries, except for the sensitivity with low interest rates, and the share of batteries in the results is considerably lower than the current pilot projects. The costs of the batteries exceed the maximum supply costs assumed (0.20 USD/kWh in 2030). Note that this limit is not well defined.

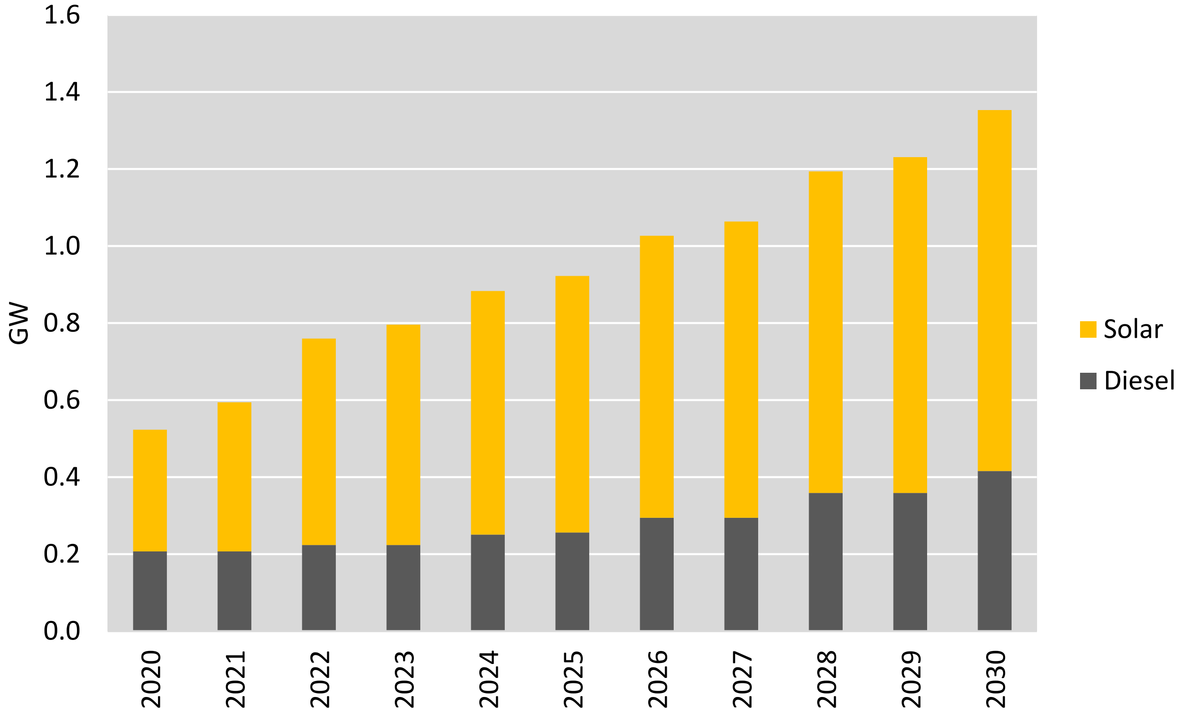


Figure 34: Capacity in the remote areas. Note: Only solar, diesel and batteries are options. Base scenario.

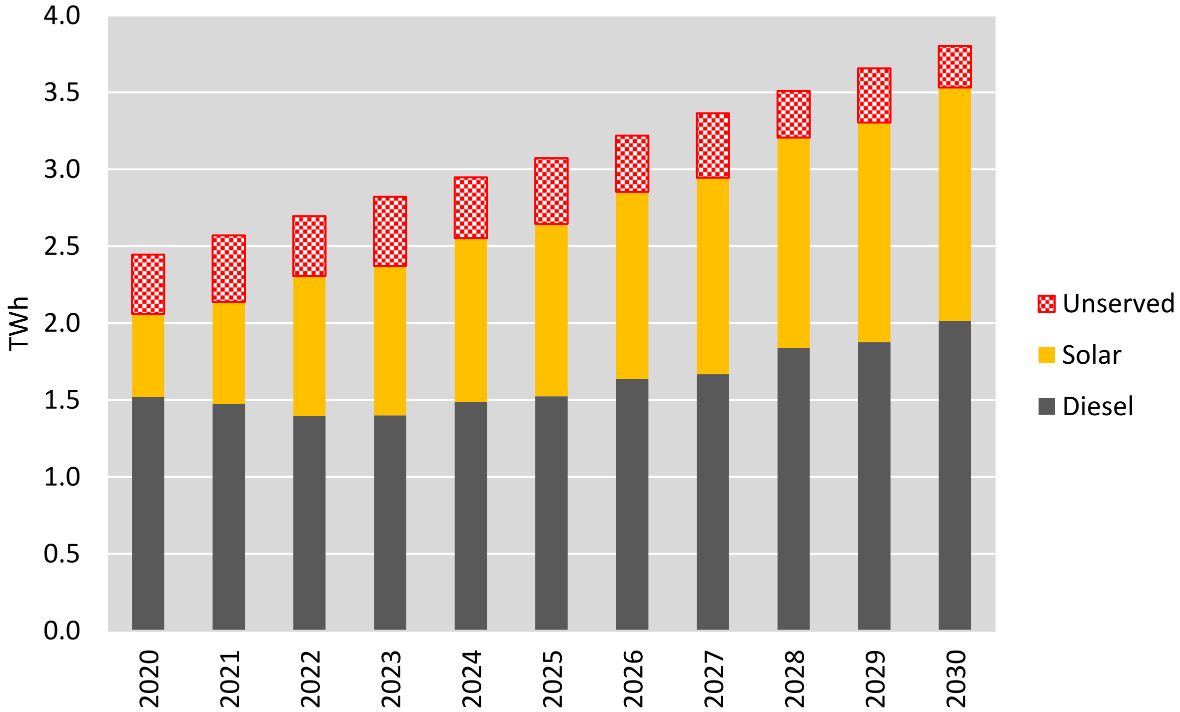


Figure 35: Supply in the remote areas. Base scenario.

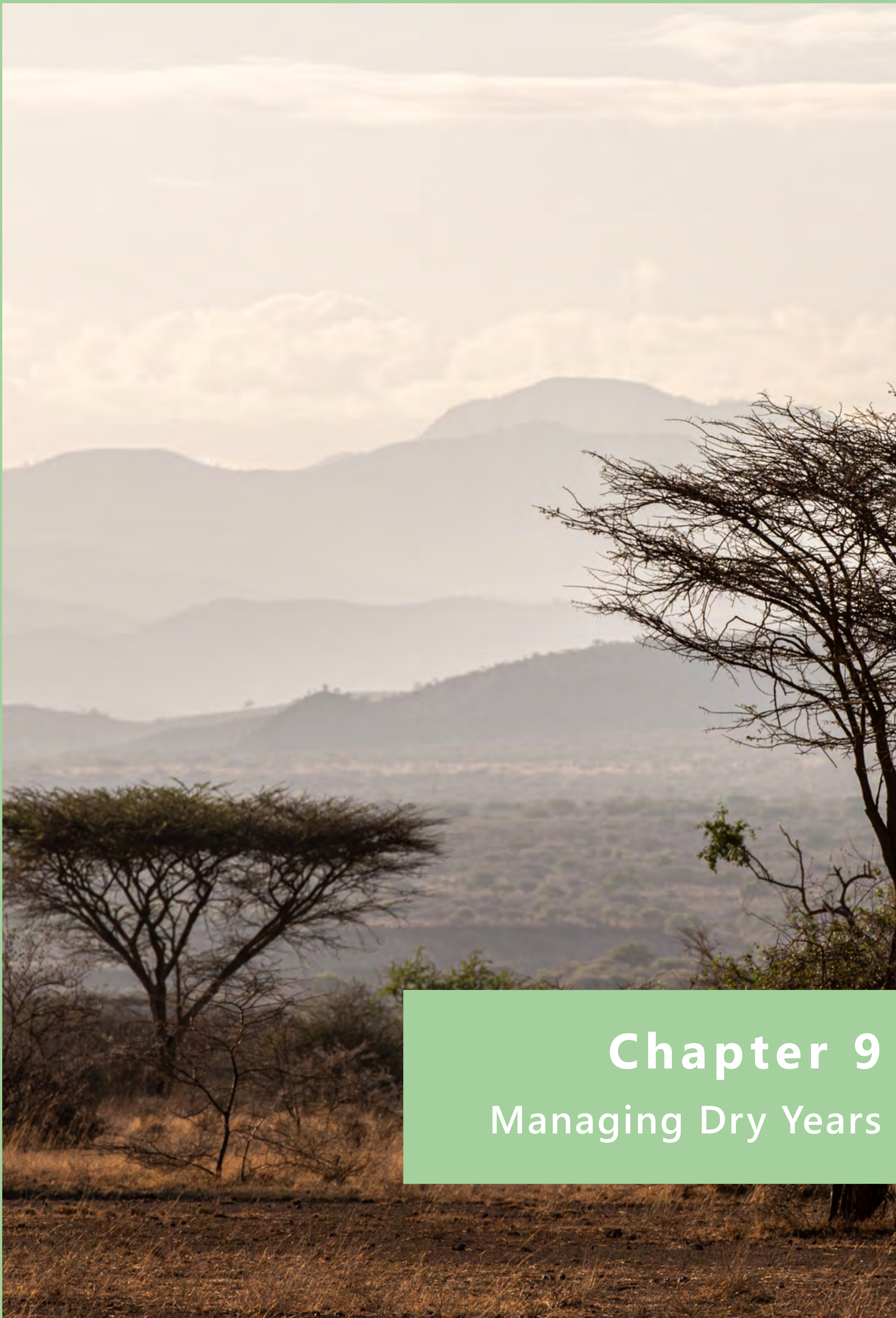
	Solar	Diesel	Unserved	Delivered via battery	CO2 Emissions (gCO2eq/kWh)
Base	40%	53%	7%	0%	314
Low fuel price	38%	60%	2%	0%	356
High fuel price (CO2)	41%	6%	52%	0%	38
Low interest (8%)	48%	43%	2%	6%	257
High Interest (15%)	39%	52%	9%	0%	308

Table 12. Supply in remote areas (TWh). Five scenarios. 2030.

Insights

The Base scenario and the sensitivity scenarios show several important insights:

- Large hydro capacity is under construction in Ethiopia. In 2030, also investments in further hydro capacity along with wind take place in Ethiopia.
    - Large investment in wind power take place in Sudan and Kenya. Better wind resources and higher electricity price makes it more attractive to locate wind here, than in Ethiopia.
- With the assumption in the Base scenario, a net export of 10.6 TWh takes place in 2025. Conversely, by 2030 a relatively small net import of 0.5 TWh occurs.
    - The export is sensitive to the development in fuel prices. If a low fuel price development is assumed, the net import in 2030 increases to 1.6 TWh. The electricity price in the receiving countries depends on the fuel price.
    - In case of a high fuel price – e.g., due to a CO_2 price – net export increases in all years after 2021 and the resulting net export in 2030 is 9.9 TWh.
    - In the scenario with delayed expansion of wind and solar in Sudan and Kenya, the export from Ethiopia is higher than the baseline scenario from 2028.
- Soon the transmission line will be opened to Kenya. A similar capacity is economically attractive to Sudan: 1,200 MW (2025).



Chapter 9

Managing Dry Years

9. MANAGING DRY YEARS

Hydroelectric power is in many ways attractive. It can deliver low-cost electricity, and can act as a storage ideal for balancing fluctuating power sources. The potential is large in Ethiopia. High mountains and good yearly rainfall make hydroelectricity appealing. In 2020, hydroelectric sources delivered 98% of the generation in Ethiopia. Most of the rain falls in the well-defined wet season (June-August) and large reservoirs are typically used in Ethiopia – needed to make it possible to generate the whole year round.

Hydro inflow variation

Figure 36 illustrates how hydroelectric inflow can vary from year to year. From these data, it can be computed that the 10 years-dry year is 25% lower than the average year.

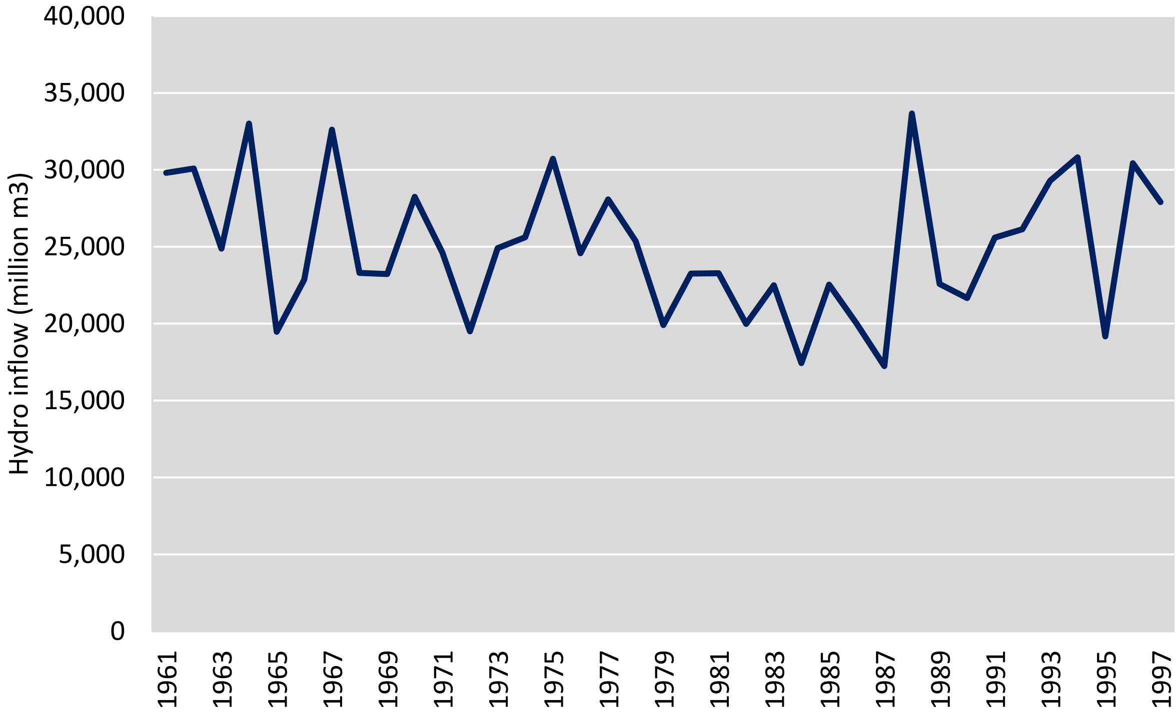


Figure 36: Yearly hydroelectric inflow. Indicator computed as the sum for all rivers. (Parson & Brinckerhoff, 2014).

With the high dependence on hydro, it is relevant to understand the possible impact of climate change on the precipitation in Eastern Africa. While climate change in general leads to higher temperature and more extreme weather, indications are that there will be an increased precipitation in eastern Africa on average. In (WMO, 2019) the impact in the mid and late 21st century has been studied with two scenarios of the future CO_2 emission (a worst case with continued high emissions, and an alternative with 90% reduction in CO_2 emissions). In all four combinations, East Africa will have increased precipitation. In the high CO_2 scenario, the change could be 10-20% increase. In the low CO_2 scenario, the change is still positive, but much smaller. The results for Eastern Africa are in contrast with the results for Southern Africa, where precipitation is expected to be reduced. Similar results are found in (Serdeczny, et al., 2017) and (IPCC, 2014).

Managing hydroelectric variation

An example. In a normal year in the 10 TWh export scenario, the demand in 2030 is 41 TWh, and hydroelectricity generates 47.3 TWh, while wind, solar, waste, geothermal generate additional 3.7 TWh (9% of demand). However, in a dry year there is approximately 25% less hydroelectric inflow, or 12 TWh, resulting. The reduced generation can be compensated for by exporting less. In this case, there would be deficit in electricity generation compared to demand in a dry year.

In general terms, there are three ways to manage dry years:

- Diversification by wind, solar, geothermal, or waste. Considered on a yearly basis, these technologies generate more or less the same every year. The variation is much smaller than for hydroelectricity: a low wind year is 2% below average compared to the 10 years-dry year for hydro (25% lower).
- Dispatchable generation, e.g., natural gas based combined cycles. In the long term, demand response can also be an option[13].
- Adjusting export/import
- Reservoir storage schemes

Diversification by wind, solar, geothermal, and waste can reduce the share of hydroelectricity generation. In the above example there was 9% non-hydro and the reduction of hydro in a dry year was 12 TWh. If the share of non-hydro sources was doubled, and hydroelectric production in a normal year was reduced correspondingly, then the reduced generation by hydro in dry year would be 10.3 TWh. So even with a significant increase in the share of non-hydro production, a considerable amount of generation would not be available in a dry year. The generation deficit must be compensated by fuel-based generation or by reduced export.

Ethiopia is about to start extracting natural gas (see chapter 6). Natural gas is a relatively clean fuel (with no sulphur and 30% less CO_2 compared with coal), and it could be used to balance the generation in dry years. Even though the natural gas is mainly expected to be exported as LNG, it would technically be straightforward to connect a natural gas based plant to the pipeline from the field in the Somalia region to Djibouti. As an example, assume that half of the generation deficit from hydroelectricity were generated by natural gas in the above export scenario (and the rest by reduced export). This would equate to 6 TWh. Assuming that there is a full year to generate the electricity, this would require a capacity of 685 MW[14].

The CO_2 emission from the consumption of natural gas should be balanced against the fact that this would allow increased hydro capacity, and the export of this electricity in normal and wet years would reduce fuel consumption in the receiving countries.

Dry year scenario

In Balmorel a simple stress test has been made[15]: the investment in generation and transmission is taken from the Base scenario, and the model is re-run with dispatch only, considering 25% reduced inflow to hydroelectric facilities (reservoir and run-of-river) in Ethiopia.

To compensate the deficit in electricity generation from hydroelectric sources, net import is increased in all years, culminating in a net import of 9.8 TWh in 2030.The only year in which net export still occurs is in 2025. For the period 2021-2030, an average net annual import of 4.3 TWh is observed for the dry scenario, compared to an average net annual export of 3.0 TWh occurs in the base scenario.

[13] *Demand response* is price dependent electricity demand. The ideal is that generation and demand can compete on equal terms: Electricity is only used if the value if higher than the price. Examples of demand response can be energy intensive industry, that may delay production, in hours with very high price. Other examples can be with demand related to heating and cooling. The supply of heating and cooling can in many cases be disconnected for one or several hours without significant comfort problems. Demand response will require meters with remote reading and hourly settlement for demand.

[14] If it is realised in the mid of the wet season, that this year could be a dry year, generation based on natural gas could start and continue to next wet season.

[15] It is planned to develop Balmorel further, so investments in generation and transmission can take place based on a combination of dry, normal and wet years. In dry years more generation is need, in wet years more transmission can be relevant.

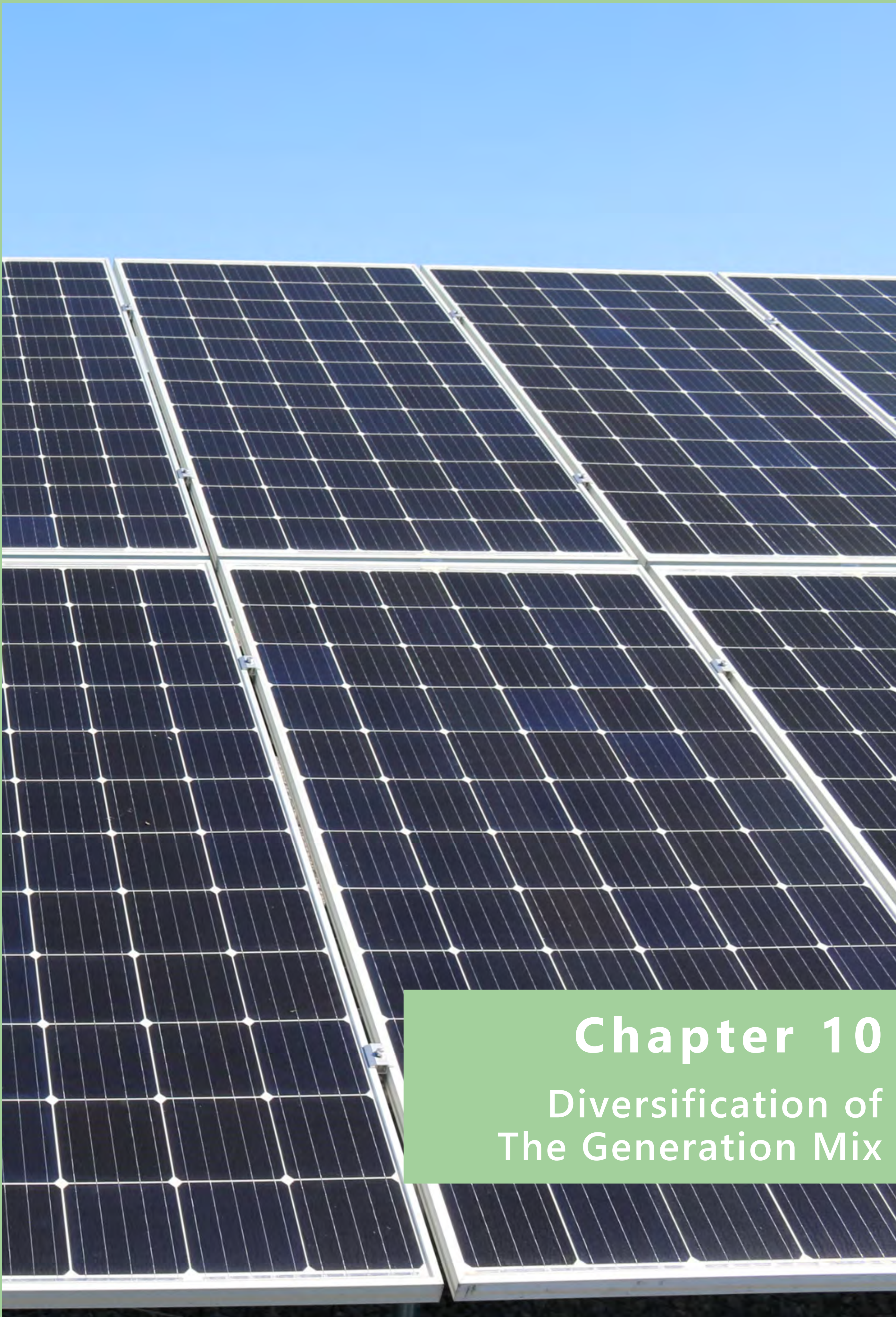
Compared to Base, in the Dry scenario the imported electricity (fuel based) is much more expensive than the hydroelectric production (in a normal year). In 2030, the extra cost for Ethiopia is 752 MUSD. A wet year has not been evaluated, but would result in a reduction in costs.

An export scenario of 15 TWh, or more, would be able to compensate for the missing hydroelectricity in a dry year by reducing export. No net import would be needed in this case.

Insights

Efficient management of dry years is crucial for a hydro dominated country such as Ethiopia. The analyses point at the following observations and opportunities:

- There are three ways of managing dry years: diversification of the energy mix, increased dispatchable generation capacity and/or balancing with import/export.
  - Diversification alone cannot balance the system in dry years.
  - Dispatchable generation could have the form of natural gas based combined cycle turbines. Natural gas could come from the planned exploration in the Somalia region. A 685 MW plant could deliver around half of the needed generation in a dry year (2030).
  - However, using export/import could be the most attractive solution. If the export from Ethiopia is 15 TWh per year in a normal year, then reduced export can balance the system in a dry year. This would require dynamic trade agreement with the neighbouring countries. Dynamic trade is also strongly motivated by the dynamic nature of wind and solar power. With large wind and solar capacities in the region, fixed export is no more relevant. Power should flow from the cheap to the more expensive area – and that is changing from hour to hour.



Chapter 10

Diversification of The Generation Mix

10. DIVERSIFICATION OF THE GENERATION MIX

As analysed in chapter 9, there can be drawbacks related to a one-sided generation mix dominated by hydropower. In dry years, generation from hydro will be 25% below average, in a 10-year dry year.

Scenario results

Nine ways of achieving a different generation mix are presented in Figure 37. Some of them, like the scenarios considering various export levels, applying a universal carbon tax and delayed RE investments in Kenya and Sudan, have a clear regional perspective and cannot be decided alone by Ethiopia.

In the Diversification scenario it is required that 25% of the generation (in energy terms, compared to national demand) must be non-hydroelectric (wind, solar, waste, geothermal, natural gas). The least cost-solution to this requirement is to add an additional 1,782 MW of solar capacity and 1,224 MW of wind capacity, compared to the base scenario. In the Mix scenario, the requirements are more detailed regarding the sources: geothermal 11%, wind 9%, and solar 5% (also giving 25% non-hydro in 2030). In this case, the largest difference from the development in Base is the additional 900 MW extra solar power. In addition, there is 470 MW more geothermal.

In the Base scenario, a large expansion of wind and solar generation takes place in Sudan and Kenya (see chapter 8). To test the consequences for Ethiopia, if the two countries are not following the ideal investment plan, a restriction is tested in the Delayed scenario: here the expansion is restricted to maximum 100 MW (per technology, per year) in those two countries. For Ethiopia, this results in additional investment in hydro and wind.

If a requirement of a specific net export (5, 10, 15, or 20 TWh) is applied, this will also change the generation mix: the extra export will result in more hydro and wind power.

Lower fuel prices or high CO_2 costs (similar to higher fuel costs) also have impact on the generation mix in Ethiopia: higher fuel price leads to more wind in Ethiopia, and vice versa for lower fuel prices.

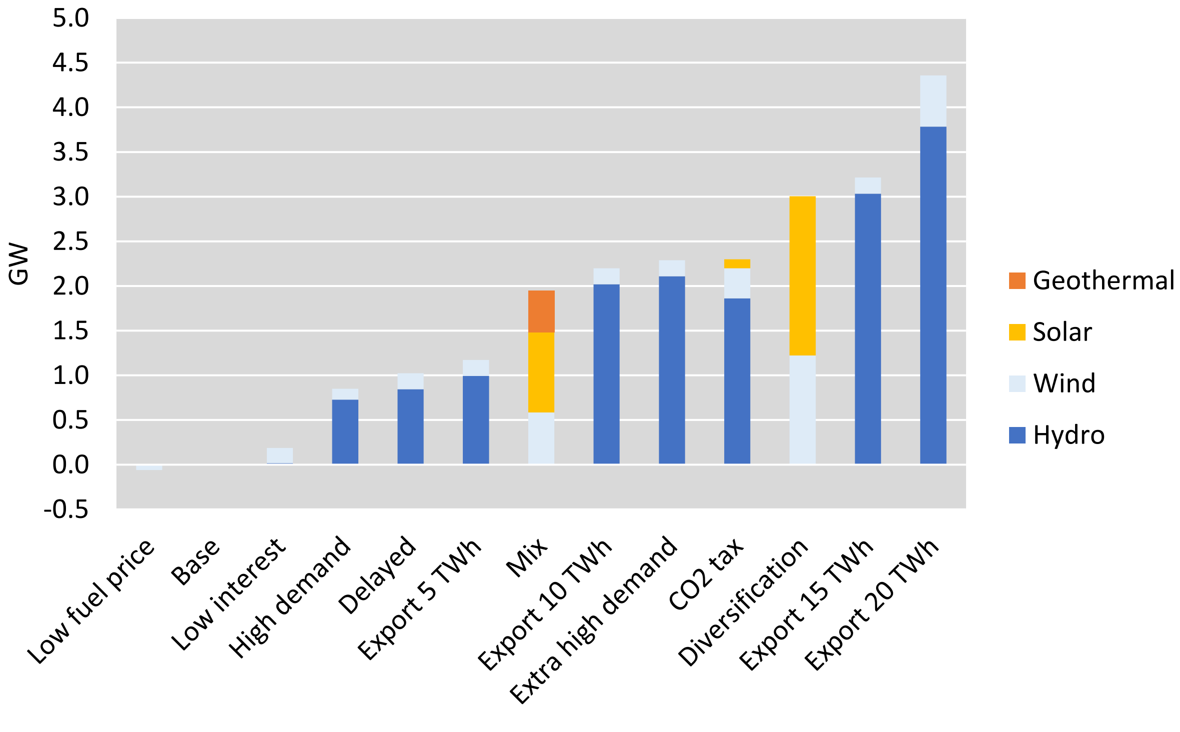


Figure 37: Change in installed capacity. Seven scenarios compared with the Base scenario. 2030.

In Figure 38, economic key values are compared for the scenarios. The Mix scenario (with the 11/9/6% requirements) is less attractive than the 25% diversification scenario. The other scenarios have increasing national costs, but also increasing value of net export. The Base is the least-cost solution, however it could be attractive to accept increased national costs, to realise a higher revenue from export (hard currency).

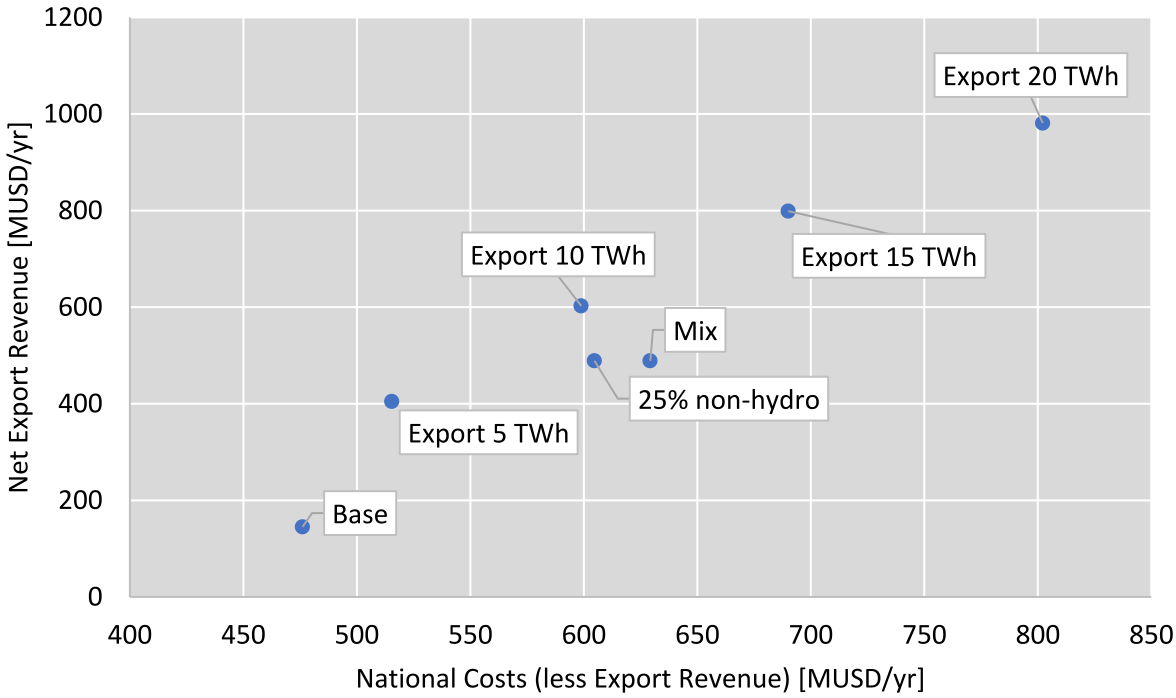
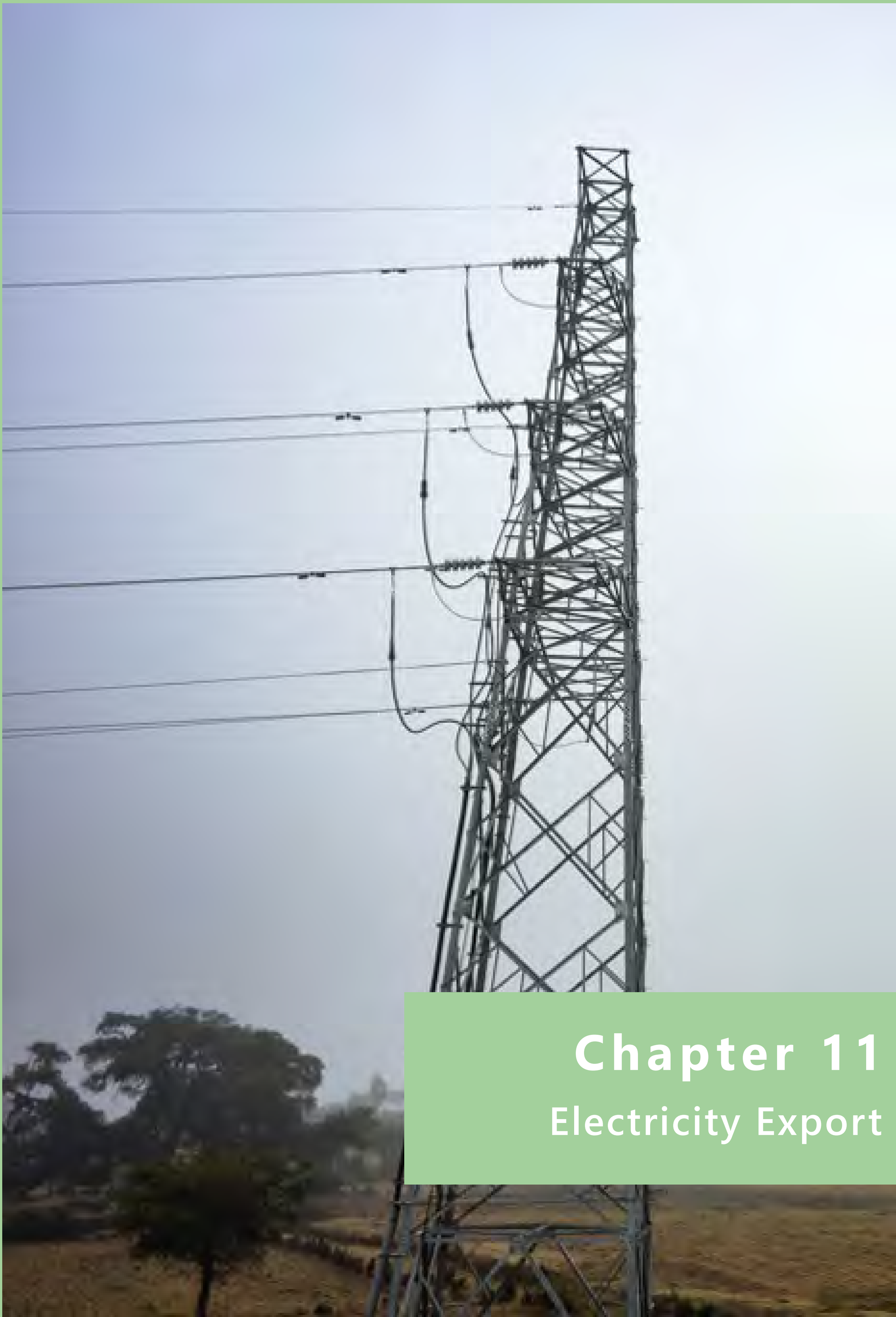


Figure 38: Economic comparison of the Ethiopian diversification and export target scenarios in 2030. National cost is the total annual costs minus the revenue from net export.

Insights

The analyses of different ways to achieve diversification leads to these insights:

- Goals for diversification should be formulated at the highest possible level: the desired share of non-hydro – not as requirements for the individual technologies, e.g., geothermal, wind and solar. The goals should be formulated in a *technology neutral way.* The technologies are very different, with geothermal being base load generation and wind and solar highly varying generation. However, a careful analysis, as performed here, can indicate which technology is most attractive for Ethiopia. The result is clear: wind power is the most attractive answer to reducing the share of hydro. This result is robust across several tested scenarios (see Figure 37). Solar and geothermal only enter the Ethiopian system, if that is directly required (as in the mix scenario). Otherwise, solar is preferentially placed in other countries, with higher resource potential.



Chapter 11

Electricity Export

11. ELECTRICITY EXPORT

A major challenge for Ethiopia is the trade balance and the difficulty of accessing hard currency (see chapter 2). For the energy sector, using electricity in transport instead of imported oil can improve the trade balance (see chapter 3). An export of electricity can create revenue in hard currency.

To study the potential for export of electricity it is important to have a detailed analysis of electricity prices in potential receiving countries. In the Balmorel analyses, we compute the marginal electricity price in Ethiopia and 11 nearby countries. In optimal dispatch, only if the electricity price is higher than in Ethiopia, export will take place. Power flows from cheap areas to more expensive areas. This is also how the incentives are in the real world: If import is cheaper than the marginal generation, then this will be preferred.

Benefit of trade

Comparing the Base scenario with the scenario where Ethiopia is assumed to act as "an electric island" (no exchange of electricity) shows that the Island case is 425 MUSD more expensive for the whole region (in 2030), and 168 MUSD more expensive for Ethiopia. This extra cost is shared between Ethiopia and other countries. The scenario with export, but no import, is 143 MUSD more expensive than Base for the whole region, and 57 MUSD more expensive for Ethiopia.

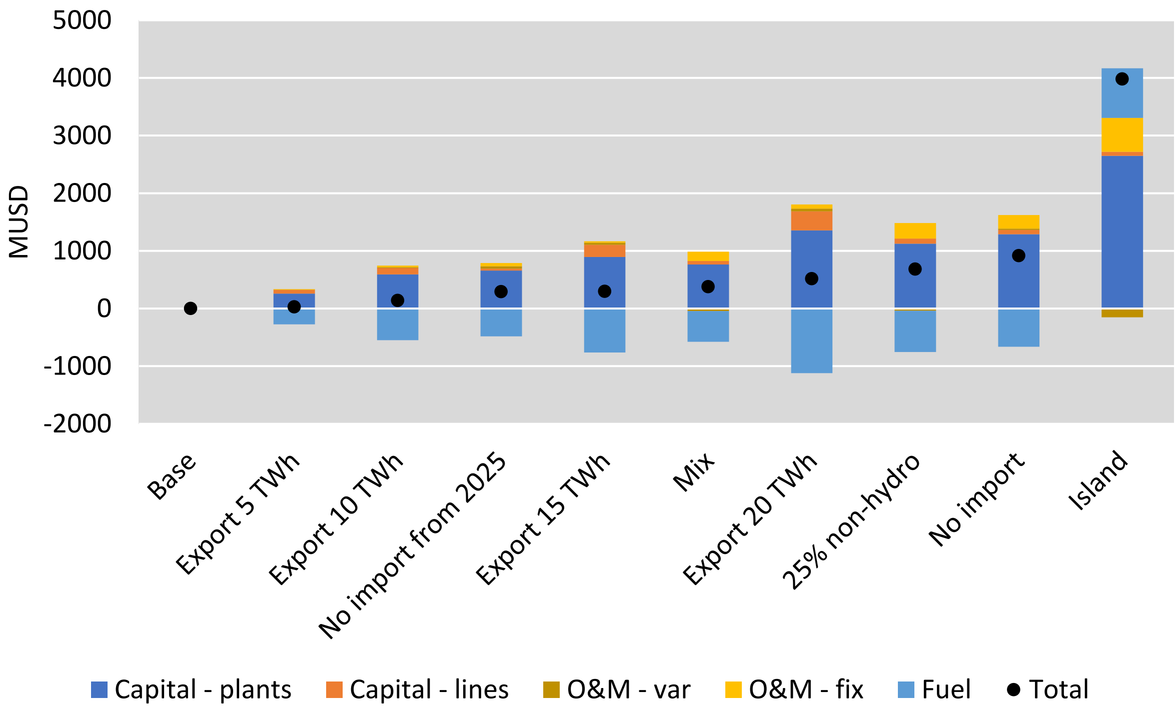


Figure 39: Difference in accumulated regional costs from 2021 to 2030, compared to the Base scenario

When considering the region as a whole, the baseline scenario results in the least cost solution, and thereby the maximum social welfare. However, the least cost scenario for Ethiopia specifically occurs when free trade can occur until 2024 (inclusive), and then only export occurs in the following years, to 2030. It is assumed in this analysis that congestion rent revenues on interconnectors are shared evenly between the interconnected countries. In practice, either country could negotiate a higher share of congestion rent revenues.

Figure 40 shows that the additional revenue gained per unit of electricity exported remains almost constant, with slightly decreasing revenues per net unit exported, when increasing from 5 to 20 TWh of net export. However, the cost of fulfilling the additional export increases significantly. The cost incurred by increasing net export from 5 to 10 TWh is 83 MUSD, while the additional increasing net export from 15 TWh to 20 TWh is 112 MUSD. Net export in 2030 for the "No import" and "No import from 2025" scenarios are 8.3 and 8.0 TWh, respectively. The Island scenario deviates significantly from the others, with a higher national cost than base, and no revenue for export. The Base scenario is clearly more attractive.

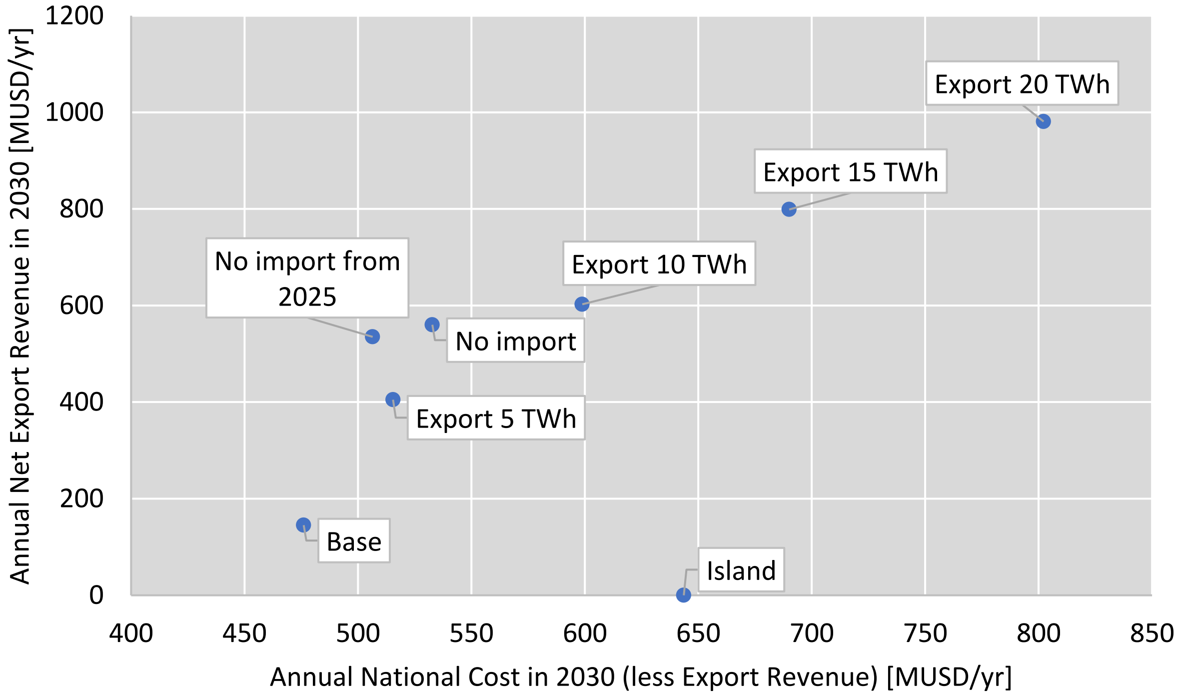


Figure 40: Economic comparison of the Ethiopian trade scenarios in 2030. National cost is the total annual costs minus the revenue from net export.

An interconnector between Ethiopia and Kenya will be commissioned in 2022. The initial capacity of the interconnector will be 400 MW. The capacity will be increased by 400 MW in each of the following two years, thus the interconnector capacity will be 800 MW in 2023 and 1200 MW from 2024. To investigate impact from inflexible operation of interconnectors, a scenario has been evaluated in which the flow on the interconnector is fixed at 400 MW from Ethiopia to Kenya.

	Base	Fixed Et-Ky Interconnector	Unit
	Least-costs, no policy restrictions	*Fixed export of 400 MW*	
Hydro	9226	9226	*MW*
Wind	754	1314	*MW*
Solar	250	920	*MW*
Geothermal	107	107	*MW*
Waste	25	25	*MW*
Net Export, 2030	-0.5	2.6	*TWh/year*
Net revenue from export, 2030	-2.9	117	*MUSD/year*
Congestion rent (50%), 2030	148	118	*MUSD/year*
Annual national cost, 2030	476	613	*MUSD/Year*

Inflexible interconnector operation results in an increase in costs for the system, and an increase in cost for Ethiopia, by 22% in 2030. The congestion rent received by Ethiopia in particular is significantly reduced when the export from Ethiopia to Kenya is fixed. This is a consequence of reduced overall flow on the line and having to export even during hours where the price in Kenya is lower than the price in Ethiopia, causing negative congestion rents during some hours. Compared to the base case, additional investments in solar and wind capacity are made, and net export increases from -0.5 TWh to 2.6 TWh in 2030, but the net profit from trade (revenue from export plus 50% congestion rent) per unit electricity traded decreases as a result of reduced flexible interconnector capacity.

Export in the Base scenario

Figure 41 shows the development of the import and export in the Base scenario. From 2025 investment in new capacity is allowed (2023 for wind and solar sources, however no wind and solar investment take place in Ethiopia in the period) and this has an impact on the export. As an average for the whole period 3.0 TWh/year is exported, and in 2030 a net import of 0.5 TWh takes place. This represents the optimal solution for the region.

It can be seen that significant import takes place, even in years with a significant net export. With a large share of hydroelectricity sources with reservoirs, Ethiopia has a stable electricity price over the year due to the large hydro reservoirs. The other countries, like Sudan and Kenya, have a much more varying price e.g., dependent on demand and the generation from wind and solar. In hours with low demand and high wind and solar generation, the price in these countries may be lower than in Ethiopia and import to Ethiopia is attractive. The imported power will be "stored" in the reservoirs as withheld water, that later will be used for additional generation. The Ethiopian hydroelectricity capacity acts as a buffer for the wind and solar generation in the region. Wind and solar generation are *game changers* and one of the consequences are the need for short term balancing. Hydroelectricity is attractive to deliver this.

The flow on the two lines Ethiopia – Sudan and Ethiopia – Kenya has been studied. It has been tested if the flow on the lines can be explained by the wind and solar generation in the three countries. This has been confirmed, e.g., 59% of the variation of the flow on the Ethiopia – Sudan line can be explained by the wind and solar generation in those two countries. Each time there is 1 MW extra wind and solar generation in Sudan, the import is reduced by 0.59 MW, and similar for wind and solar generation in Ethiopia: export to Sudan is increased with 0.16 MW[16].

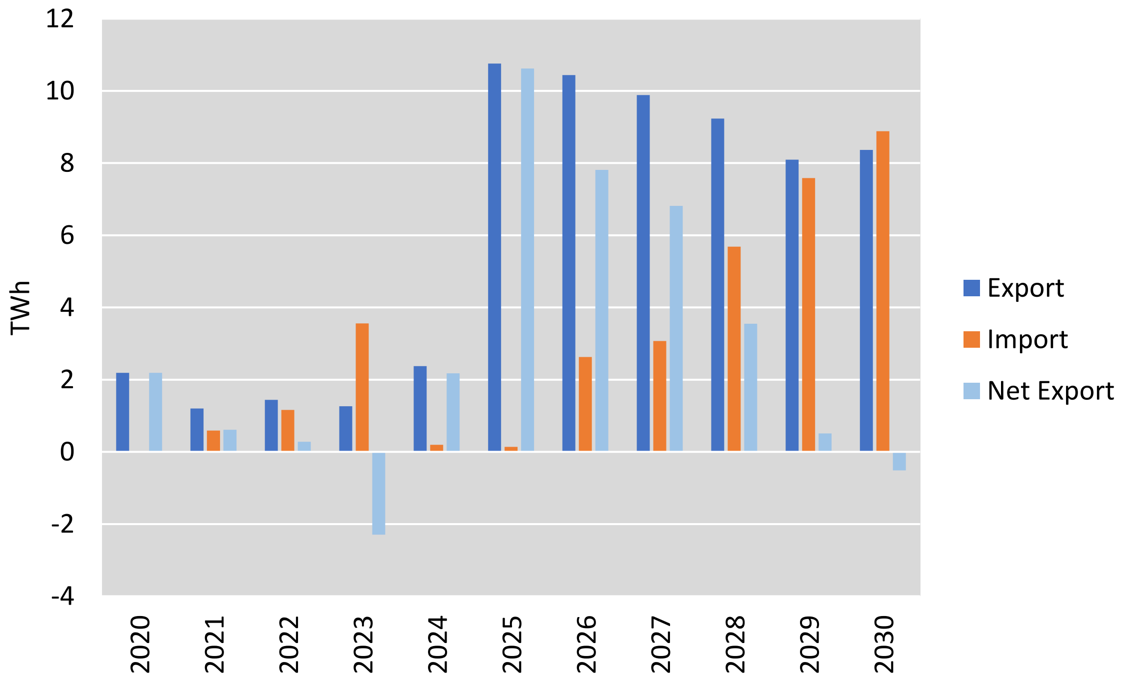


Figure 41: Import and export in the Base scenario.

[16] The analyses are based on an hourly simulation with a net 18 TWh export from Ethiopia.

Scenario with extra export

Alternative scenarios have been tested, with 5, 10, 15 and 20 TWh net export as a requirement. See Figure 42. These will be more expensive, with respect to national costs, but will increase the revenue from export (hard currency). The scenarios with 15 TWh export (or more) have the additional benefit, that there will be a positive net export, even in dry years. Comparing Base and the 15 TWh export scenario shows that the latter has 214 MUSD higher national costs, but also 654 MUSD higher export revenue. This may be and attractive trade-off.

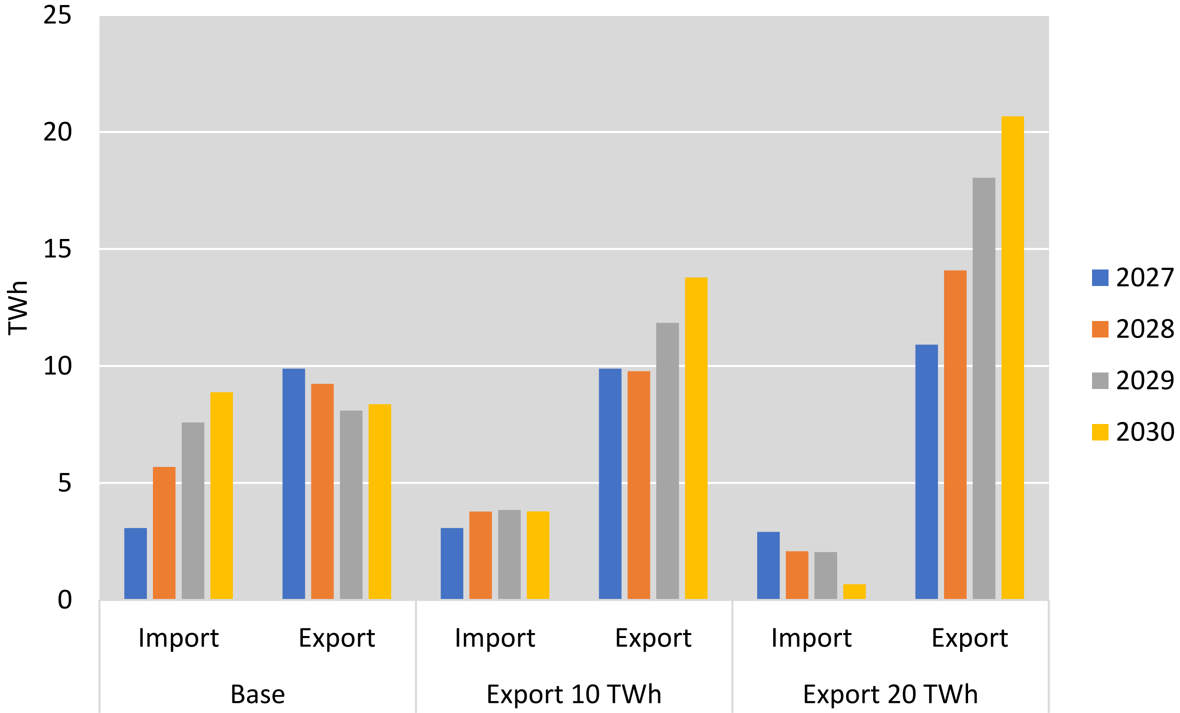


Figure 42: Import and export in Base and two export scenarios.

While Base has the optimal export, the 5, 10, 15 and 20 TWh scenarios are more expensive, but they also deliver a higher revenue in hard currency (see Figure 40). For Ethiopia the best trade off, may be extra export, to gain the needed hard currency.

In Figure 44, net export to Kenya and Sudan in the 15 TWh Export scenario is compared with the expectation in the latest demand prognoses (USAID and Power Africa, 2021). The 15 TWh export scenario is presented since it results in similar net export to Kenya and Sudan (11.0 TWh) as the prognoses report (10.5 TWh) in 2030 the model results based on the 15 TWh scenario indicate a higher export to Sudan and a low to Kenya (and Tanzania). It should be noted that in the prognosis, an increase of the export to Sudan is foreseen in 2031 (to 1,100 MW). The results indicate that trade with Sudan is more important than considered by the prognoses report.

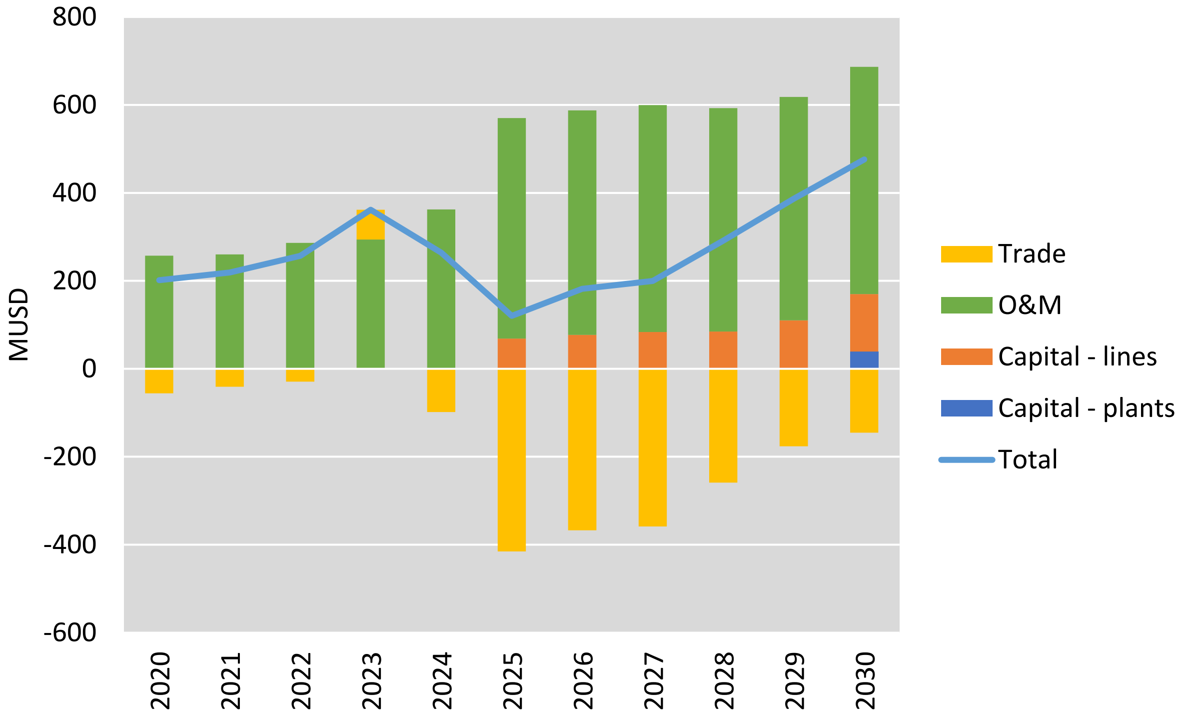


Figure 43: National costs for the 10 TWh Export scenario.

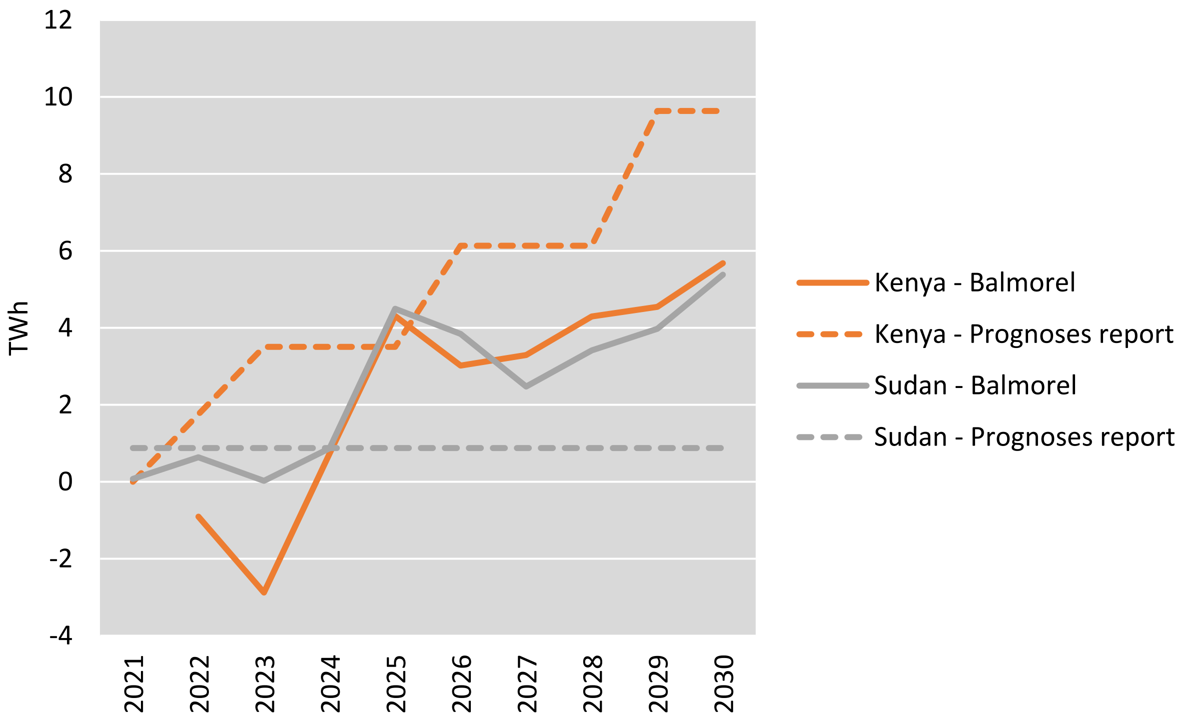


Figure 44: Average net export in Balmorel (15 TWh scenario) and in demand prognoses report (USAID and Power Africa, 2021). In the demand prognoses report the export is given in MW. This is multiplied with 8,000 hours to get the yearly export.

Dynamic, bilateral trade

Exchange of electricity between countries can be attractive. By exporting from cheap to expensive areas, the total cost can be reduced, and both sides can benefit. Ethiopia already has export to Sudan and Djibouti, and export to Kenya will soon follow.

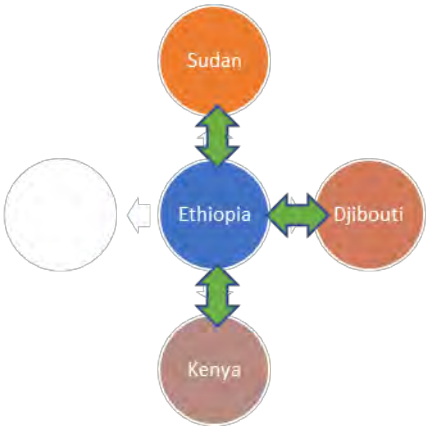


Figure 45. The first round of bilateral trade. Somalia, Eritrea, Yemen and South Sudan can follow.

With the expansion of solar and wind power in the region, dynamic trade becomes relevant. The marginal costs of providing electricity change in correspondence with the weather systems. The hydropower of Ethiopia can play an important role as buffer for wind and solar – not only in Ethiopia, but in the region.

Until a regional electricity market is established, dynamic bilateral trade can take place. This can be a preparation for a centralised regional market, as planned for the Eastern African Power Pool, EAPP.

With inspiration from the cooperation in the Nordic countries before Nord Pool, a possible way of having a dynamic bilateral trade is sketched:

- The countries agree to share information about the marginal costs of generating electricity. This could be on an hourly basis, to reflect both the daily variation of demand and the varying wind and solar power generation.
- Trade is voluntary and takes place when both sides agree, and the price is the mid-price of the prices in the two countries.
  - For countries where the marginal generation is fuel based, the marginal costs are the fuel price divided by the efficiency plus variable O&M costs. Key data about efficiency is shared beforehand, and a common reference for fuel prices is used.
  - Ethiopia is dominated by generation with marginal costs close to zero (hydro and wind), and the water value is used instead[17]. Computation of the water values can follow these steps:
    - The estimated available generation for export is computed as potential generation minus national demand. The value could cover the following 12 months.
    - The water value acts as the guiding variable for hydro: When this value is lower than the marginal costs in another country, export takes place – and vice versa.
    - The estimated yearly generation for export and the water value is evaluated weekly. If the actual export is higher than the goal, the water value is increased – and vice versa.

17 See this report for description of computing water values for a Norwegian hydro company (page 144 ff): https://www.ea-energianalyse.dk/wp-content/uploads/2020/10/Region_Report_on_flexibility_measures.pdf

This system could be implemented for Sudan, Djibouti and Kenya. Having all three would be beneficial in relation to a trustworthy computation of Ethiopia water values. Acknowledging that water values are an abstract value, it is important for the transparency that:

- The same water value for Ethiopia is used in relation to trade with all three countries
- Ethiopia accepts import, when the marginal costs in another country are lower than the water value. It should be recognised that imported electricity will later be exported as a net export goal is part of the computation of the Ethiopian water value.

A common office with representatives from the participating countries could be established to manage and overview the operation.

Insights

The analyses of export possibilities highlight the following insights:

- With the expansion of wind and solar generation, efficient exchange of power is dynamic: the power should always flow from the cheap to the expensive area. This will reduce the total costs and each side has clear economic incentives to fulfil this goal. Import will take place with that is cheaper than generating the power locally.
- Sudan is the country with the highest potential for import from Ethiopia. Expansion of the transmission capacity in that direction should be prioritised.
- Delivering net export after 2030 increases the cost for Ethiopia. However, it does create a revenue of hard currency. An export of between 10 and 15 TWh seems to be an attractive balance between additional costs, and additional revenue.

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